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SEA-PROVEN EXPLOSION RESISTANT ELECTRODYNAMIC PROJECTOR FOR MINESWEEPING

M. LETICHE (1), M. PERRIER (2)

(1) (2) THOMSON MARCONI SONAR S.A.S. - 525, route des Dolines BP 157 - 06903 SOPHIA-ANTIPOLIS Cedex - France
Tel : (33) 04.92.96.30.59 - Fax : (33) 04 92 96 30 66
E-mail : Michel.Letiche@tms.thomson-csf.com

ABSTRACT

Thanks to its specific characteristics - such as broadband capability in the very low frequency regime, great spectral purity and stability of the emitted signals, omnidirectionality, low overall dimensions and weight versus other technologies - the electrodynamic transducer is a very good candidate to generate programmable and high fidelity signals in a large bandwidth.

It is capable of accurately generating ship signatures, including simultaneously both single tones and noises, within the required bandwidth (typically from 4 Hz to 2 kHz) and so, very well adapted for minesweeping applications.

Within the STERNE minesweeping programme for the Belgian Navy, the challenge was to use compact and low mass electrodynamic transducers, because of their acoustic characteristics, and to upgrade their mechanical performances, specially the shock resistance (1 ton of TNT at 30 meters), in order to achieve the specified objectives.

The aim of this paper is to focus on the design of this new electrodynamic projector, capable of delivering powerful and high likelihood acoustic signatures while proving robust in an hostile environment. The different steps used for designing this transducer will be described.

The transducer has been fully qualified during operation at sea and its major features will be analysed and discussed.

1. INTRODUCTION

In currently influence minesweeping systems under development, the two primary minesweeping objectives to be fulfilled are :

- The emulation of the influence signatures of ships as the first and utmost priority,.
- As a lower priority, the ability to sweep a spectrum of generic mine concepts.

When assessing the relative merits of one minesweeping approach versus another, consideration must be given to many factors, including operational effectiveness, ease of deployment, control, and recovery, explosive shock resistance, development, production, and life cycle cost, risk to control platform, risk to sweep system, and system compatibility with MCM ships.

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The ship signatures of interest are passive acoustic, active acoustic returns, passive magnetic (static magnetic, static electric, alternating electric and alternating magnetic), hydrodynamic (pressure) and combinations of these influences that result in an overall ship signature.

The major feature of an minesweeping system is the capability of delivering powerful and high likelihood signatures in an hostile environment.

This paper is concerned with the acoustic minesweeping system development and specially with the very low frequency regime.

After analysing the performance of several candidate acoustic source technologies, including hydrodynamic, sparkgap, piezoelectric, electromechanical, and electrodynamic, a new moving coil electrodynamic source has been developed. This acoustic source has the following major advantages :

- broadband acoustic output in the low frequency range,
- small dimensions and weight compared to other technologies,
- omnidirectionality and explosive shock resistance.

2. MOVING COIL PRINCIPLE

The electrodynamic transducer or moving coil for underwater use is similar in principle to the air loudspeaker and like the loudspeaker, is used primarily as a wide band sound source.

The basic structure of a coil moving in a magnetic field, so common in a loudspeaker is show in Figure 1.

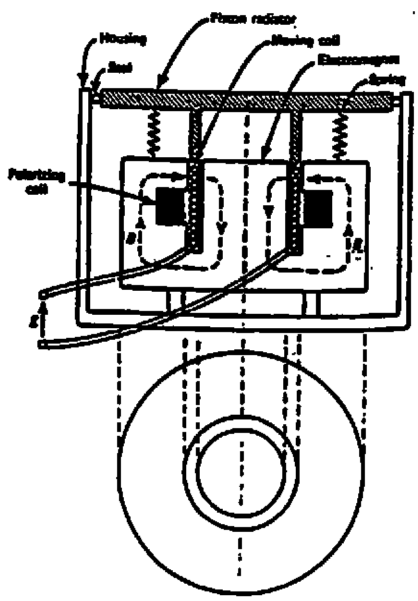

Figure 1 : Schematic of an electrodynamic transducer [1]

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The essential difference is in the type of radiating surface required for the two media, air and water.

The moving coil principle is as follows : a current-carrying conductor in a magnetic field is acted on by a force F equal to the product of the magnitudes of the field B, the current i, and the length L of the conductor normal to the direction of the field :

$$F = B\,L\,i$$

From the definition of mechanical impedance and the radiation of sound from a small diaphragm moving with uniform velocity, we can see why the transmitting current response is constant above resonance [2] :

$$F = j\,\omega\,m\,u$$

$$p \,\#\, \omega\,u$$

where ω is angular frequency, m is the combined mass of coil, diaphragm, and water load, u is the linear velocity of coil and diaphragm, p is the radiated sound pressure and # means "proportional to "

Combining the three equations produces :

$$p \,\#\, \omega\, u = \omega\left(\frac{F}{j\omega m}\right) = \frac{BLi}{jm} \,\#\, i$$

These equations are valid only when both mechanical and acoustical impedances are mass controlled and the diaphragm is small compared to the wavelength. The mechanical impedance is mass controlled at frequencies above the basic spring-mass resonance and below the flexure mode resonances of the diaphragm. The acoustical or radiation impedance is predominantly a mass reactance at frequencies where the diaphragm is very small in comparison with a wavelength in water.

