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A STUDY OF THE OUTPUT OF A HYDROPHONE FIXED ON A VIBRATING STRUCTURE

C. AUDOLY and C. GIANGRECO

*D.C.N. Toulon, C.E.R.D.S.M., Le Brusc, F-83140 Six-Fours, France***ABSTRACT**

In the design of sonar systems, the hydrophones, which are the basic acoustic pressure sensors for the receiving arrays, are generally fixed on a supporting structure. The vibrations of the support generate self noise on the hydrophones, that reduces the performances of the array. In fact, the output signal on a hydrophone due to the vibrations of the supporting structure comes from two contributions:

- the signal related to the accelerometric sensitivity of the hydrophone, caused by the mechanical vibrations of the piezoelectric element;
- the signal related to the acoustic pressure sensitivity of the hydrophone, caused by the radiation of the vibrating support in the nearfield.

The purpose of this paper is to put forward these phenomena. After a brief presentation of the theory, some numerical examples of the output of hydrophones fixed on a vibrating support are first given. Then, a specific experiment is described: two experimental large area hydrophones (different with respect to their sensitivities) have been built. First, the pressure and accelerometric sensitivities are measured using conventional techniques. Then, a global experiment has been done in an acoustic facility, where the hydrophones were fixed on the head of a "Tonpilz" type projector. It is verified that the outputs of the hydrophones are formed by the two contributions mentioned above. This result may have consequences in the design of hydrophones for sonar arrays.

1. INTRODUCTION

The receiving arrays for sonar systems onboard submarines or ships are made with a large number of hydrophones, generally fixed on a metallic support (for example a steel cylinder or sphere), or the hull of the ship itself. The output signal U_{tot} delivered by the hydrophones contains:

- the contribution U_{sig} of the external incident plane wave on the array, which is the useful information (the system is looking for echo or passive signal coming from another ship to detect);
- a disturbing noise U_{amb} due to the underwater ambient noise;
- self-noise components such as flow noise U_{hyd} and mechanical noise U_{vib} generated by the vibrations of the structure supporting the array.

The purpose of this paper is to study more precisely the disturbances caused by the vibrations of the supporting structure. As the hydrophones use piezoelectric materials, they are both sensitive to acoustic pressure and acceleration. They are often designed to reduce their intrinsic accelerometric sensitivity, using an appropriate mounting of the ceramics. In fact, the output of a hydrophone fixed on a vibrating structure has two contributions:

- the signal related to the accelerometric sensitivity S_y of the hydrophone, caused by the mechanical vibrations of the piezoelectric element;
- the signal related to the acoustic pressure sensitivity S_h of the hydrophone, caused by the radiation of the vibrating support in the nearfield.

These phenomena can be summarized by the following equations:

$$U_{\text{tot}} = U_{\text{sig}} + U_{\text{amb}} + U_{\text{hyd}} + U_{\text{vib}}$$

$U_{\text{sig}} = S_h \cdot P_{\text{ac}}$, where P_{ac} is the acoustic plane wave to detect,

$U_{\text{vib}} = S_\gamma \cdot \gamma + S_h \cdot P_r$, where γ is the acceleration and P_r is the acoustic pressure radiated in the nearfield of the vibrating structure. In the following sections, theoretical and experimental examples will be given to determine the respective order of magnitude of the two latter components.

2. SENSITIVITY OF A HYDROPHONE TO ACOUSTIC PRESSURE AND ACCELERATION

The active component of a hydrophone is in most cases a piezoelectric material, that generates an open-circuit voltage on the electrodes.

The acoustic pressure sensitivity (fig. 1a) is obtained when the hydrophone is submitted to a uniform acoustic field of pressure P_{ac} (i.e. a uniform normal stress) :

$$S_h = \frac{U}{P_{\text{ac}}}$$

The accelerometric sensitivity is obtained when the hydrophone is submitted to a uniform acceleration in air (fig. 1b). In that case the effect of the radiated acoustic pressure is negligible, due to the weak coupling with air :

$$S_\gamma = \frac{U}{\gamma}$$

Fig 1. b : Accelerometric sensitivity

Fig 1. a : Acoustic sensitivity

Now, when a hydrophone is placed in water, and fixed on a supporting structure, the vibrations of the latter generate the output:

$$U = U_1 + U_2 \quad U_1 = S_h \cdot P_r \quad U_2 = S_\gamma \cdot \gamma$$

As an example, let's consider the case of a planar hydrophone, made with one layer of piezoelectric material. Theoretical low-frequency sensitivities are given by:

$$S_h = g_h \cdot e, \text{ where } g_h \text{ is a piezoelectric coefficient and } e \text{ the thickness;}$$

$$S_\gamma = 0.5 \rho e S_h, \text{ where } \rho \text{ is the volumetric mass.}$$

