LOW-FREQUENCY JANUS-HELMHOLTZ TRANSDUCERS FOR GREAT-DEPTH ACOUSTICAL OCEANOGRAPHY

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1. INTRODUCTION

Initially designed for low frequency active sonar, the double-ended Janus-Helmholtz Acoustic Source (JHAS) has attractive applications for acoustical oceanography, namely Ocean Acoustic Tomography (OAT) [1] and Very High Resolution (VHR) reflection seismic [2].

In 1994, IFREMER launched the development of a new autonomous instrumentation adapted to OAT basin-scale studies (@ 1000 km). Due to its low-frequency and high-power properties, the JHAS technology was well-suited to these long range applications. Thanks to a technological evolution of the JHAS concept, the problem of high hydrostatic pressures has been solved. The first very low frequency (VLF) JHAS prototype was optimised to work in two frequency bands located around 250 and 400 Hz [3]. The large electrical Q-factor values, the small TVR values and the limited available power (500 VA) prevented a use between both resonances (250 Hz) with enough bandwidth and sound level. A use around the second resonance (400 Hz) was then decided and 600 km ranges were obtained during Cambios experiment.

Following the description with working principles and the evolution of the JHAS technology, the performances of this first VLF prototype are presented with experimental results. A second JHAS prototype with a better coupling between both resonances, allowing a use around 250 Hz with a 70 Hz bandwidth and a constant sound level at any depth, will be achieved in 1999.

Furthermore, the large-bandwidth depth-unlimited JHAS concept appeared very promising in soil survey, compared to conventional VHR seismic sources.

2. THE JANUS-HELMHOLTZ TRANSDUCER

2.1 Description

The Janus-Helmholtz Acoustic Source (JHAS) is made up of a piezoelectric ceramic stack inserted between two similar headmasses (Fig. 1). This structure, called Janus driver, is mounted inside a vented rigid cylindrical housing and the decoupling between headmasses and housing is provided by a very thin slit. A fluid with a low compressibility modulus ($\rho.c^2$) is inserted inside the cavity (instead of depth-limited glass-resin-composite compliant-tubes) in order to satisfy the Helmholtz resonance condition, to work at low frequencies and to have a **free-flooded device** without pressure

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compensating system. Due to the coupling of two resonances, a **wide frequency band** is available. Two frequency bands are usable for OAT applications :

- Between both resonances to have a large bandwidth with almost-constant impedance values, and to be hydrostatic pressure non-dependent (verified from deep-sea measurements in the Mediterranean Sea).
- Around the second resonance to have large Transmitting Voltage Response (TVR) values with a high electroacoustic efficiency, allowing small voltage values even if frequency is higher than in the first case.

This kind of transducers allows the realisation of **low-frequency and high-power devices** : a Janus-Helmholtz acoustic source, called standard JHAS, with a 0.6 m length and a 0.45 m diameter offers a first resonance frequency near 600 Hz and TVR values over 130 dB (ref. 1 µPa/V at 1 m) up to 1.1 kHz (Fig. 2) [4]. 0° and 90° respectively correspond to the axial and radial direction of the transducer. The **high measured electro-acoustic efficiency** in the working frequency band (over 60 %) is another attractive characteristic in the case of autonomous sources that will allow the reducing of the weight and size of the batteries.

