A Topographic Parametric Sonar, TOPAS

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ABSTRACT

In many offshore and civil engineering survey operations, the combined need for a swathe bathymetry and a sub-bottom profiling system is often present. Some of these applications are subsea completion surveys, site-surveys and pipeline pre-route; as laid and inspection surveys.

The paper describes a combined electronic scanning topographic and sub-bottom penetrating sonar. The sonar being a parametric source uses both the primary and the secondary frequencies simultaneously to obtain both topography and penetration.

The sonar exists in two versions designed for mounting on standard ROVs, towed or hull mounted.

In this paper the design parameters and the sonar functions are described and data from calibration tests and field trials are presented.

A TOPOGRAPHIC PARAMETRIC SONAR, TOPAS

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1. INTRODUCTION

In many offshore, defence and civil engineering surveys, the need for both swathe bathymetry and sub-bottom profiling is often present. Offshore applications are subsea completion surveys, site-surveys and pipeline pre-route; as laid and inspection surveys.

In order to meet this double requirement, an integrated survey system performing at the same time both swathe bathymetry and sub-bottom profiling has been developed. The system is based on a new and unique electronic scanning parametric sonar.

The sonar exists in two versions designed for mounting on standard ROVs, towed or hull mounted.

In the following the design parameters and the sonar functions are described and data from calibration tests and field trials are presented.

2. DESIGN PARAMETERS

The requirements to be met by a sonar system designed to perform both topographic mapping and seismic profiling are here just briefly summarized. A more detailed discussion is previously given by Løvik [1].

2.1 Topography.

In the offshore industry the surveys tend towards deeper water and a new system should cover all water depths down to at least 1000 m.

The resolution required varies with the application. Pipeline survey/inspection may require a few centimeters resolution while general topography is widely covered by 0,25 - 1 meter resolution.

To meet these requirements, the beamwidth must be kept small, and certainly less than 5-10 degrees for continental shelf topographic applications.

Large savings in survey time are obtained if the sonar is made scanning.

2.2 Seismic profiling.
Within seismic profiling the user may want deep penetration combined with high horizontal and vertical resolution. For many applications like detection of buried pipelines a 3-D profiling system is required. Detection of buried pipes or cables is with present technology done by surveying the area in a zig-zag manner, using the pipe or cable crossings for detection. A 3-D system will scan the beam across the pipe as the sonar moves along the pipe without the need to constantly alter the course of the vessel or the ROV.

Most profiling sonars may operate with a reasonable wide band width, but few are able to produce a narrow beam. The latter is normally restricted by the size of the transducer.

One way to overcome the problem is by using a parametric sonar. This sonar gives a directive low frequency beam by non linear interaction of two directive high frequency beams.

The interaction takes place due to the fact that water is a slightly nonlinear propagation medium. The parametric sonar then has all the benefits of a normal sonar and may for instance be electronically beam steered.

3. THE PARAMETRIC SOURCE

The general theory of parametric sources is fairly complicated and the design of such sources involves normally numerical models. However, the basic principle is simple and the generation of low frequency sound is accomplished by using a conventional sonar transducer. The transducer is simultaneously exited by two primary frequencies f_1 and f_2 separated by Δf around a mean primary frequency f_0.

$$f_{1,2} = f_0 \pm \frac{1}{2} \Delta f \qquad (1)$$

The non-linearity will cause the two primary waves to interact thereby generating a sum and a difference frequency component of which only the difference frequency Δf is of prime interest for applications.

The calculation of the secondary sound level is in general quite complicated and approximations and numerical methods must be used. A particular simple and illustrative case is when the nearfield extends so far out that interaction is limited by absorption in the nearfield. The difference frequency source distribution then resembles a continuous end-fire array with an exponential taper. This case was originally treated by Westervelt [2] and gives the secondary source level as

$$P_s = \text{constant} \times (\Delta f)^2 P_p^2 \qquad (2)$$

and the directivity function

$$D_s(\theta) = \frac{1}{[1 + (2\pi \frac{\Delta f}{c_0 \alpha})^4 \sin^2 (\frac{\theta}{2})]^{1/2}} \qquad (3)$$

with a beamwidth of

$$\theta_0 = 2 \left(\frac{2\alpha c_0}{\pi \Delta f}\right)^{1/2} \qquad (4)$$

where α is mean primary attenuation
c_0 is the speed of sound
P_p is the primary pressure.