Case n°1 : If the vibrating support is an infinite plane with uniform acceleration γ at steady-state circular frequency $\omega = 2 \pi f$:

$$P_r = \rho_0 c \frac{\gamma}{i\omega}, \text{ where } \rho_0 \text{ is the volumetric mass of water and } c \text{ the speed of sound.}$$

Case n°2 : If the vibrating support is a circular piston of radius R at low frequencies, we have:

$$P_r = 0.613 \rho_0 R \gamma$$

Table I gives the ratio $(S_\gamma \cdot \gamma) / (S_h \cdot P_r)$ between the two contributions along frequency for the two cases, for a hydrophone made with one layer of piezoelectric lead titanate ($e = 5 \text{ mm}$, $\rho/\rho_0 = 7.3$):

f (Hz)	2000	3000	4000	5000
Case n°1	0.155	0.23	0.305	0.38
Case n°2 (R = 6 cm)	0.495	0.495	0.495	0.495

Table I : Ratio $\frac{U_2}{U_1}$

It can be seen that the response due to radiation is predominant, even for this type of hydrophone with high S_γ , and that the ratio between the two contributions depends on the radiating behaviour of the supporting structure.

3. EXPERIMENT

Two planar hydrophones of size $50 \times 50 \text{ mm}$ have been built. Number 1 is made with two layers of PVDF piezoelectric polymer of thickness 1 mm , mounted in order to reduce the accelerometric sensitivity as much as possible. Number 2 is made with one layer of lead titanate, of thickness 5 mm (see fig. 2).

First, the pressure and accelerometric sensitivities have been measured using conventional methods:

- for the measurement of S_h , a standard comparative calibration was performed in an acoustic tank;
- for the measurement of S_γ , the response of the hydrophones were compared to a reference accelerometer when placed on a shaker in air (see § 2).

In the frequency range of interest (from 2 to 5 kHz), the sensitivities were found approximately constant along frequency:

- hydrophone n°1: $S_h = 5.3 \cdot 10^{-5} \text{ V.Pa}^{-1}$; $S_\gamma = 3 \cdot 10^{-5} \text{ V.m}^{-1}.\text{s}^2$;
- hydrophone n°2: $S_h = 1.15 \cdot 10^{-4} \text{ V.Pa}^{-1}$; $S_\gamma = 2 \cdot 10^{-3} \text{ V.m}^{-1}.\text{s}^2$.

The two hydrophones were then stuck on the head of a "Tonpilz" type underwater projector. The radius of the head is 6.2 cm . In order to evaluate the acceleration of the projector head, two reference accelerometers of sensitivity $10^{-2} \text{ V.m}^{-1}.\text{s}^2$ were also stuck. The projector, equipped with the test hydrophones and the accelerometers was then placed in an acoustic tank and driven by a steady-

Fig. 2: Planar hydrophone

Fig. 3: Experimental set-up

state voltage. In that frequency range, the projector head vibrates like a piston. At the same time the outputs of the test hydrophones, the reference accelerometers were recorded. In addition, the nearfield radiated pressure was estimated using the measurement from a reference hydrophone of sensitivity $2.5 \cdot 10^{-6} \text{ V.Pa}^{-1}$ placed at 30 mm from the head of the transducer. See fig. 3.

Using the estimates of the actual head acceleration and radiated pressure given by the reference accelerometers and hydrophone, and the values of S_h and S_p obtained using conventional techniques, the theoretical voltages U_1 and U_2 on the test hydrophones can be computed, and compared to the measured value of U_{mes} in that final experiment. The results are shown on table II and III:

f (Hz)	2000	3000	4000	5000
U_1	0.11	0.43	0.17	0.12
U_2	10^{-3}	$4 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	10^{-3}
U_{mes}	0.14	0.54	0.16	0.11

Table II - Hydrophone n°1

f (Hz)	2000	3000	4000	5000
U_1	0.08	0.39	0.19	0.14
U_2	0.04	0.16	0.09	0.04
U_{mes}	0.12	0.58	0.2	0.16

Table III - Hydrophone n°2

The results are consistent with the theory, for which we should obtain $U_{\text{mes}} = U_1 + U_2$. Taking into account the imprecision of the acoustic measurements, the tendency is clear for hydrophone n°2, where the gap between U_1 and U_{mes} can be explained by the accelerometric sensitivity.

4. CONCLUSION

This paper has shown that the output of a hydrophone placed on a vibrating structure is related with both the accelerometric and pressure sensitivities. In most situations, the acoustic effect is larger than the direct accelerometric effect. This may have consequences in the design of hydrophones, because in some cases it is not worth looking for a very low accelerometric sensitivity. These phenomena are investigated theoretically and experimentally. New experiments, using nearfield acoustic holography techniques, are undergoing.