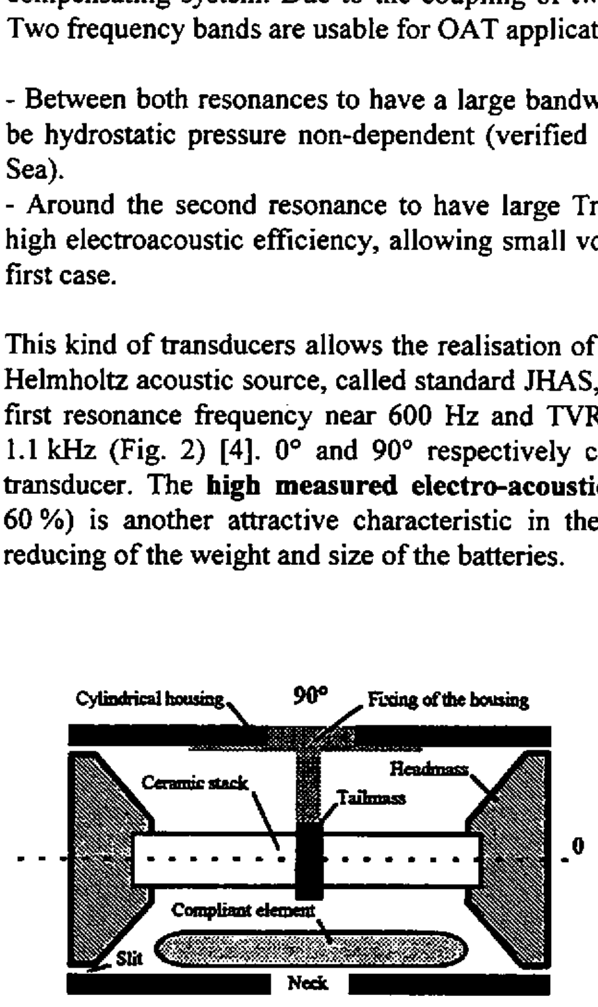

Fig. 1 : section of the Janus-Helmholtz (JH) transducer

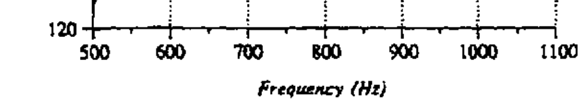

Fig. 2 : TVR of the standard JHAS (by courtesy of DCN INGENIERIE SUD)

2.2 Modelling with the finite-element code ATILA

ATILA (Analyse de Transducteurs par Integration des equations de Laplace) is a finite-element code specifically developed to aid in the design of transducers radiating into a fluid. It permits static, modal and harmonic analyses of elastic, piezoelectric and magnetostrictive structures [5]. Taking advantage on its revolution axis, a bi-dimensional mesh of the Janus-Helmholtz transducer has been achieved with ATILA (Fig. 3). In this simulation, compliant cavity, rubbercoat for waterproofing, fixing of the housing and internal losses (complex matrix) are taken into account.

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Figure 4 presents the comparison between theoretical and experimental radial responses of the standard JHAS. One observes good frequency and level agreements in the whole frequency band [500, 1300 Hz]. In the case of OAT experiments, we only consider levels in the radial direction because of the vertical positioning of this transducer, in order to be omnidirectional in bearing.

