SASSO program – development of an expendable underwater acoustic array with sensors based on fibre optic technology

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Abstract – SASSO (*Sistema Acustico di Sorveglianza con Sensori Ottici)* program deals with opto-acoustic sensors for underwater surveillance. The fibre optic (FO) sensors are very small, 100x12x10 mm, and operate at very low frequencies, down to 50 Hz, the low bandpass cut-off frequency being only required to filter the hydrostatic pressure. The sensors have a 2,500 Hz maximum frequency limited by the technology used. A mechanical filter regulates the sensitivity of the sensors, which use a Fibre Bragg Grating (FBG) modified with Distributed Feed Back-Fibre Laser technologies (DFB-FL). Each sensor is composed of a FBG laser sensor accurately integrated with a polymeric mechanical amplifier purposely realized by means of a 3D printer. The laser sensors are optically pumped by an additional laser beam, which, in turn, enables the lasing pertaining to each active FBG cell. The receiver transforms in real time the light in an electronic signal converted in digital at the signal processing input. The SASSO antenna is composed of a high sensitivity array and a FO link, which can be up to 10-30 km long. The acoustic array of SASSO can be installed on board surface vessels and submarines as well as on board underwater or surface unmanned vehicles for the detection of very quiet targets. The very low dimensions of the sensors limit the towing drag. Moreover, when deployed from a ship, the SASSO antenna remains fixed, while the FO link is unwound. The sensors are supposed to be free from flow noise and the target of the SASSO technology is to obtain a very long detection range and to reveal extremely silent underwater means. Experimental trials are scheduled in June and further data will be available during the tests scheduled in two years time.

1 Purpose

The SASSO (*Sistema Acustico di Sorveglianza con Sensori Ottici)* program has the purpose to explore a new concept of underwater surveillance by means of expendable arrays of sensors.

This approach is made possible by the study of a new type of fibre optic (FO) interferometric hydrophone.

These FO sensors are arranged in arrays connected to the patrolling platform via FO links even at far distances.

In order to be integrated on board of small platforms or submarines, the same type of FO sensors can be arranged in towed thin line arrays.

2 Introduction

The SASSO program is based on interferometric FO hydrophones. First interferometric FO hydrophones were proposed in the late 70s [1], offering advantages like geometric versatility, multiplexing capability and immunity from Electro-Magnetic Interference [2].

More recently, fibre laser strain (FLS) sensors [3] have been introduced to achieve sensitivities suitable for underwater surveillance applications.

FLS are composed of a narrow linewidth fibre laser exposed to the pressure to be measured and are supplied by an optical pump. Variations of the external pressure produce fluctuations of the laser frequency, which can be accurately measured. The sensitivity of such sensors is regulated by means of mechanical amplifiers such as the flexural beam bender [4] and the polymeric ring overlay [5].

The SASSO program studied an evolution of the FLS sensor with beam bender amplifier to reach very high performances at low manufacture complexity.

3 Approach

The performances of the towed arrays are limited by the flow-noise. Therefore, patrolling must be executed at limited speed in order to maintain good acoustic ranges.

The new concept is based on patrolling large areas with flow-noise free arrays, without limiting the ship navigation speed.

The array of sensors is connected to the patrolling ship by means of a FO link, up to 30 km long. The deployment speed is the same of the platform navigation speed.

When the ship has to change area of patrolling, the sensor array is released and a new one is deployed.

The SASSO system is made up of four main blocks: a wet part, constituted of a sensing FLS array and a connecting FO cable, a deployment system, an optical pump and a receiver on board the platform.

The sensitivity (S) of the FLS with bender mechanical amplifier is defined by the intermediate frequency of the C-band (ν), the opto-elastic coefficient (e_z), the Young modulus of the bender material (E) and by the thickness of (T), length of (L) and pressure applied to (p) the bender:

$$\mathcal{S}(\omega) = \frac{|\Delta\nu(\omega)|}{p} \sim \frac{3\nu(1-e_z)L^2}{4T^2E} \qquad (1)$$

The chosen material, polycarbonate, allows a theoretical sensitivity in the order of 48 nm/MPa.

