REMOTELY DETACHABLE SUMARINE OPTICAL LINK

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Abstract: The present paper relates to a remotely detachable fiber optic communication coupler device that is designed to serve underwater. The device has a magnetic lock and release mechanism, which allow mating the optical couplers to be joined for the transfer of information between electronic devices, while been able to physically release such links remotely in submarine environments.

Keywords: underwater, coupler, wet-mateable, connector, submarine, detachable, oceanography.

1. Introduction

The present work describes the design of a remotely detachable submarine optical connector born to cover the needs of a specific oceanographic lander use case. The process describes the requirements and constrains of the use case, the limitations of the available submarine solutions and the challenges intended to be solved by the new design.

Oceanographic landers are modular structures, equipped with various sensors to be positioned directly on the seabed and operate for defined timeframes. Some lander sensors, such as the bandwidth thirsty image-based ones, can provide useful information not only during the study period, but also while the deployment process is carried out. The landers can be deployed and picked-up using remotely operated towed vehicles (ROTV), which serve as a steering guide or grabber apparatus that already has direct real time communications with the vessel's control room. Previous to the lander deployment operations it is beneficial to perform a video image survey identifying the specific location and direction of the deployment target. While these surveys can be done using the ROTV gear, they could also be achieved by using the lander´s own cameras and sensors if they could communicate with the ROTV. Having such a communication link would serve as reference and feedback for high precision landing and targeting, allowing to achieve both high quality positioning objectives and guarantying a better target accuracy. Additionally, by carrying out sea bottom surveys simultaneously to the deployment procedures the costly vessel operation times can be reduced, providing valuable hoisting time savings during survey operations. Therefore, the benefits of having a high bandwidth communication link with the landers during the deployment process would range from enabling new real time profiling methods, to performing faster and more accurate deployments.

There are several ways to solve this need, however the existing solutions do not match the low cost, high bandwidth, and very high pressure the sea environment demands for the oceanographic sector. The traditional acoustic modems can not reach high bandwidths, while the rest of the wireless solutions are hampered by the high attenuation of electromagnetic waves underwater, the most promising of which are optical modems [1] that offer reasonable ranges at low or medium bandwidths, but with a power tag difficult to meet the month-long deployment periods of oceanographic landers. The wired solutions on the other hand can easily reach high bandwidth rates, using very low power requirements, however they would need a submarine connector to be disconnected underwater when the deployment process finishes. While the offshore industry has several well-established commercial submarine connectors, there are currently no standard low-cost communication connectors that would allow disconnecting the link underwater when releasing the lander, nor turning off any energy consumption the link might use afterwards.

The present design builds on the lessons learnt from previous oceanographic survey cruises to produce a low-cost submarine optical connector that would satisfy the requirements of the specific use case. The connector is designed to be mated on board the vessel and later be detached underwater - at high depths- where the deployment takes place. The design aims are to optimize the costs by selecting simple solutions for each required functionality. The bandwidth tests prove that it will be able to transmit high quality video feeds while providing low power requirements and enabling the controlled shut down.

2. Underwater connectors

The oceanographic sector and industry standards offer few commercially off-the-shelf options to cover the underwater connector requirements for the desired use case. On an initial approach submarine connectors can be classified as dry mateable and wet mateable types (see [2]). The dry mateable connectors (DMC) being the ones that are mated on board, under dry environments, where the mating interfaces can be easily sealed from the seawith water-tight seals. Wet mateable connectors (WMC) are designed to be mated or unmated under wet environments, which allows carrying operations underwater, but have more difficulties to protect and guarantee the quality and stability of the links with time.

One of the most important benefits of dry mateable connectors is the robustness of their solutions, however this feature also inhibits them to be easily detachable, since any screw or airtight based solutions are impractical under deep sea conditions. Wet mateable connectors, on the other hand, are designed to take into consideration the high pressure and conditions of the seawater by using different technical solutions, but they are quite expensive and used normally on the telecoms and petrol sector.