Large diaphragm volume displacements are needed to radiate acoustic power at low frequencies. With inherently stiff piezoelectric or magnetostrictive transducers, this is difficult to do without resorting to very large transducers where large radiation area can compensate for limited small linear displacements. In a moving-coil transducer, the stiffness is all in the diaphragm spring suspension, which can be made almost arbitrarily compliant. This enhances the usefulness of the moving-coil transducer at low frequencies, but it also makes it mechanically fragile.

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Moving-coil transducers have automatic compensating systems for equalising the gas pressure inside the transducer with the hydrostatic pressure on the outside. For modest depths (down to about 30 meters), a collapsible bag arrangement is used. For greater depths, a Scuba-type mechanism can be used. Even with a properly operating compensation system, standard moving-coil transducers are relatively fragile instruments.

Designing electrodynamic transducers for mine sweeping applications means that we have to deal with the two following challenges :

- transform a fragile device into an explosion resistant equipment (1 ton of TNT at 30 m.),
- generate very low frequency signals (below 10 Hz) with a compact source.

3. DESIGN OF ELECTRODYNAMIC TRANSDUCER FOR MINESWEEPING APPLICATION

To achieve this ambitious goal, all the functional and technical components of the transducer have been carefully analysed and separately specified. The first point was to separate the mechanical and the acoustical properties of the transducer. The following items have been studied (see Figure 2).

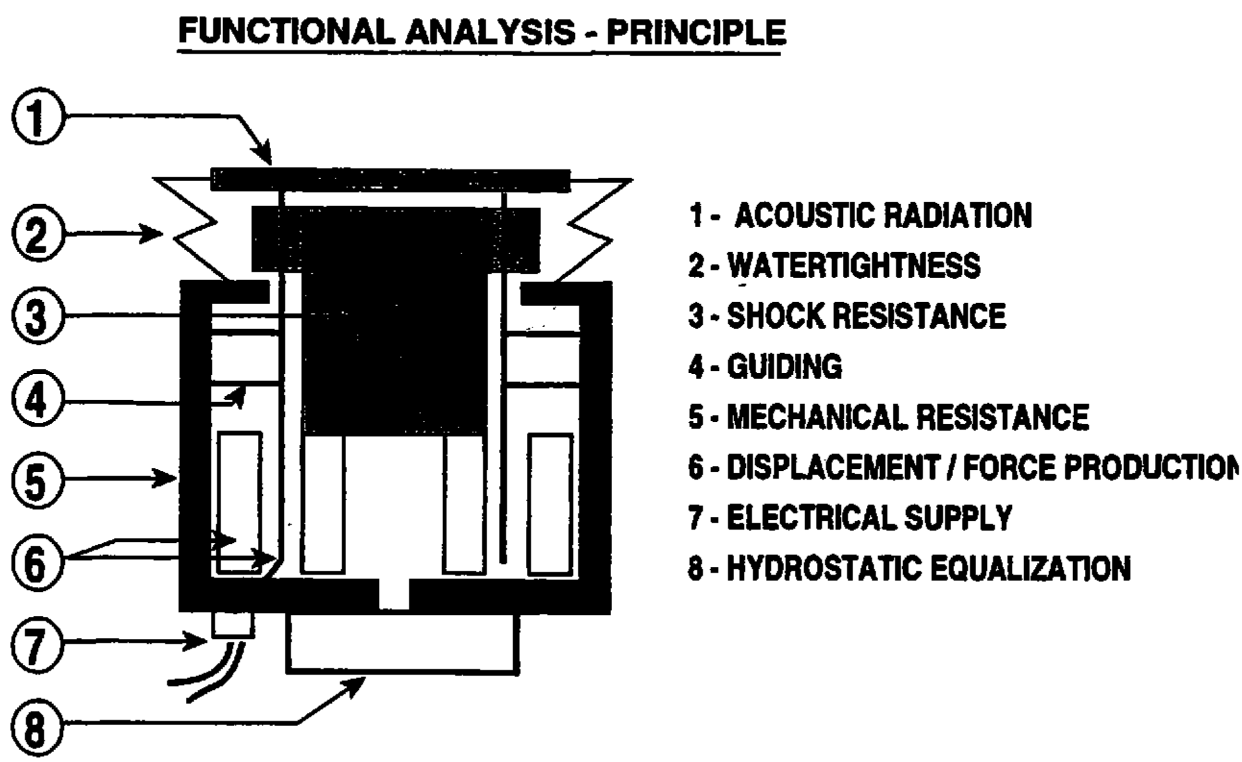

Figure 2 : Electrodynamic transducer principle

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3.1 Acoustic radiation

Starting from the sound level required for the total array and taking into account the geometry of the array and the acoustic interactions between transducers, the nominal source level SLo of the elementary transducer has been defined. Using some well-founded assumptions, SLo is linked to the area Sp and the acceleration γ of the radiating face by the relation :

