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THE REALIZATION OF AN OPTIC FIBER AIR BACKED MANDREL HYDROPHONE FOR FREQUENCIES UP TO 20 KHz

M.Anghinolfi[1], A.Calvi[3], A.Cotrufo[3], M.Ivaldi[1], O.Yershova[2], F.Parodi[1], D.Piombo[1], A.Plotnikov[2] and L.Repetto[3]

[1]) INFN-Sezione di Genova, Via Dodecaneso 33, I-16146 Genova, Italy
[2]) Moscow State University, 119992 Moscow, Russia
[3]) Università degli Studi di Genova, Dipartimento di Fisica, Via Dodecaneso 33, I-16146 Genova, Italy

Abstract

We describe how we have realized the prototype of an optic fiber air backed mandrel hydrophone designed to measure frequencies up to 20 kHz. The characteristics of the materials we have selected, the procedure of winding the optic fibers and the coating process are described in detail.

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1 THE HYDROPHONE DESIGN

In a previous report [1] we have determined the geometry of the hydrophone according to the required band width and sensitivity and using the results of the elastic theory as a guideline. According to this study, in fig.1 we present the drawings of our prototype. The 'passive' inner cylinder, shown in the left part of the picture, was machined from an anticorodal aluminum rod while the conical part is used to lead the optic fibers from the coils down to the axis of the hydrophone. The two 1.5 mm large slots located at the edges house the o-rings ($Ø_{in}$ =10.78 mm, $Ø_{out}$=16.02 mm) that support the 'active' cylinder, represented in the central part of fig.1. This 'active' cylindrical shell, obtained from an ULTEM1000 [2] plastic rod of 25 mm diameter, is 1mm thick, 20 mm long and 15 mm of inner diameter to provide a 1 mm clearance for air backing. The right part of the same figure represents the final assembly of the hydrophone where the removable end cap in the right , made with the same anticorodal aluminum of the inner support, is needed to allow the insertion of the o-rings and to fix the ULTEM 1000 shell as well as the fiber coils.

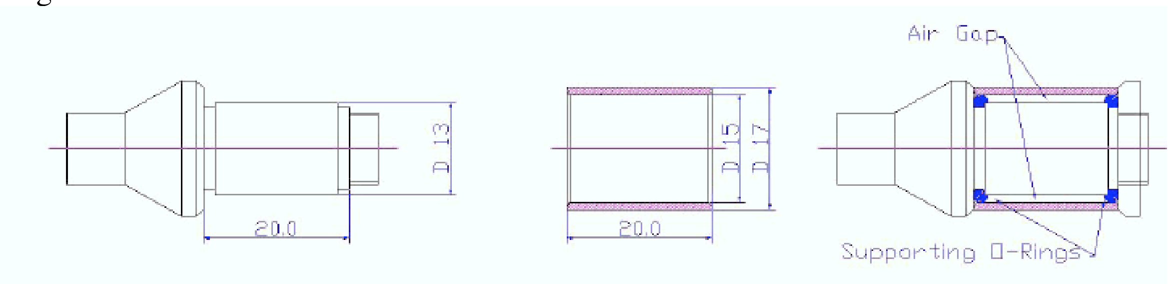

FIG. 1: The layout of the hydrophone

2 THE CHOICE OF THE OPTIC FIBER

The following step to realize the prototype included the choice of the optic fibers and the study of the best winding procedure to realize the fiber solenoid .

Different factors drive the choice of the fiber, in our case the main constraints being represented by the radius of the coil which limits the light transmission. In order to minimize this bending effect we have selected some special fibers with high numerical aperture and small bending radius [3] like the ClearLite 1310-16, 1310-16S and 1310-16D models . In the following table we present the main characteristics of these fibers.

TABLE 1: the main characteristics of the selected optic fibres.

	CL1310-16	Micro CL1310-16S	Micro CL1310-16D	standard
Numerical aperture	0.16	0.16	0.16	0.13
Mode field Ø (μm)	6.7	6.7	6.7	≈ 9
Core Ø(μm)	6.0	6.0	6.0	8.2
Cladding/coating Ø(μm)	125/250	80/135	80/165	125/250
Short term bend radius (mm)	>5	7	4	≈ 25
Long term bend radius (mm)	>9	11	6	≈ 50

The fiber was selected according to the measured attenuation as a function of the bending radius for a fixed length of 25 m. The results, presented in fig.2 , show that both CL1310-16 and Micro CL1310-16D fibers have good transmission properties also for small bending radius values. For practical purposes (immediate availability) we choose the 80/165 CL1310-16D fiber.

