HIGH POWER FREE-FLOODED RING TRANSDUCER

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ABSTRACT

A new Free Flooded Ring (FFR) transducer technology has been developed to meet the requirements of low frequency active sonar systems for long range detection.

The FFR basically comprises a prestressed piezoceramic driver ring housed in a waterproofed boot. It has two resonant frequencies which are the ring resonance and the cavity resonance.

Thanks to the coupling of the two resonances, the FFR operates on a very wide bandwidth (more than one octave). It also has a very high power capability within an optimised weight since more than 70% of the total mass is active material. Combined with a high electro-acoustic efficiency and vertical intrinsic directivity, this leads to a very high sound level performance.

The FFR can perform at very deep depth with characteristics unchanged since all FFR parts are in equipressure, and can also perform in shallow water since its large radiating surface allows generation of high acoustic power without cavitation.

Thanks to its handling convenience, it is easy to make FFR arrays that can be integrated into a towed body or hull mounted.

Acoustic performances has been fully proven during lake testings and sea operation. Environmental qualification was performed and life cycle was demonstrated through extensive fatigue tests.

1. SELECTION OF TRANSDUCER TECHNOLOGY

1.1 Transducer requirements and tradeoffs

Low frequency active sonar systems for long detection range require specific sources that should be able to generate high sound level on a large frequency bandwidth, that should be compact and operational at sufficient great depth in the case of towed systems.

At low frequency, high sound level becomes a problem since the radiation resistance decreases with frequency. This therefore demands a high input electric power or large radiating surfaces in order to compensate this acoustic phenomenon. Moreover low radiation resistance leads to high quality factor of the transducer and then to a small frequency bandwidth.

HIGH POWER FREE-FLOODED RING TRANSDUCER

High input power is governed, in turn, by physical limitations at transducer level (thermal effect), at system level where the whole power train needs to be designed according to current and voltage demand of the transducer. It is itself limited by the power supply on board if one does not want to store electrical energy for safety concern.

Large radiating surfaces require bulky transducer, which is not compatible with compactness demand of offboard equipment. This becomes a real issue in the case of towed transducer arrays since the size and the weight of the transducers is a determining parameter for the whole towed system (towed body, towed body cable, towed body handling system) and therefore a key parameter for the ship itself.

In the case of towed system, the transducer should be able to withstand hydrostatic pressure and its performances should preferably be depth independent.

1.2 Comparison of transducer technologies

For low frequency, high power and wide bandwidth transducers, the free flooded ring is a very good candidate among the different possible technologies such as flextensional transducers, tonpilz and air-backed rings. Indeed it is a good compromise towards the conflicting requirements described above. Flextensional transducers have good coupling factor and are compact but they are depth-dependant, have a limited bandwidth and a limited power capability. Tonpilz tranducers have narrow bandwidth. Air backed rings have a high power capability but a limited bandwidth and are depth-dependant. Free flooded rings have a high power capability, a large bandwidth and are operational at great depth since they are in equipressure.

Tranducer technology	Power Capability	Bandwidth Capability	Compactness	Depth capability	Efficiency
Tonpilz	Medium	Low	Medium	Medium	**High**
Flextensionnal	Medium	Medium	**High**	Medium	**High**
Free-Flooded Ring	**High**	**High**	Medium	**High**	**High**
Air-backed Ring	**High**	Medium	Medium	Medium	**High**

Table 1 : Comparison between transducers technologies

2. FFR DESCRIPTION

2.1 FFR breakdown

The free flooded transducer technology developed in Thomson Marconi Sonar (TMS) is composed of three identical piezoelectric rings superimposed. They are held together with a verticalprestress. Each

HIGH POWER FREE-FLOODED RING TRANSDUCER

elementary ring is composed of ceramic slab segments, a conformer that withstands the prestress applied to the ceramics and a mechanical device that enables to apply the prestress to the ceramic ring. The piezoceramic structure is housed in a waterproofed rubber boot filled with oil that provides isolation between the electrical connections and an acoustic impedance matching with water. Watertightness is made with the rubber boot and two lids that also provide mechanical interface with the surrounding structure. This interface is compatible with a hull mounted version or a towed body conception. Electrical supply is delivered to the transducer via one single connector.