The use case needs a wet mateable connector approach to be able to detach the landers at great depths, but it allows for a dry mating procedure to happen before the deployment starts, therefore facilitating the attachment process on-board and avoiding the strict requirements of pure WMCs. While the costs of developing an underwater connector can be very high [3] it is also true that it is common to purchase tailor-made ones to fit exactly the project needs [2] in order to guarantee a better match.

3. Optical fiber connector design

The current connector design builds on existing two POF (Polymer Optical Fibers) communications devices to provide an electrical to optical conversion, adding the required housing mechanical properties and elements to cover the desired connector functions.

According to the basic underwater connector function units [3] the design consists of a connecting unit represented by the plug, or male connector, and the receptacle, or female connector. It uses a cylindrical shaped container to provide the required level of lateral alignment. The locking unit however is not mechanical but instead magnetic, since a magnetic lock provides a balance between the required mating and demating characteristics of the application, plus offering extra rotational alignment measures.

The benefits of using POF on the application are several. On the one hand the technical benefits: high data rate (up to 1Gbit/s), the lack of corrosion problems, more than sufficient coverage (up to 100 m), very big numerical aperture, electrical isolation and flexibility. On the other, the economical benefits: the low cost characteristic of the technology, due to their manufacturing nature and the existing economy of scale. The current commercial POFs such as selected Mitsubishi Optohome POF (ESKA™), were originally developed for home entertainment purposes.

Table. 1: Specification of the ESKA CK40 POF (from [4]).

Material	*Core (PMMA resin)*	*Cladding (Fluorinated polymer)*
Diameter (typical) (μm)	*980*	*1000*
Young's modulus (GPa)	*3.09*	*0.68*
Poisson's ratio	*0.3*	*0.3*
Refractive index	*1.492*	*1.405*
Yield strength (MPa)	*82*	
Transmission loss (@ 650 nm) (dB km^{-1})	*200*	
Maximum operating temperature (°C)	*70*	
Approximate weight (g m^{-1}) 1	*1*	

The fiber has an attenuation ranging from 80 dB/km to 120 dB/km in its transmission window around 650 nm. The PMMA (Poly-Methyl MethAcrylate) core has a refractive index of 1.492, while the Fluirinated Polymer (fluoroalkyl methacrylate) cladding has an index of 1.402. The core has a diameter of 980 micrometers, while the cladding reaches 1000 micrometers and the outside cover 1100 micrometers. The core diameter of 1mm improves the coupling characteristics.

The selected material for the structure is Polyoxymethylene (POM), also known as Acetal, due to it´s high strength, stiffness, low friction, good wear properties and quite stable elastic modulus ratio as function of hydrostatic pressure [5].

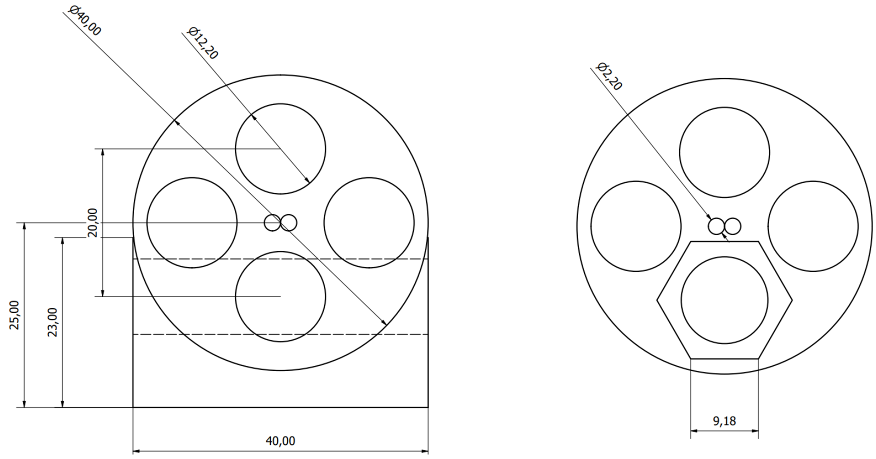

Fig. 1: Optical fiber connector terminal design for the male connector (left) and female connector (right), with the Tx and Rx fiber in the middle and the bigger aligning and locking magnets around.

