A vertical electro-optical data cable for KM3NeT

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on behalf of the KM3NeT Consortium

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Abstract

KM3NeT is a research facility which will be built at the bottom of the Mediterranean Sea. The facility will host a neutrino telescope with several hundred detection units - vertical mechanical structures to which the optical sensors modules of the telescope are attached. A data cable will run the full length of the structure. In order to allow for a compact deployment of the detection unit, the cable must be flexible and at the same time protect the two copper conductors and eleven optical fibres inside. To comply with these requirements a pressure balanced oil filled cable has been designed, for which a prototype is being built for in-situ tests at the anticipated telescope depths of three to five km. At the level of each optical sensor module a short horizontal cable breaks out which is connected to the readout components inside the glass sphere of the module via a novel tapered glass transit. We will present the design and assembly method of the cable, the design of the glass transit and the results of laboratory tests.

Keywords: KM3NeT, neutrino telescope, PBOF cable, deep-sea technology, submarine cable, penetrator, deployment, drag
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1. Introduction

The future KM3NeT neutrino telescope will consist of several hundred detection units - long vertical structures with at regular intervals optical sensor modules attached [1] [2]. The units will consist of 23 mechanical bar structures attached to ropes every 40 m. Of these, the upper 20 will suspend two optical modules, while the lower three are a base structure to balance the detection unit and two separators to prevent twists in the unit. A top buoy will keep the detection unit vertical. Two data cables - the Vertical Electro-Otical Cables (VEOCs) - run the full length of the detection unit with breakout units at the level of the optical modules. The detection unit will be anchored to the seabed as a compact package with the bar structures and the top buoy stored on the anchor [3]. During unfolding of the package, each bar structure will successively rise to its final position driven by the top buoy. With the two data cables running at each side of the bar structures a stable (symmetric) hydrodynamic behaviour of the detection unit is achieved. To minimize the contribution of the data cables to the horizontal displacement of the top of the detection unit, the diameter of the cables must be as small as possible; to minimize the size of the top buoy, the weight of the cables in sea water should be as low as possible. Both objectives can be met by using a Pressure Balanced Oil Filled (PBOF) cable structure. We report on the design and assembly method of the KM3NeT PBOF data cable structure and the design of a glass transit for the optical module to connect to the readout electronics.

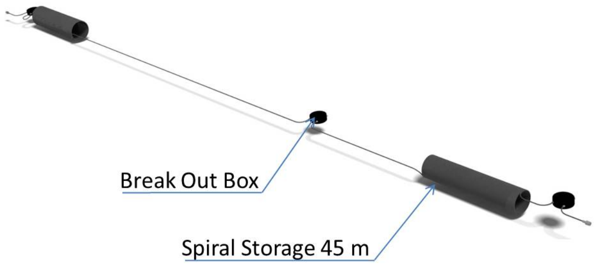

Figure 1: Schematic view of the VEOC cable.

2. Vertical Electro-Optical Cable

The Vertical Electro-Optical Cable (VEOC) for the KM3NeT detection unit has been designed for operation at a depth of maximally 6000 m, a mission time of 15 years and reliability better than 90%. The Pressure Balanced Oil Filled cable consists of a hose with two copper wires, eleven optical fibres and breakout boxes at the storey level for connection to the optical module via the storey cable (section 3).

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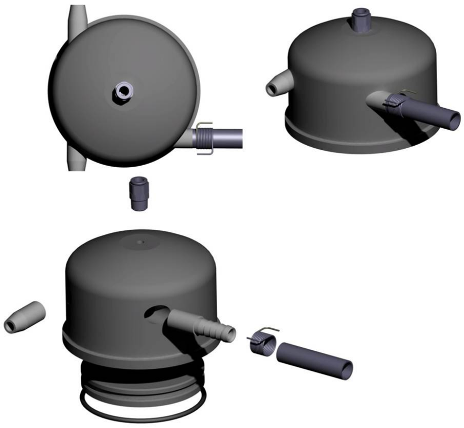

Figure 2: Breakout box in the VEOC.

2.1. Mechanical Design of the VEOC

In the PBOF VEOC, wires and fibres have to operate under the ambient hydrostatic pressure of 60 MPa. The hose of the cable has to withstand an overpressure of 0.6 MPa to adapt to the in-situ pressure difference between the top and the bottom of the cable and an overpressure which can be caused by temperature differences during storage and transport. The hose material has to be seawater resistant and environmentally friendly. The cross section of the hose must be as small as possible to minimize the drag of the cable in sea water. For storage in the stack of storeys unit during deployment of the detection unit, the cable has to be flexible. To meet these requirements, for the hose of the KM3NeT VEOC, a tube of low density polyethylene has been chosen with an outer diameter of about 6 mm. During transport and deployment of the detection unit, the VEOCs are stored on the bar structures in a folded spiral around one of the suspending rope of the detection unit (see Figure 3). Since fibres are sensitive to longitudinal stress, the ropes have to carry all mechanical forces. Therefore, the VEOC is about 10% longer then the ropes to ensure that the cable remains in a spiral form without any snap. For the tube, the wire isolation and the oil, environmental friendly material has been chosen [2]. The density of the oil is close to that of seawater.