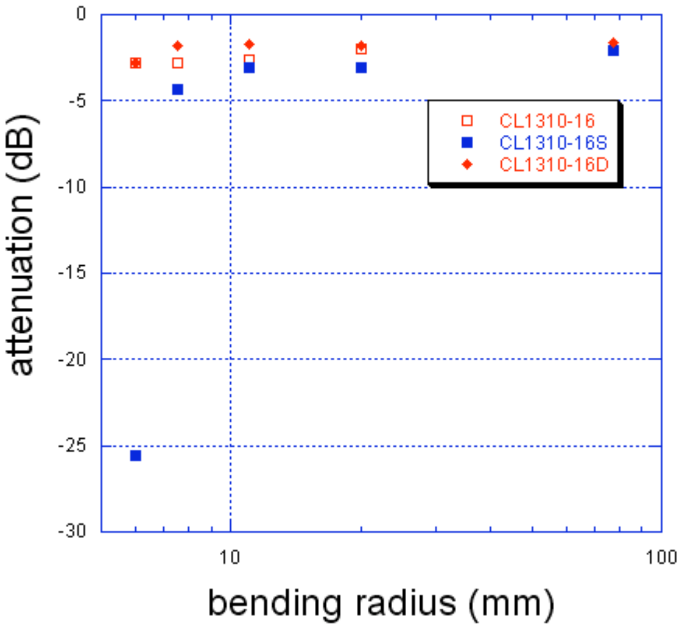

FIG. 2: The measured optical attenuation for a fixed fiber length as a function of the bending radius for selected fiber types.

3 THE CONSTRUCTION OF THE FIBER SOLENOID

The fiber, available with a length of 300m on a 12.5 cm radius drum, was spliced at each end with two FC-PC terminators to match the Acterna OLS-6 (1310/1550 nm) optical light source and the Acterna OLP-6 optical power meter. With this set up we were able to measure the light attenuation during the coil fabrication and to stop the process whenever the fiber was badly wound. When completed, each layer of the fiber solenoid was covered with the two component transparent epoxy casting resin STYCAST 1264 which becomes rigid in a 24 hours period.

The process is automatically run by the winding machine Meteor M20 which accepts, as inputs, the number of coils to be performed in a given direction (forward, backward), the step size (equivalent to the external diameter of the fiber) , as well as the winding speed. The fiber from the drum, slightly pre-tensioned by a pulley system, is lead to the hydrophone spool which moves and rotates according to the parameters given to the machine. A Wild Heerbrugg M3Z Microscope was focussed in the spool and connected to a Panasonic CC TV colour camera to produce in a monitor a clear image of the region were the coil is created. This system, together with the measurement of the light attenuation, was found very efficient to control the winding process, in particular when changing from one layer to another. The first layer was wound with good accuracy in 120 coils but the following layers had a lower number because it was impossible to avoid gaps or misalignments. The number of coils and the light attenuation for the different layers is presented in table 2.

TABLE 2: the values of the optical attenuation on of the number of coils/layer as measured during the winding process.

Number of layers	Total N° of coils	N° of coils in each layer	Light attenuation, dB
0 (slices only)	0	0	-1.2
1	120	120	-2.2
2	237	117	-1.3
3	351	114	-1.1
4	465	114	-1.0
5	587	122	-1.0
6	698	111	-1.1

Taking into account the systematic uncertainty of +/- 0.3 dB, the light attenuation in the hydrophone does not increase with the number of layers, the average value of -1.3 dB being produced by the two splices and the fiber in the drum.