$$SLo = 20\log\ \gamma\ + 20\log Sp + 177.8\ (dB\,ref\ \mu Pa\ at\ 1m.)$$

above the resonance frequency.

Consequently, the force generated by the magnetic field, the displacement and the mass of the moving part are defined. It has to be noticed that, due to the compactness of the projector, the stiffness is directly linked to the air volume inside the transducer.

3.2 Watertightness

In order to radiate high acoustic power in water, large diaphragm displacements are needed. That is to say that the rubber membrane in charge of the watertightness has to support large amplitude deformations when the transducer is excited at low frequency and also to be explosion resistant.

3.3 Shock resistance

During mine explosion, the moving part of the transducer has to support both large peak pressure and very large acceleration. Shock absorbers have been developed to minimise their effects.

3.4 Guiding

The moving part has to be guided during its large deplacements over a large bandwidth.

3.5 Mechanical resistance

The difficulty is to develop a small weight transducer which is mechanical resistant to mine explosions.

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3.6 Displacement / force production

The magnetic motor made with permanent magnets is designed to generate large force, large displacement in a small volume.

3.7 Electrical supply

One objective is to minimise the electric current in order to minimise the negative thermal effects.

3.8 Pressure compensation

A bladder has been studied in order to compensate the hydrostatic pressure without increasing the overall dimensions of the transducer.

4. PERFORMANCES

4.1 Mechanical characteristics

Compared to other technologies, this low frequency acoustic transducer presents small dimensions and weight, i.e. :

overall dimensions :	diameter : 360 mm
	height : 310 mm
mass :	60 kg

Furthermore, a prototype has been successfully tested within the French Navy facilities under an equivalent explosion shock of 1 ton of TNT at 30 meters, that is to say the transducer can support a 150 bars peak pressure.

The other mechanical and physical features are the following :

- Operating depth at full power : 3 - 10 meters
- Maximum moving part displacement : ± 15 mm
- Maximum force generated : 500 N
- Maximum electrical current : 4 ARMS
- Maximum electrical power : 600 W
- Operating temperature : +2, +30°C
- Storage temperature : -40°C, +75°C

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4.2 Acoustic performances

Maximum output for this transducer type is determined, in the low frequency region, by a mechanical limitation, i.e., peak to peak radiating face displacement, and by a thermal limitation, i.e., maximum input current, at the higher frequencies.

The operating frequency band is typically from 10 to 2000 Hz. Measurements at sea have been made down to 4 Hz with a reduced output power.

The maximum sound level SL (dB of N Pa at 1 m) versus frequency shown on Figure 3.

