A mechanical design for a detection unit for a deep-sea neutrino telescope

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Abstract

The future KM3NeT neutrino telescope will be built on the seabed of the Mediterranean Sea at a depth between three and five kilometers. The high ambient pressure, but also the fact that the detector is hardly accessible, put severe constraints on the mechanical design of the detection units of the telescope. A detection unit is a vertical structure which supports the optical sensors of the telescope. It has a height of almost 900 m; two data cables run along the full length of the structure. The detection unit will be installed at the seabed as a compact package. Once acoustically released, it unfurls to its full length. The stability of the detection unit during unfurling and during operation is an important requirement for the mechanical design of the structure. We present the evolution of the design of the detection unit for the KM3NeT detector.

Keywords: KM3NeT, neutrino telescope, deep-sea technology, deployment, drag
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1. Introduction

The future KM3NeT neutrino telescope [1] [2] will consist of several hundred detection units - vertical structures anchored to the seabed of the Mediterranean Sea suspending the optical sensors of the detector. Each detection unit will contain 20 storeys - Aluminium frames with a length of 6 m and a KM3NeT Digital Optical Module (DOM) at either end. The DOM is a pressure resistant glass sphere with diameter of 17 inch, containing 31 small photomultiplier tubes [3]. The DOMs are connected to the flexible electro-optical backbone cables that run at either site of the storeys over the full length of the detection unit [4]. The 20 storey frames - so-called DOM-bars are placed in the detection unit every 40 m. In the lowest 100 m of the vertical structure two frames without DOMs are placed to avoid twist in the detection unit. The unit will be kept vertical using both a top buoy and buoys at every storey. In total, its height will be almost 900 m. The frames in the detection unit are vertically connected with four 12 strands braided Dyneema® ropes with a diameter of 4 mm. To give the vertical structure sufficient mechanical stiffness the ropes connect the frames in such a way that each storey is perpendicular to the adjacent one (the tower concept). The installation of the detection units on the seabed with all storeys in the correct position is a big challenge. The detection unit is deployed and positioned at the seabead folded in a compact package. After acoustically releasing the folding mechanism of the package, the storeys will float to their position, top one first. During the KM3NeT preparatory phase [1] the concept of compact deployment of towers has been worked out in several mechanical designs. We will describe the evolution of the mechanical design of the DOM-bar which is determined by its hydrodynamical behaviour both during and after unfurling of the tower. The evolution has led to the final design described in [5].

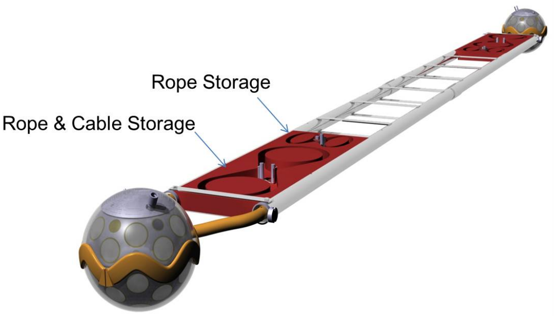

Figure 1: DOM-bar design with synthetic foam cassettes for storage of ropes and data cables.

2. Mechanical shape of the storey frame

The first DOM-bar (Fig. 1) consisted of an Aluminum frame with cassettes made of buoyant syntactic foam in which the ropes and data cables were stored. Although

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Figure 2: A small scale (1:70) DOM-bar structure with a closed surface floating upward in a position with a 45° angle with respect to the horizontal direction due to horizontal drift of the structure.This is a snapshot of videoclip [6]).

attractive in its simplicity, the design was abandoned because tests with small scale prototypes (scale 1:70) showed that a flat frame that is not open enough has the tendency to horizontally drift when floating upward and consequently will loose its horizontal orientation (Fig. 2). In addition, it appeared to be not trivial to safely release the ropes and cables from the cassettes while keeping the ropes under tension during unfurling of the tower. The latter is important to avoid strangling of the ropes during the unfurling process.

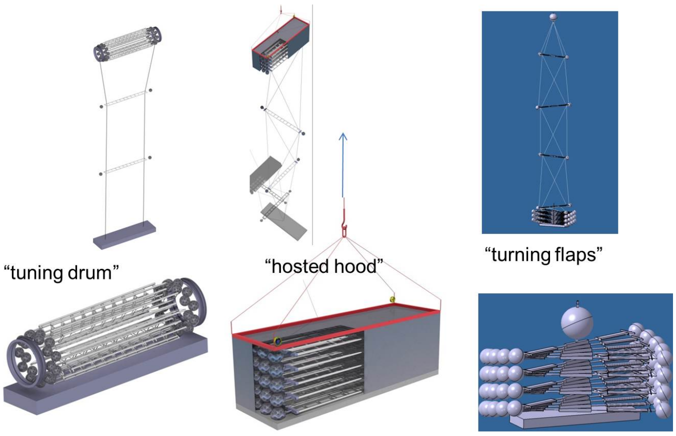

Figure 3: Three design options for the unfurling of a detection unit.