4. Misalignment effects

The extrinsic coupling losses of the connector might be caused by several types of misalignments between the connectors. Misalignment losses affecting the design can be categorized as: longitudinal displacement or end face separation, lateral offset or misalignment, angular misalignment, rotational misalignment and the fibre end cut misalignment. The current analysis considers the first three as the most important ones and compares the theoretical results with the throughput measured in the laboratory:

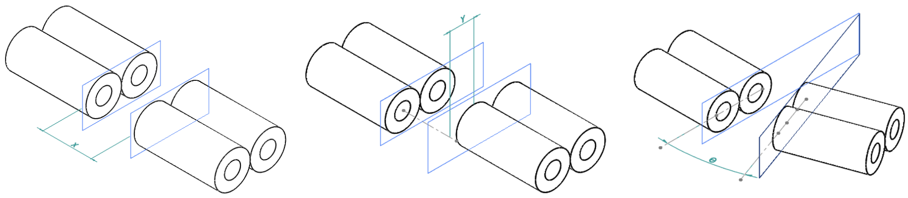

Fig. 2: Longitudinal, Lateral and Angular misalignments.

Since the simple solution is to use two fibers, the rotational misalignment has similar effects to the lateral misalignment. When analysing the coupling efficiency for these misalignments we can detect how for small angular or lateral displacements - in the range of very few degrees or distances similar to the core radius- only the edges of the transmitting core signal miss the receiving fiber. The edge of the core transmits the higher-ordered modes, while the lower end are transmitted near the center. Since higher-ordered modes are more attenuated than lower modes, the edge contains less power than the core center, and therefore small misalignments are less detrimental. However, for big misalignments, the resulting bandwidth is deteriorated rapidly as confirmed with throughput tests in the laboratory. Therefore, the cylindrical sheath that needs to serve as the main mechanical alignment unit shall guarantee less than .5mm slack to avoid lateral misalignments or less than 2 degree angle misalignment between female and male parts.

When analysing the longitudinal misalignments, it was found that the robustness of the link will be naturally more resilient against these disruptions, and even more if they happen underwater than in the air. The reason for this is that since the Numerical Aperture (NA) of a fiber is the sine of the largest angle an incident ray can have to achieve total internal reflectance in the core (2), and also the square root of the relation between the core reflection index and that of the cladding, we see how the change of the reflection index underwater will benefit the solution by reducing the incident angle(3). This fact was confirmed in the laboratory by comparing the throughput with and without water.

$$NA = \sqrt{n_c^2 - n_{cl}^2} = \sqrt{1.492^2 - 1.405^2} \approx 0.5 \quad (1)$$

$$NA = n \sin \alpha \quad (2)$$

$$\alpha = \sin^{-1}(\frac{NA}{n}) \Rightarrow \begin{cases} air: n = 1 \Rightarrow \alpha = 30° \\ water: n = 1.35 \Rightarrow \alpha = 22.08° \end{cases} \quad (3)$$

Therefore it is logical for it to concentrate more the light underwater despite the separation between the terminals. The resulting throughput difference can be compared in the next graphs.