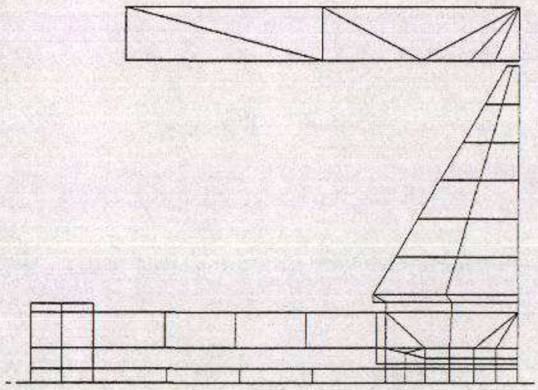

Fig. 3 : 2D mesh of the standard JHAS

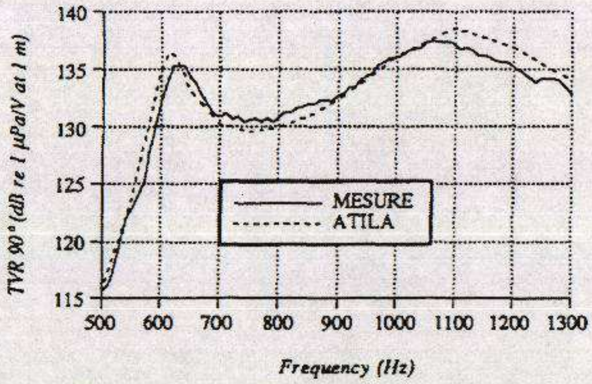

Fig. 4 : theory-measurement comparison

2.3 Working principles

The first resonance of the Janus-Helmholtz transducer was usually interpreted as the Helmholtz resonance (stiffness of the cavity and fluid-mass in the neck) and the second resonance as the driver one (driver dynamic-mass and elasticity). Various modellings and measurements (cavity filled with several tubes or fluids, housing-length from 0 to 26 cm, ...) reveal that the two observed resonances are driver-cavity coupled resonances. Moving fluid-mass inside the cavity and driver-elasticity have a major influence on the first resonance while cavity-compliance and driver dynamic-mass mainly act on the second resonance [3].

3. JHAS PROTOTYPES FOR OAT EXPERIMENTS

3.1 The first JHAS prototype (JHAS1)

The first very low frequency JHAS prototype (Photo 1) has been optimised in collaboration with SHOM/CMO (Oceanography Military Centre) to work in frequency bands located around 250 and 400 Hz (Fig. 5). The large electrical Q factor values ($Q = \omega.R_p.C_p$), the small TVR values and the limited available power (500 VA power amplifier) did not allowed to use this capacitive transducer between both resonances (250 Hz) with enough bandwidth and sound level to reach large ranges with a good time resolution. For this first mock-up, a use around the second resonance (400 Hz) was then decided.

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As the inner-fluid properties mainly act on the second resonance, the sound level unfortunately decreases when the transducer-depth increases. For CAMBIOS experiment in North-East Atlantic, the transducer was moored at 600 m depth and the sound level dropped to 191 dB (ref. 1μPa at 1 m). Expected ranges are then reduced to 600 km, instead of 1000 km. First results of CAMBIOS are given afterwards.

JHAS1 performances with a 500 VA Class D power amplifier (experimental results) [6] :

- Central frequency : $F_0 = 400$ Hz (second resonance)
- -3 dB bandwidth : $\Delta f = 50$ Hz
- Maximum sound level : SL = 195 dB (ref. 1μPa at 1 m) with $U = 400\ V_{rms}$
- Electroacoustic efficiency : $\eta = 70$ %
- Weight in water : M = 190 kg
- Length : L = 1.15 m
- Range : Hydrostatic-pressure dependent (600 km at 600 m depth)

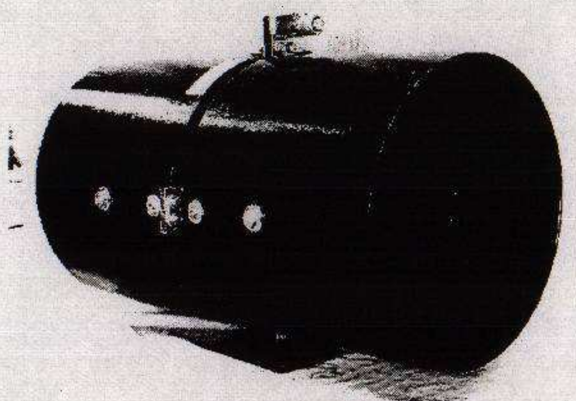

Photo 1 : the first JHAS prototype (JHAS1)