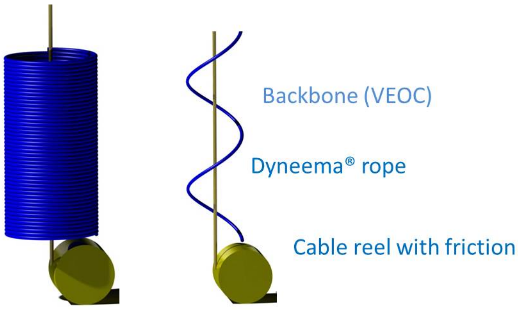

Figure 3: VEOC spiraled around a rope.

2.2. Electrical design of the VEOC

At the connection of the detection unit with the sea floor network, the nominal voltage level will be 400 V. At the storey level, a DC-DC convertor is integrated in the storey cable (section 3) to convert the 400 V voltage level of the VEOC to the 12 V level of the optical module. The cross section of the two copper wires in the VEOC must be sufficiently large to deliver the power at a voltage level of 350-400 V at the input of the DC-DC converter. Since the optical modules in the detection unit are connected in a tapped chain, only a two pole connection is necessary. It has been calculated that for the copper wires in the VEOC, a diameter of 1 mm^2 (18 AWG) is sufficient. To keep the voltage and power loss in the wires low, environmental friendly isolation for the 400 V layout is used.

2.3. Optical design of the VEOC

The VEOC is built from two sections, connected by an Optical Fanout Module (OFM). Each section contains an open bundle of 11 optical fibres. At the storey level, the optical module is connected to the VEOC by a single optical fibre (via the storey cable described in section 3). All optical modules communicate via a unique wavelength with the shore. For connection to the sea floor network in the detection units these wavelengths are multiplexed onto a one fibre for Rx and another fibre for Tx in the OFM between the two sections of the VEOC. The OFM is situated between storey 9 and storey 10, counting the bottom storey first. In this way, 11 fibres in both sections are sufficient to connect 20 optical modules in a star network. The upper section of the VEOC contains 11 fibres for connection to 11 optical modules; the lower section contains Rx, Tx and 9 connections to the optical modules. To minimize attenuation, optical connection by splicing at every storey level is avoided. The optical contacts in the connectors are APC type contacts preferably. The average attenuation in both directions of the cable assembly will be $\leq$ 0.25 dB/km and the optical back-reflection will be better than -55 dB/connector. To ease mechanical handling of the cable, BendBright type fibre is used in the VEOC, which has a high resistance against losses due to macro bending.

3. Breakout Electro-Optical Cable

On each storey of the detection unit the optical module is connected with a custom designed storey cable - the Breakout Electro-Optical Cable (BEOC) - to the vertical cable. Also the BEOC is a PBOF cable. The BEOC terminates in a custom designed penetrator for transision of the ambient pressure in the BEOC to the pressure inside the glass sphere of the optical module. The other site of the BEOC terminates in a connector for connection to the breakout box in the VEOC (Figure 2). The choice for a separate storey cable instead of a cable integrated in the design of the VEOC has been driven by the wish to ease the integration of the detection unit with "plug and play" connections to the optical modules. In the future, the ease of cable assembly has to be balanced against the cost of a connector.

3.1. Mechanical Design of the BEOC

Figure 5 shows a schematic layout of the oil filled storey cable structure. The hose has a diameter of about 10 mm. The cable has two sections which are connected via an oil filled splitter box. One section of the cable is about 0.3 m long and terminates in a dry-mateable connector (1 UTP and 1 fibre) to connect to the breakout box in the VEOC. The other section with a length of about 1 m terminates in a custom designed penetrator (3 UTP, 1 fibre) for the transistion of the ambient pressure in the BEOC to the pressure in the optical module. The splitter box allows for the connection of satellite instruments other than the optical module the readout electronics inside the optical module. An example of such a satellite instrument is a high precision thermistor to measure temperature differences of the seawater for marine science research. Another example is a hydrophone which not only can contribute to position calibration of the optical modules but also is of interest for biological research. For connection to a satellite instrument, a dry-mateable bulkhead connector (2 UTP) is available. The custom designed Titanium penetrator (Figure 4) has a conical shape to fit in a conical hole in the glass sphere. FEM calculations and several tests at a pressure of 60 MPa in a hyperbaric tank have shown the feasibility of this approach. With this shape, the high partial pressures in the glass that occur by using a classic screwed penetrator are avoided. In addition, with this penetrator no special tooling and handling will be required to integrate BEOC and optical module.

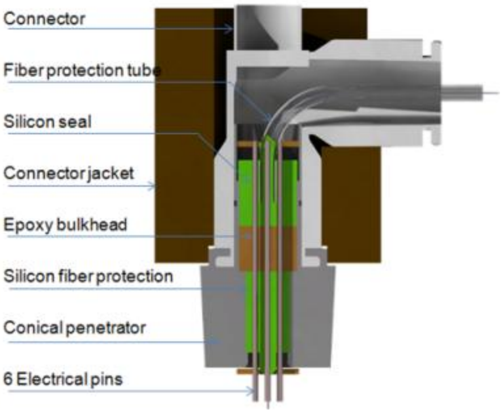

Figure 4: Custom designed penetrator.