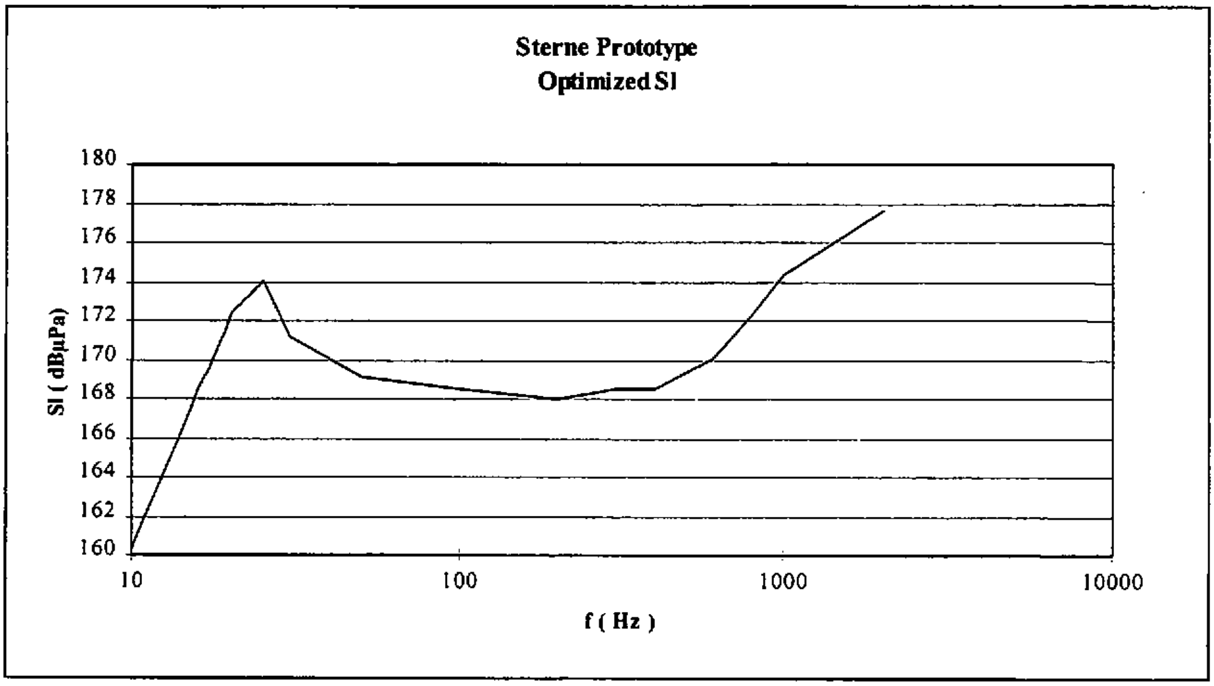

Figure 3 : Sterne transducer sound level

5. APPLICATIONS

This transducer has been designed for minesweeping applications. It can be used alone, in airborne minesweeping system, for example. A single electrodynamic transducer is capable of the continuous output spectrum shown in Figure 4.

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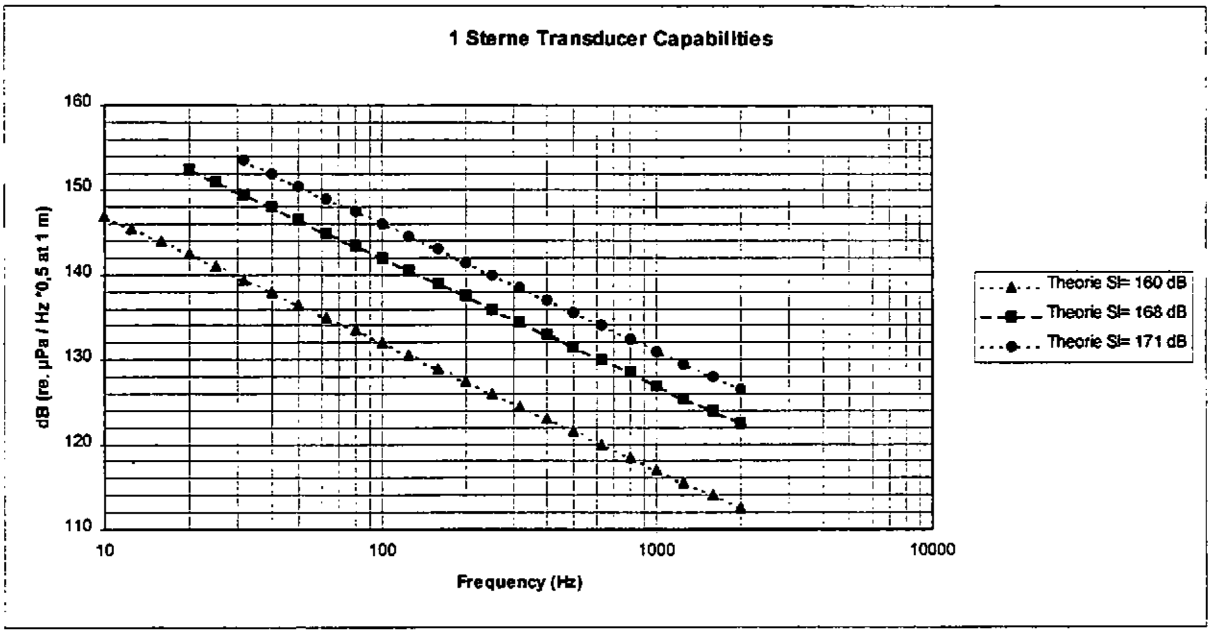

Figure 4 : Examples of radiated spectrum noise using a single electrodynamic transducer.

Thanks to its small size and its high fidelity and large bandwidth response, the transducer can be used in an array in order to simulate the exact acoustic signature radiated by a specific ship or by a class of ships, taking into account both broadband noise and specific lines.

6. CONCLUSION

A new powerful electrodynamic transducer has been designed for minesweeping application. Its very high performances allow to increase the capabilities of the multi influence minesweeping system under development.

Current studies concern the thermal performances of this transducer in order to enhance the electrical capability and then to increase the radiated sound level.

7. REFERENCES

[1] Leon W. CAMP - « Underwater Acoustics » - 1979 - John Niley & Sons
[2] Robert J. BOBBER - « Underwater Electroacoustic measurements » - 1970 - Naval Research Laboratory