3. Unfurling methods and rope management

The next step in the evolution of the DOM-bar design was the optimization to allow for an unfurling method in which the ropes are kept under tension during unfurling. Three different concepts were considered: turning drum, hosted hood and turning flaps (Fig. 3). In the turning drum concept, a recyclable drum shaped frame is used as an equivalent of the launching vehicle designed for deployment of a string type detection unit [8]. DOM-bars are stored in the launching vehicle and are released bottom one first while the drum unrolls the detection unit to its full length. Tension of the ropes is secured in this unrolling concept. However, the storeys which are connected by only two ropes will be parallel. Therefore, the resulting tower does not comply to the requirement of storeys perpendicular to the adjacent ones. In the hosted hood concept, the storeys are stored in a container connected to the anchor. By lifting the container using a crane at the deployment vessel, the storeys - lowest one first - are released via the open bottom of the container. Although in this concept, tension on the ropes is relatively well secured, the risk that the vertical movement of the deployment vessel would have a too large effect on stable unfolding of the detection unit was considered too high and the design was abandoned. In the turning flap design the detection unit unfurls top storey first. This design is a precursor to the final design with rope drums with constant torque brakes to keep the ropes under tension.

4. Cable management during unfurling

In the next step in the evolution of the DOM-bar design the focus was on the handling of the flexible data cable during unfurling and the safe fixation of the cable to the ropes of the detection unit. Essential is that mechanical force on the data cable is avoided at any time, both during unfurling and during operation of the detector. In the early designs of the DOM-bar the data cable was clamped onto the tensioning rope in such a way that the data cable could slide through the clamps to avoid stress on the cable. The risk of such a solution is that the data cable can be blocked in one of the connections during unfurling. To avoid this, the final choice was to spiral the data cable around the tensioning cable (Fig. 4) taking into account the minimum bending radius of the fibres inside the cable.

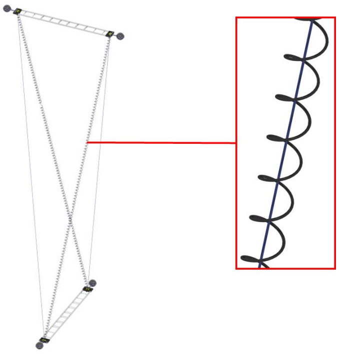

Figure 4: Ropes and data cables between two storeys. The data cable is spiraled around a suspension rope.

5. Open design of the DOM-bar

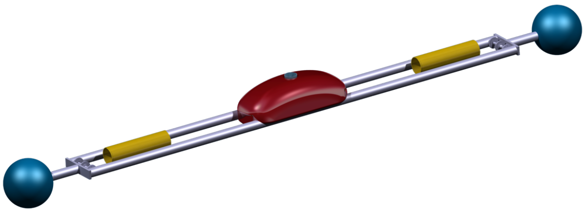

Figure 5: An open DOM-bar structure with a buoy of syntactic foam mounted in the middle and data cables spiraled around the ropes mounted near the end of the Aluminum structure. DOMs are mounted at either end.

Figure 5 shows the first DOM-bar design with the mechanical features described above. It has an open structure; the rope drums and the spiraled data cables are mounted on top of the Aluminium frame. Since the centre of gravity of the DOM is above the centre of the glass sphere, a local buoy is mounted on the topside of frame to avoid tipping over of storeys during unfurling of the detection unit. The stability during unfurling of this DOM-bar design has been verified in a test with a small scale (scale 1:70) prototype (Fig. 6).

Figure 6: A small scale (1:70) DOM-bar structure with an open structure floating upward in stable horizontal position without displacement in horizontal direction. This is a snapshot of videoclip [7]).

6. Displacement of the top of the detection unit

The detection unit will be kept vertical using both a top buoy and buoys at every storey. The required buoyancy is determined by the requirement for the displacement of the top of the detection unit from the vertical due to horizontal sea currents. At a horizontal sea current of 0.3 m/s the deviation of the top must be smaller than 180 m - the foreseen horizontal distance between detection units in the KM3NeT detector. In the current design, a top buoy with a buoyancy of 1000 N is foreseen, while the buoyancy of the DOM-bar storey is 450 N. These numbers are the result of drag calculations. To calculate the deviation of the top of the detection unit, 20 rigid blocks were considered, each of which represents the frontal surface for a horizontal current of a DOM-bar structure plus 20 m ropes and cable above and 20 m below the structure. The drag force on a block can be calculated using

$$F = \frac{1}{2}\rho v^2 C_d A \tag{1}$$

where $\rho = 1028\ kg/m^3$ is the density of seawater, $v = 0.3\ m/s$ is the velocity of the horizontal sea current, A is the frontal surface area of the block in m^2 and C_d is the dimensionless drag coefficient of the block which can be determined using the Reynolds number of its components.