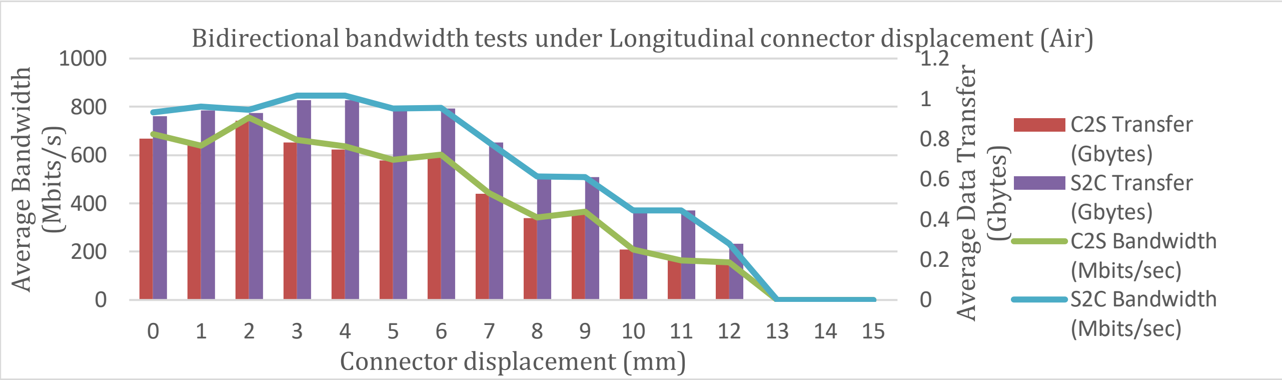

Fig. 3: Data Throughput test of connector under longitudinal displacements in air.

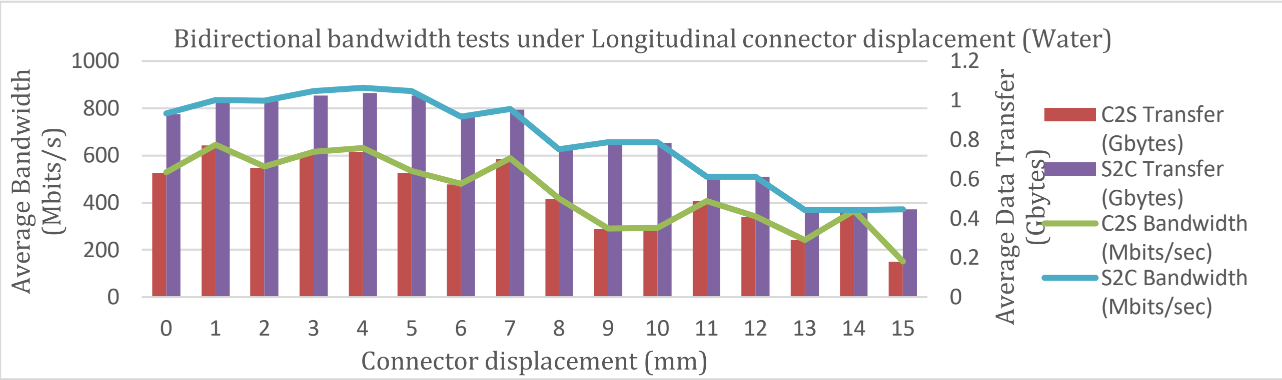

Fig. 4: Data Throughput test of connector under longitudinal displacements in water

4. Conclusions

The design of a simple two fibre optic dry-matable+wet-dematable connector can be challenging. In this case the cylindrical Polyoxymethylene container and the endcap magnets are able to provide mechanical support, avoiding the main misalignment losses. To guarantee the capability of de-mating the connector it is designed to work open to the sea pressure. The potential longitudinal misalignments caused by the water will be compensated by the huge numerical aperture of the POF and the performance robustness shown underwater. A simple index matching oil placed between the end caps could help improve this performance and even providing some sealing functions.

The POF characteristics has proven of great assistance to maintaining the high bandwidth communications underwater. The pressure effects are yet to be tested, but it seems as if there shall be no risk for the multimode fibre of becoming a monomode due to the size reduction.

Future work shall include testing the design under deep sea environments, exploring new transmission lambdas, since PMMA fiber´s attenuation improves for green and blue lambdas, as it does with water, and studying the long-term stability of POF's physical properties, since there is little or no literature on whether it may suffer undesirable changes in their optical and mechanical properties when aging under high pressure changes, seawater interaction, and use.

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