Moreover, the material can be easily manufactured by moulding or by 3D printing and the sensors are mounted without any need for special tools, as shown in figure 1.

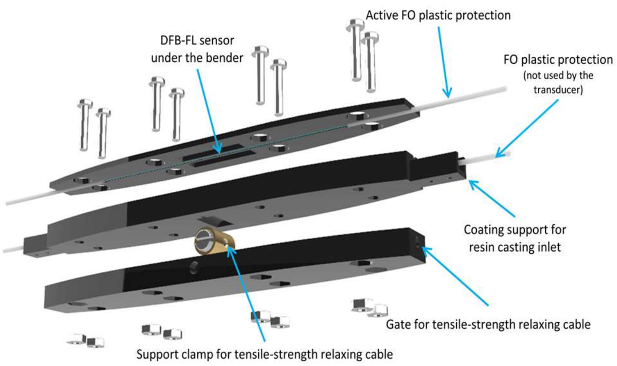

Fig. 1. SASSO sensor manufacturing

The overall size of the sensors already realized is 120x16 mm with 12 mm height, allowing the possibility to unwound and wound the fibre on reels.

An optical pump powers the sensor and the interferometric signal, received by an optical to electronic converter, is then conditioned by analogue to digital conversion, signal and data processing.

The Minimum Detectable Level for this type of sensor is determined by the purity of the pump frequency.

The purity of the pump frequency is $4*10^{-11}$ $nm/(Hz)^{1/2}$, which corresponds to 19 $dB\mu Pa/(Hz)^{1/2}$, always lower than sea state 0. The detection of the sensors is then limited only by the environmental noise.

On the one hand, the formula (1) is valid only at frequencies far from the resonance of the bender, which is estimated in the order of 6 kHz. This makes the SASSO sensor fitted for frequencies lower than 2.5 kHz.

On the other hand, since patrolling is done at variable depth and the sensors are sensitive to hydrostatic pressure, compensation is required. This compensation makes the sensors sensitive to frequencies higher than 50 Hz.

More sensors, up to 16, can be arranged on the same fibre and more fibres can be combined in single or multiple arrays. The laser frequency of every sensor in one fibre is different to distinguish the single detections.

An innovative algorithm locates the relative position of each transducer in the array using anisotropic noise in the water (e.g. propellers). During detection, the knowledge of the location of the sensors is used to solve the left-right uncertainty.

4 Lesson learned and future work

The SASSO program has already demonstrated that FLS sensors guarantee at low frequency better acquisition performances than the currently used piezo-electric transducers. They can be gathered in towed arrays for underwater vehicles and submarines or in temporary static surveillance systems.

To patrol large areas, the array is deployed at the centre of the area and, thanks to its sensitivity and flow-noise immunity, continuously monitors the area while the platform is free to manoeuvre. The array acquisition range in good propagation conditions is estimated to overcome 30 km and the array remains operational up to the moment in which the platform has run a distance equal to the FO length.

The acquisition range can be increased splitting the array in more subarrays deployed by the platform in different points, and using multistatic processing.

The SASSO program is now approaching the evaluation in laboratory and, in two years time, will perform the trials at sea.

The integration on other platforms and the towing of these sensors require additional study on the reduction of the occupied volume, mainly of the optical pump, and on the effects of the applied towing force.

Possible applications should be the discovery of underwater threats and monitoring of large areas in real time to perform Defence Against Terrorism (DAT) and Harbour Protection (HP) activities, as long as monitoring of environment, fauna, seismic and water pollution.

References

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Walter Cappelli – born in Italy in 1978, joint the Navy in 1997 and graduated Telecommunication Engineer in 2004. WEO on board, in 2013 he started to professionalize the Underwater Warfare experiences. He is currently responsible for the procurement of HWT contracts and UW MNRP programs at the Naval Armament Directorate.

Vittorio Falcucci – born in Italy in 1954, in 1980 graduated Electronic Engineer and joint WASS, reaching the position of Technical and R&D Director and gathering 34 years of experience in Underwater Warfare. National Expert for H2020, Teacher in SONAR Systems, he is now Technical Director of TECNAV Systems and EUROTORP consultant.