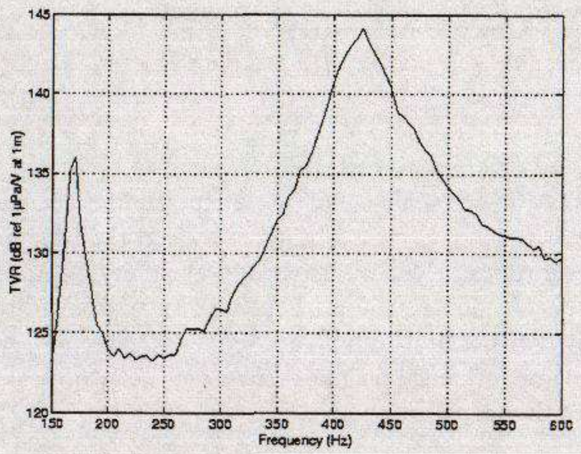

Fig. 5 : measured TVR of the JHAS1

3.2 The second JHAS prototype (JHAS2)

A working frequency band located between both resonances is the better way to fulfil bandwidth requirements and to have a constant sound level at any depth, but an improvement of the electrical behaviour is necessary. Due to the length of the ceramic stacks, it is not possible to strongly modify the parallel capacitance (C_p) of the JHAS. The only way to optimise the electrical Q factor and to minimise the power consumption is to have a better coupling between both resonances which implies an increase of the TVR values in this frequency band (i.e. a decrease of the voltage values) and a decrease of the parallel resistance values (R_p). Headmass-shape and opening between cylindrical housings have then been modified (ATILA finite-element modelling). As these modifications led to a frequency shift, the length of the driver has been extended.

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The improvement of the JHAS TVR is showed on the figure 6 (theoretical results). A 7dB gain is obtained between the resonances, the electrical Q factor is divided by two in the working frequency band, and the electroacoustic efficiency is much better. Thanks to the use of more fluid inside the cavity, the in-water transducer-weight remains unchanged. The study of the impedance matching circuit reveals that sound level and bandwidth requirements to reach 1000 km ranges with enough time resolution (SL = 190 dB ref. 1µPa at 1 m ; Δf = 70 Hz) could be satisfied with a 1.5 kVA Class D power amplifier. New transducer and power amplifier will be achieved before the end of 1999.

JHAS2 performances with a 1500 VA Class D power amplifier (theoretical results) [6] :

- Central frequency : F_0 = 250 Hz (between the resonances)
- -3 dB bandwidth : Δf = 70 Hz
- Maximum sound level : SL = 190 dB with U = 1000 V_{rms} (ref. 1µPa at 1 m)
- Electroacoustic efficiency : η = 35 %
- Weight in water : M = 190 kg
- Length : L = 1.5 m
- Range : R = 1000 km

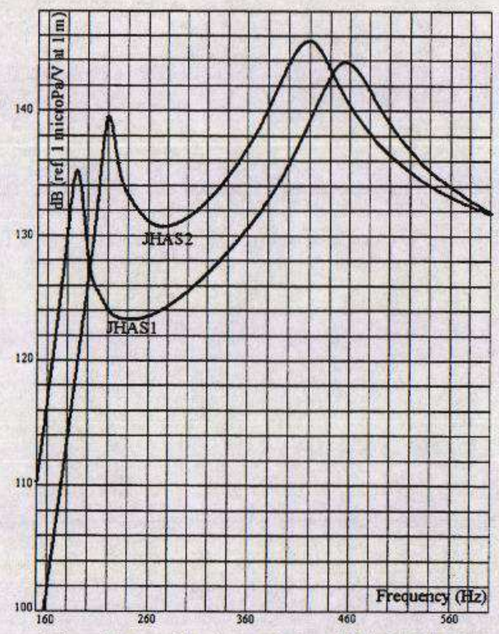

Fig. 6 : evolution of the JHAS TVR

3.3 Experimental results (CAMBIOS experiment)

The whole tomography system [6], including JHAS1 with its power amplifier and impedance matching unit, the autonomous acoustic receiver (microcontroller, acoustic receiver, storage unit, navigator, time base, pressure and temperature module) and the batteries (Photo 2) has been deployed in Atlantic during the oceanography campaign Cambios, at a 600 meter depth.

Transmissions were received at 260 and 560 km. The received SNRs (19.3 and 13.4 dB) are quite in accordance with the source level and the environmental and geometrical conditions. The observed time resolution, i.e. the peak width (15 ms), is also in agreement with the expected one. On the received signal with a receiver 560 km away from JHAS1 (Fig. 7), one can distinguish the different time delays according to the different travel paths [6].