These Reynolds numbers are calculated using

$$Re = \rho v l/\mu \tag{2}$$

where l is length of the component in m along the sea current and $\rho = 0.0013$ Pa s is the dynamic viscosity of water at $10°C$. For a prolate ellipsoid top buoy with an axis length ratio of 3, the Reynolds number is $Re = 2.5 \cdot 10^5$ from which a drag coefficient $C_d = 0.35$ can safely be extrapolated. The resulting drag force is 5 N. The vertical force on the top block of the detection unit - i.e. from the top buoy to top storey - is 1000 N, the horizontal force 4N. The resulting horizontal deviation is 0.1 m. To calculate the drag force on the blocks with a storey plus ropes and cables, the angle between the direction of the storey and the sea current is chosen 45° as an average value for the alternating directions of the storeys. The calculated drag force on the top storey is calculated 107 N in the direction of the sea current. The horizontal deviation of the top buoy will then be 3.2 m. The total deviation of the top buoy is calculated to be 162 m, which is well below the requirement of 180 m. In Figure 7 the relative contributions to the horizontal displacement of the top of components of the detection unit is shown. The ropes and the data cable (labeled VEOC) constitute the largest contribution). Recent simulations of the KM3NeT detector sensitivity indicate that the horizontal distance between detection unit might have to be reduced to 130 m. This would imply

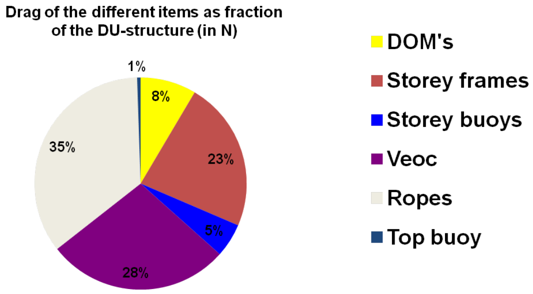

Figure 7: Distribution of the drag in a Detection Unit (the data cable is labeled VEOC)

that the horizontal deviation of the top of the detection unit should also be less than 130 m. This can be achieved by increasing the buoyancy of the top buoy from 1000 N to 2500 N.

7. Stacking design

Finally, stacking of the storeys is designed. In Figure 8 a package of 20 DOM-bars is shown, stored on an anchor and stacked in five columns. Each storey is clamped with a spring tensioned brake on one of the five vertical tubes which are part of the anchor (see Fig. 8). Once the top buoy - visible on top of the stack - is released, they are lifted one by one to unfurl the detection unit to its full length. The released storeys will make a turn of approximately 45° while floating upward. During unfurling, the tension on each rope is kept to 100 N.

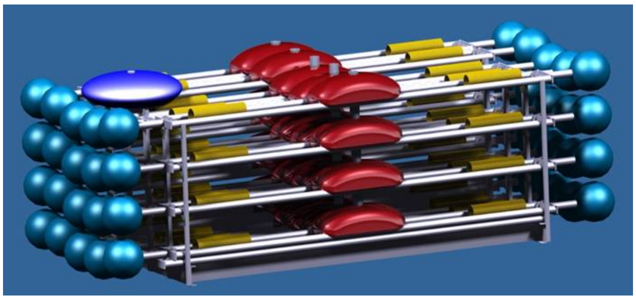

Figure 8: Stacked DOM-bars. Outer dimensions are L x W x H = 5800 mm x 2380 mm x 2050 mm. The package fits a "flat rack" container for easy transport.

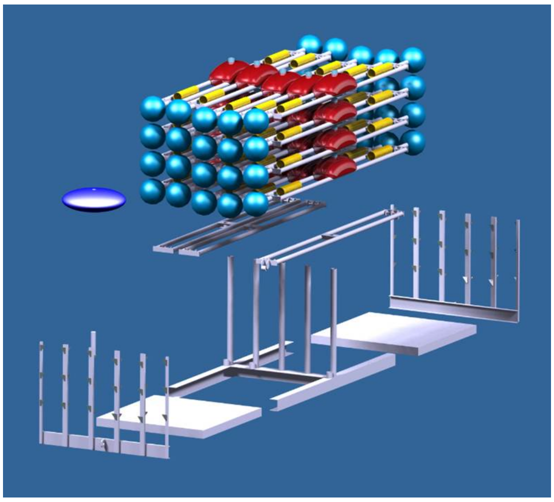

Figure 9: Exploded view of the stacked detection unit with 6 m long DOM-bars.

8. Conclusions

In the presented design of a KM3NeT detection unit, the storeys are stacked in five columns for deployment to comply with the requirement of compact deployment. The rope and data cable management is designed in such a way that it will maintain the required tension on the ropes during unfurling of the detection unit, while avoiding forces on the data cables. Drag calculations are presented which show that the deviation of the top of the structure is well below the required distance of 180 m. Evaluation of the described design has led to the final design which is described in [5].

9. Acknowledgment

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