2.2 FFR working

The transducer generates sound by an alternative motion which corresponds to the oscillation of its mean diameter around its equilibrium position. It has two resonance frequencies that are the radial mode (whose resonance frequency depends on the diameter of the ring), and the cavity mode which corresponds to the oscillating motion of the water volume inside the cavity. Thanks to the coupling of these two modes, the FFR transducer is capable of a large bandwidth, greater that one octave.

The FFR transducer is omnidirectional in bearing and is directional in elevation (directivity pattern depends on its height), which brings the benefit of the directivity index to the sound pressure level generated in the horizontal plane. Moreover it diminishes the discrepancies coming from the bottom and the water surface in shallow water.

In result of the effort devoted to optimising the weight of the transducer, more than 70 % of its weight corresponds to active material. This makes the transducer capable of high power within a compact volume and small weight.

The FFR transducer has an intrinsic good radiation efficiency since it benefits not only from its large outer radiating surface but also from its inner face. This large radiating surface area brings another major advantage since it can perform in shallow water at high power level without cavitation.

It can withstand great depth because all components are in equipressure and the transducer characteristics remain unchanged with the hydrostatic pressure.

3. DESIGN METHODOLOGY

The development process of the TMS FFR design was based on extensive finite element modelling that was then validated by experiments on different FFR versions. The use of predicting tools enabled to optimise the FFR design.

The design study was performed with TMS calculation facility, which is based on FEM-BEM modelling. It takes account of design geometry, piezoelectric materials and elastic materials characteristics, including damping, and fluid-structure interaction which brings the actual performances of the immersed structure in water. FEM-BEM modelling is performed by three numerical codes that are available on the market :

- I-DEAS Master Series (developed by SDRC) for the mesh,
- ATILA (developed by ISEN) for the modelling of the structural behaviour of the piezoelectric and elastic components of the transducer,
- SYSNOISE (developed by LMS) for the modelling of the fluid-structure interactions and then the prediction of the transducer performances (sound level, impedance, coupling factor, directivity, directivity index).

The interfaces between those three codes were specifically developed for TMS calculation purposes.

HIGH POWER FREE-FLOODED RING TRANSDUCER

The degree of modelling accuracy (and therefore the degree of complexity) was increased step by step, beginning with a simple model of the driver ring, until the calculations give good predictions compared to measurements. The first step consists in modelling the driver ring only (simple model). The second step takes the surrounding mechanical structure (undamped full model) into account. The third step adds the specific damping effects due to waterproof devices (damped full model). Figure 1 shows the Transmitting Voltage Response (TVR) measured on the first fabricated FFR version and the predicted response computed with the three model levels. It shows very good agreement of the prediction with the most accurate model. This proves that the numerical model implemented is a real design tool if a sufficient degree of accuracy is considered and can be used with a high degree of confidence for the design of any FFR versions.
Regarding the performances of this first FFR version, figure 1 shows that the cavity mode and the radial mode (respectively first and second peak of the TVR) are not equally balanced in terms of response level which means that the two modes are not properly coupled.
The design effort was then made to better couple the two modes and get an efficiency optimised through a large frequency bandwidth. Particularly, it was possible to define accurately the diameter and the height of the transducer such that the cavity mode and the radial mode are well coupled. This study has led to the current FFR version fabricated by TMS. Figure 2 shows the TVR measured on the current version where the -3 dB bandwidth is greater than one octave.

4. FFR PERFORMANCES

4.1 Mechanical characteristics

• Mass in air :	135 kg
• Outer diameter :	627 mm
• Height :	271 mm

• **4.2 Acoustic characteristics**	
• Operational frequency bandwidth :	800 - 2500 Hz
• Maximum Sound Level :	216 dB (ref µPa @ 1 m)
• - 3 dB bandwidth :	950 - 2250 Hz
• Electrical power capability :	27 kW
• Directivity in bearing :	omnidirectionnal
• Directivity in elevation (2 $\varphi 3$) :	< 90° at 1750 Hz

Figure 3 shows the sound level capability of the FFR transducer. Figure 4 shows the directivity in elevation at 1750 Hz.