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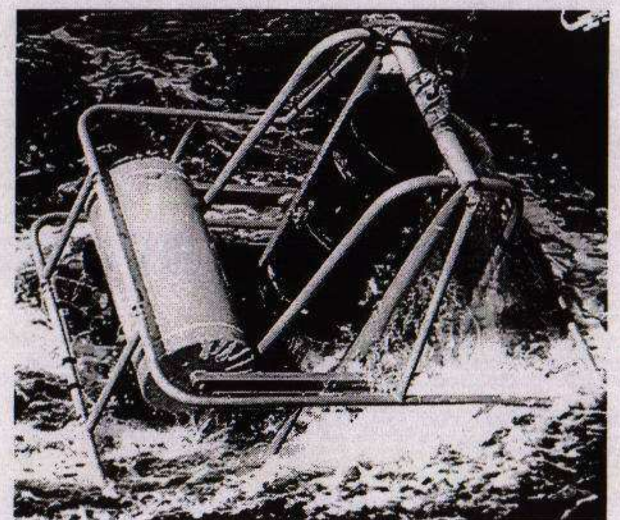

Photo 2 : OAT instrumentation with JHAS1

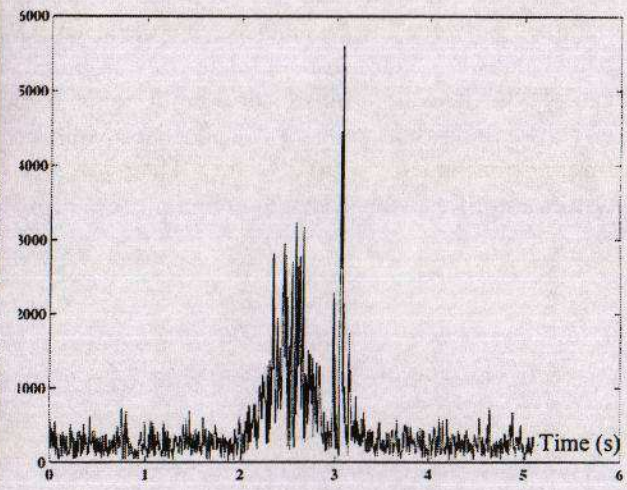

Fig. 7 : received signal
(receiver 560 km away from JHAS1)

4. THE STANDARD JANUS-HELMHOLTZ TRANSDUCER FOR SOIL SURVEY

4.1 The flat-TVR JHAS

Existing "chirp" sub-bottom profilers are limited in term of penetration by their frequency range (Tonpilz technology). Therefore, according to its large bandwidth and low frequency properties, the standard Janus-Helmholtz transducer seemed to be well-suited for soil survey. The JHAS technology offers an unexisting repeat of a well-known large bandwidth acoustic signal allowing accurate soil characterisation.

The internal cavity of the standard JHAS has been modified in order to have a -3 dB flat-TVR between 600 and 2000 Hz. The use of a 3 kVA power amplifier with an impedance matching unit implies sound levels over 193 dB (ref. 1 μPa at 1 m) in the whole frequency band. Moreover, according to its low frequency domain, this transducer is light enough (80 kg in air ; 40 kg in water) to be mounted on a towed-fish. As the depth capability of this kind of transducers is unlimited (without pressure compensating unit), this technology is able to drive VHR studies toward deep sea surveying.

This development was partly founded with the project CEP&M N°M1207/97 (Partners : Triton Elics International - Eramer - Ifremer - Total).

4.2 Experimental results

Photos 3 and 4 display the driver of the standard JHAS developed for VHR reflection seismic and the associated towed-fish. Up to now, only shallow water feasibility trials have been achieved. Figure 8 displays the results of a preliminary attempt to achieve VHR seismic profiling using a linear FM transmitted signal between 600 and 2400 Hz (no amplitude modulation). With limited sound levels (up to 192 dB ref. 1 μPa at 1 m), a penetration over 50 ms has been obtained in less than 10 m water-depth and the resolution appears excellent. Further sea trials will be carried out in the near future with higher electric power, allowing sound levels up to 200 dB (ref. 1 μPa at 1 m).