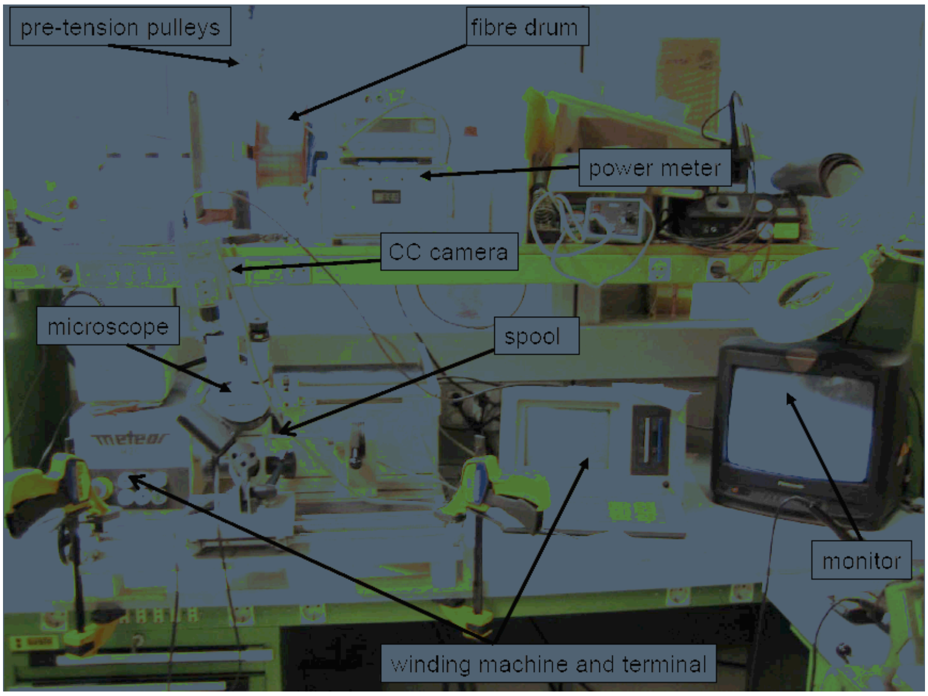

FIG. 3: The experimental apparatus used to construct the hydrophone.

This result is compatible with the measurements reported in fig. 1 where the fiber CL1310-16D shows negligible attenuation for bending radius≥ 8.5 mm. The set up used to wind the fiber is presented in fig. 3 while a picture of the spool at an intermediate step of the machining is shown in fig.4

After the completion of the 6th layer, two mirrors have been spliced at both ends of the solenoid to produce the arms of the interferometer. The mirrors are custom fiber Bragg gratings produced by the O/E Land Company in Canada [4] with available reflectivity of 1.5±0.5%, 20±3 % and 40±3 % at λ=1319±0.2 nm. In this hydrophone the interference happens between the signal reflected by the first mirror M1 and the signal from the mirror M2 located after the solenoid. The configuration where both M1 and M2 have the same 1.5% reflectivity should be preferable since the reflected signals have almost the same amplitude in this case. However in our condition we found that the 1.5% + 20 % version was more effective and that was the configuration we choose.

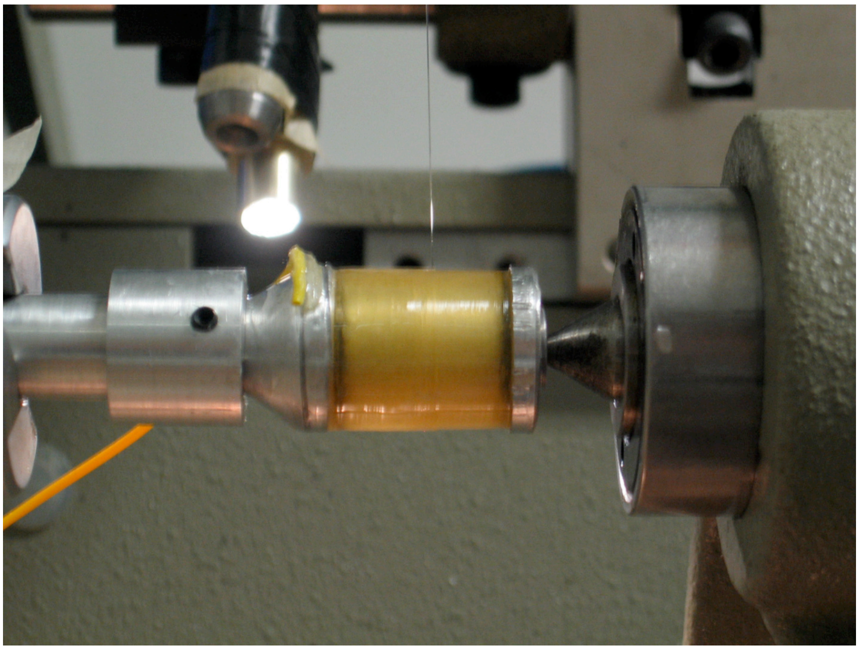

FIG. 4: The winding of the optic fiber in the spool.

The final phase of the construction includes a cast resin coating to protect the hydrophone from the external environment as well as for a safe handling.

This protection was performed using a dedicated mould containing the hydrophone while the two mirrors, spliced at the two ends of the fiber solenoid, were housed inside a water tight aluminium box. The mould, shown in fig. 5, is 40 cm long: two cylindrical regions are carved at the two ends to house the hydrophone body and the penetrator for the splicing box. The clearance of 1 mm between the mould and the hydrophone when in place ensures a sufficient thickness of the coating.

The two components cast resin, model 3M Scotch1471 N, were mixed together and de-gassed for few minutes inside a small vessel connected to a pumping system.