4.3 Design proving

Full qualification was performed on the FFR transducer :

- Acoustic qualification during lake testings,
- Environmental Qualification,

HIGH POWER FREE-FLOODED RING TRANSDUCER

- High power capability of the FFR : endurance tests in water,
- Fatigue tests in air that proved no relaxation of the prestress,
- Qualification at sea,
- Qualification for underwater explosions
  (operational shock factor = 0.66 and survival shock factor : 1.59)

5. CONCLUSION

A new FFR transducer was developed at TMS for low frequency active sonar. This transducer has high performances in a very compact volume. In case of towed application, the compactness and the light weight of the transducer is the key for a towed system that is easy to handle in operational conditions.

Extensive tests have been performed and proved the performances and the reliability of the FFR transducer.

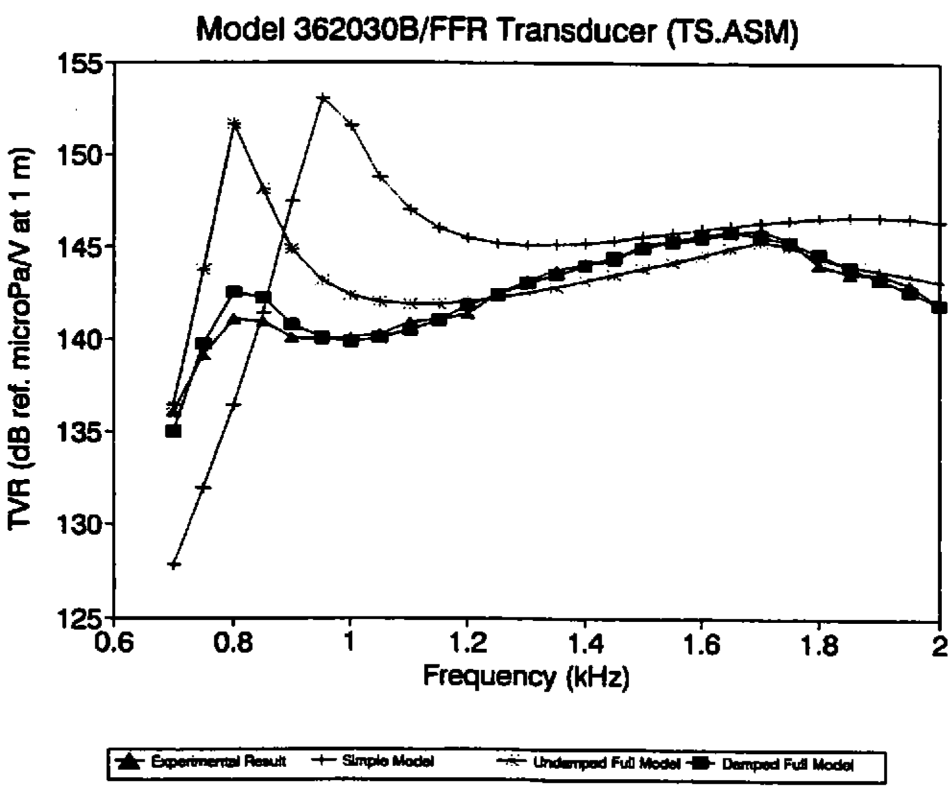

Figure 1 : Calculation and experiment comparison

HIGH POWER FREE-FLOODED RING TRANSDUCER

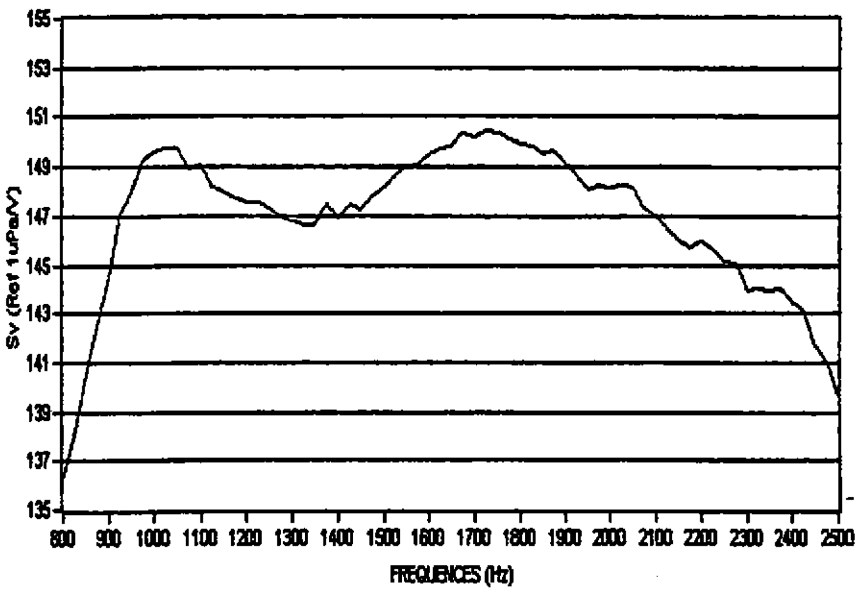

Figure 2 : Transmitting Voltage Response measured on the current FFR version

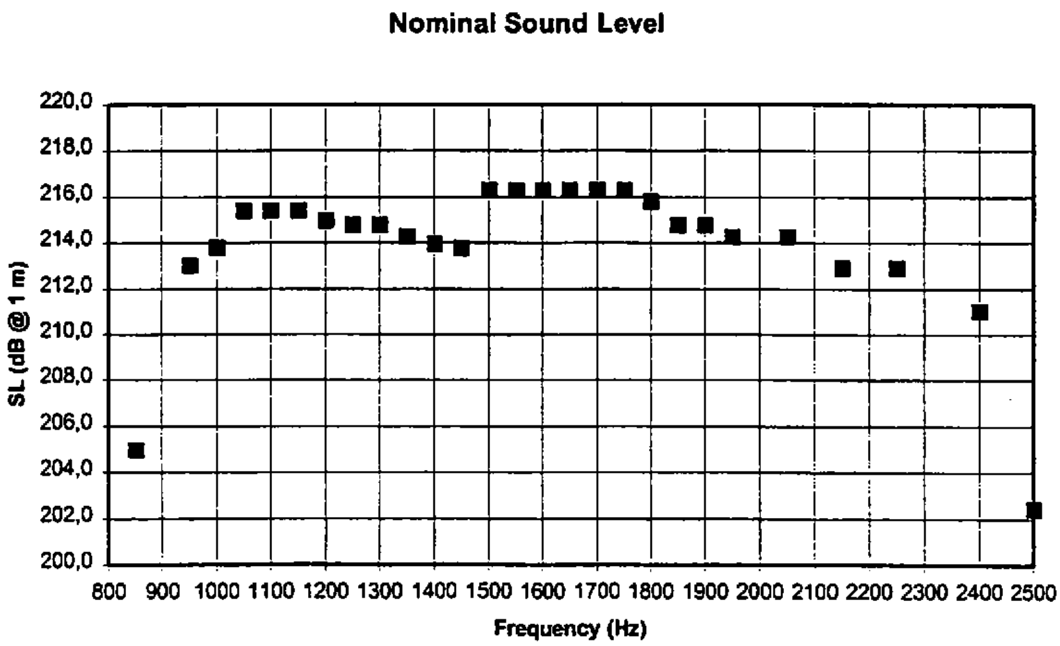

Figure 3 : Sound Level of the FFR transducer

HIGH POWER FREE-FLOODED RING TRANSDUCER

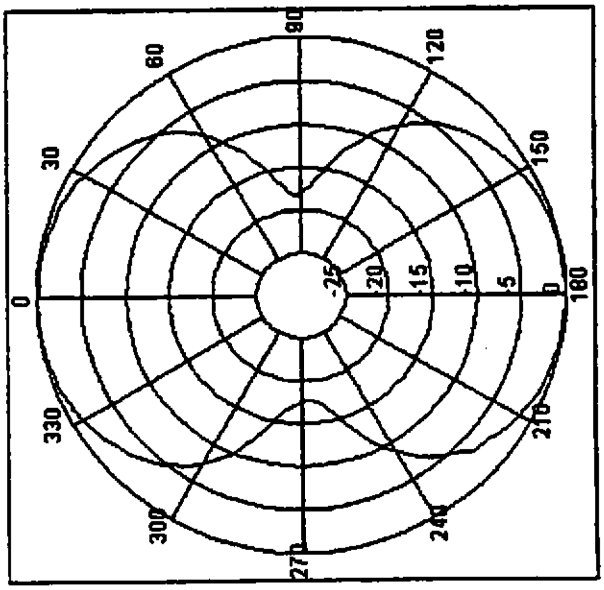

Figure 4 : Directivity in elevation at 1750 Hz of the FFR transducer