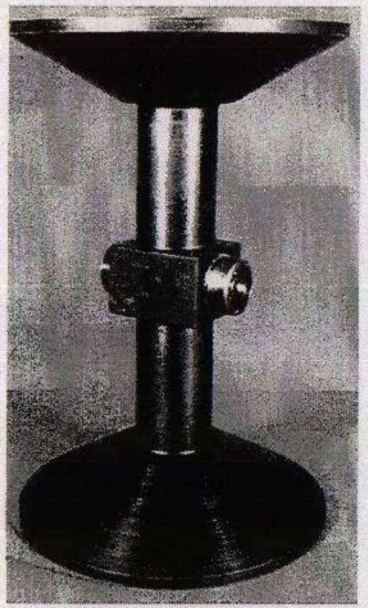

Photo 3 : driver of the standard JHAS

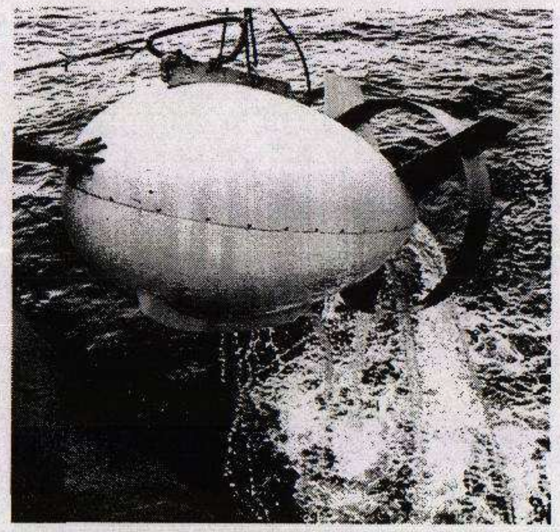

Photo 4 : towed VHR seismic JHAS

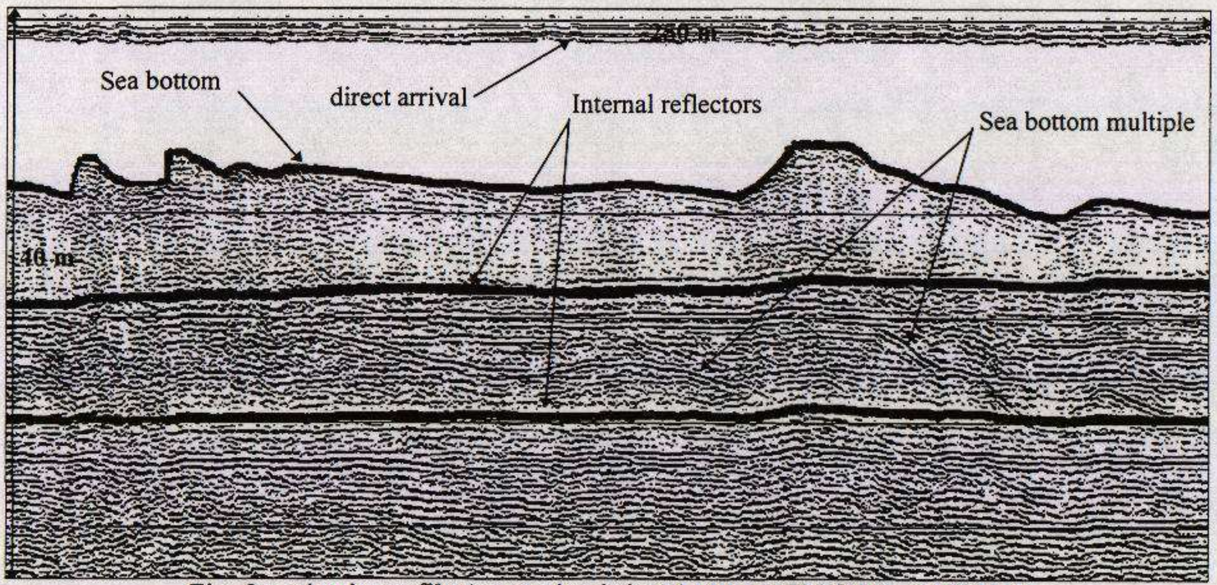

Fig. 8 : seismic profile (transmitted signal : linear FM [600 - 2400 Hz])

5. REFERENCES

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