Different materials have been considered to optimize the coating process. The best solution we found corresponds to a mould made in Teflon were the surface in contact with the resin was sprayed with a PR long lasting mould release. In this configuration we were able to perform a uniform coating without the formation of bubbles and easily detachable from the mould. In fig. 6 we show the final result with the box containing the two mirrors and the hydrophone on the right end. This system was proven to be water tight when merged in a water bath: we plan to simulate realistic environmental conditions using an hyperbaric chamber up to 50 atm corresponding to 80% of the maximum pressure value which can be sustained by a 1mm thick, 20 mm long ULTEM 1000 cylinder shell loaded outside.

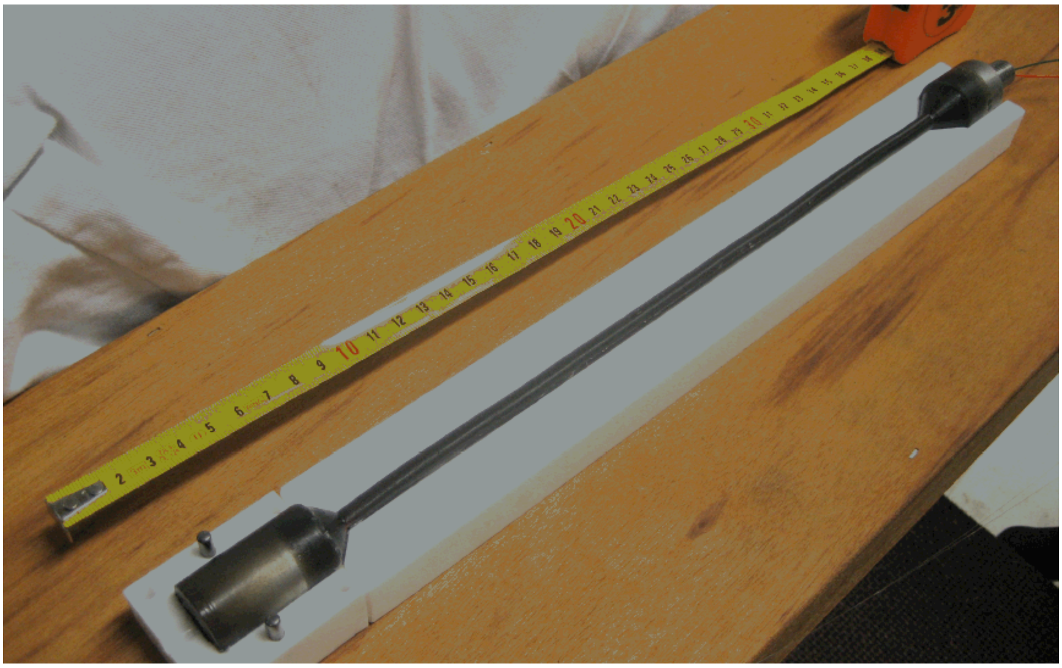

FIG. 5: The white mould in Teflon with the coated hydrophone (left) , the two optic fibers (center) and the penetrator (right)

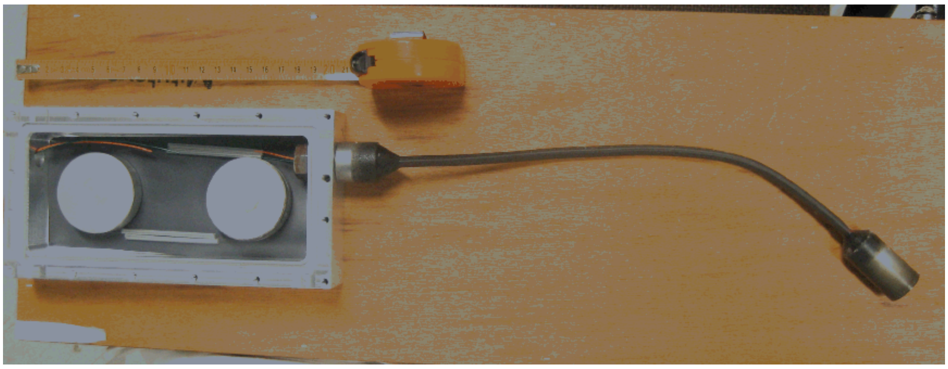

FIG. 6: The sensor after the coating process: the hydrophone (right) and the box containing the two fiber Bragg gratings.

In our work we have demonstrated that we were able to realize in our laboratory the optic fiber hydrophone using a dedicated winding machine and some other simple instrumentation.

The measurement of its response in air has been finally performed up to 10 kHz and will be presented in a fore coming INFN report.

4 REFERENCES

(1) Technical report INFN-TC-06-14 november 2006
(2) Ultem® 1000, General Electric's polythermide
(3) see e.g. THORLABS catalogue Vol. 17 2005 http://www.thorlabs.com
(4) O/E Land Inc., 4321 Garand, Saint Laurent, Quebec H2R 2B4, CANADA