3.2. Eletrical Design of the BEOC

The splitter box in the BEOC contains a DC-DC convertor to convert the 400 V voltage level of the VEOC to the 12 V level of the optical module. The total electrical power withdrawn from the VEOC at each storey will be less than 18 W; the total power transferred to the satellite instruments will be less than 2 W. To mininize the interference between the electrical circuits, the copper wires are twisted by function (i.e. power to, power from, signals). The 12 V is easy to handle during the assembly of the detection unit following the European low voltage directive.

3.3. Optical Design of the BEOC

The fibre type used in the storey cable is a BendBright optical fibre. This type of fibre allows for a "right angle" penetrator. The maximum bending radius for the fibre inside the penetrator is 14 mm. The splitter box in the BEOC is used to store the fibre left after mounting the penetrator at one end and the connector to the cable at the other end of the BEOC.

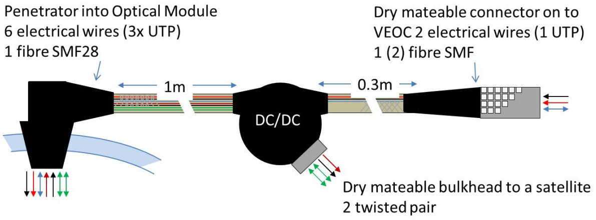

Figure 5: The BEOC storey cable (see text).

4. VEOC Assembly

The assembly of the VEOC requires a construction hall with a lenght of at least 60 m. Tube sections of about 45 m are positioned parallel to each other and each tube section will have a wire guiding funnel at either end. Breakout boxes are placed at the ends of the cable sections. A pull cord, which is connected via a cable guide to the wires and the fibre bundle, is routed through the tube sections with a fleeter. The fleeter is a conical shaped device pushed

Figure 6: VEOC in assembly hall; breakout box at the front.

forward by compressed air. The cable sections are joint by routing the fleeter through the breakout box between sections. After completion of routing the wires and fibres through the cable sections, the funnels are removed. In figure 7 the assembly scheme is shown. The two cables running on either side of the detection unit come together in a container at the base structure for connection to the seafloor network. For this, a conical penetrator (2 wires, 2 fibres) is mounted at one end of the cable. To connect to the optical fan-out module a conical penetrator is mounted to the other end (2 wires, 11 fibres). Both penetrators are of the same type as used in the BEOC. Once the cable structure is completed, each section is spiralled using hot steam during about 5 minutes and then left to rest for about 1 hour. The resulting spiral diameter is about 18 cm.

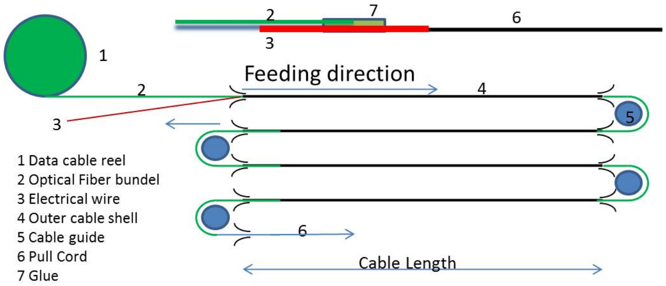

Figure 7: Assembly of the VEOC cable.

5. Conclusion and Outlook

For the KM3NeT detection unit an electro-optical cable structure has been designed based on the concept of a pressure balanced oil filled cable. The vertical cable has a diameter of 6 mm and contains 20 breakout boxes for connection with 20 optical modules via a custom designed storey cable. The storey cable terminates in a custom made penetrator for connection to the electronics and the optical components inside the optical module. Two copper wires and a bundle of 11 BendBright type fibres connect the 20 optical modules in a star network, via an optical fan-out module at half height of the detection unit. At the base of the detection unit, the two cables running along either side of the detection unit are joint and connected to the seafloor network. To secure safe storage of the cable in the stack of storeys prior to unfurling and to avoid mechanical stress on the cable during and after unfurling, the cable is spiralled around one of the suspending ropes of the detection unit. Validation of the cable system and the custom designed penetrator is in progress. Tests have shown that the fibres and wires perform well at an ambient pressure of 60 MPa. Other tests have shown that the spiralling of the cable requires the use of bundled fibres i.s.o. loose fibres and the use of BendBright fibre types. The optical behaviour of the cable during unfolding in water has not been measured yet. Contacts with industrial partners to optimize the design and make it ready for production have been established.

6. Acknowledgment

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References

[1] km3net.org
[2] KM3NeT, "Technical Design Report for a Deep-Sea Research Infrastructure in the Mediteranean Sea Incorperating a Very Large Volume Neutrino Telescope", ISBN 978-90-6488-031-5 (Apr.2008).
[3] M. Musumeci, Mechanical design of the Pre-Production Detector Unit Model of KM3NeT, this issue