These results are only valid for a particular case but they illustrate some important properties of a well-designed parametric source. The secondary source level will increase with the square of the difference frequency and with the square of the primary sound pressure. The directivity pattern is without significant sidelobes and almost as narrow as the primary beamwidth. Since a typical ratio between the primary and difference frequency is about 10 this means that secondary beamwidth is considerably less than conventional operation of a transducer of the same size.

The buildup of the secondary pressure is quite rapid, and will for the smallest system described here have a maximum at 4-5 meters from the transducer.

4. SYSTEM DESCRIPTION

The parametric sonar to be described is designed to meet the two fold requirement of simultaneous swathe bathymetry and seismic profiling. The system TOPAS exists in two versions designed to be mounted on a ROV or tow fish, or to be hull mounted.

The sonar has a range capability of 1000 meters (small version) or 5000 m (large version) at the primary frequency covering all offshore application and most hydrographic ones. The resolution is less or equal to 10 cm.

The seismic profiling is accomplished with the secondary frequencies in the band from 1-10 kHz (0.5-5 kHz) giving penetration equal to boomer systems.

Further the sonar is electronically beam steered giving swathe bathymetry and 3-D seismic from a single source.

In the towed or ROV mounted PS 040 version the basic system comprises a subsea transducer unit and amplifier/control unit, a top side signal processing and display units, interfaces for attitude data, navigation data and communication with external computers, as shown in figure 1.

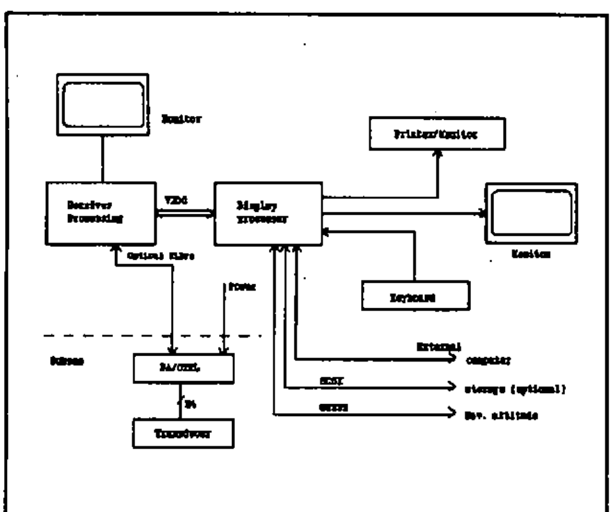

Figure 1. System units.

The transducer is organized in rows of elements with individual cables to the power amplifier units. A total of 240 elements transmits the 12 kW pulses.

The power amplifier, PA, unit is compact due to the short RF-bursts transmitted, and are mounted in an aluminum pressure container together with control electronics, receiver/ buffer and interface electronics, CTFL.

Data transmission may be done on optical fibre or on twisted pair/coax.

Both primary or first harmonic and secondary frequency signals are transmitted to the receiver, where amplification, filtering, TVG and A/D conversion takes place.

The data are displayed by using a separate processor where inputs and corrections for attitude are available. The display is a quasi 3-D waterfall display showing both topography and the underlying substructure.

The system modules of the hull version, PS 018, are similar to those of PS 040, but some differences exists:

	PS 018	PS 040
Primary frequency	18 kHz	40 kHz
Secondary frequency	0.5-5 kHz	1-10 kHz
Max. output power	32 kW	12 kW
Max. burst length	60 ms	1 ms
Max. number of beams	90	45
Beamwidth		
Primary	3.5 deg.	2.5 deg.
Secondary	5 deg.	6-2.5 deg.
Max. range (through water)	5000 m	1000 m
Max. angular coverage	90 deg.	80 deg.

5. SYSTEM PERFORMANCE

The system performance has been assessed both in calibration tests and during field trials.

5.1 Calibration tests.

A number of different secondary wavelets can be generated by amplitude modulation of the primary frequency signal. A quasi Ricker wavelet is generated by a Haversine modulated primary signal as described by Dybedal & al [3].

An example of a recorded wavelet is shown in figure 2 along with its spectrum.

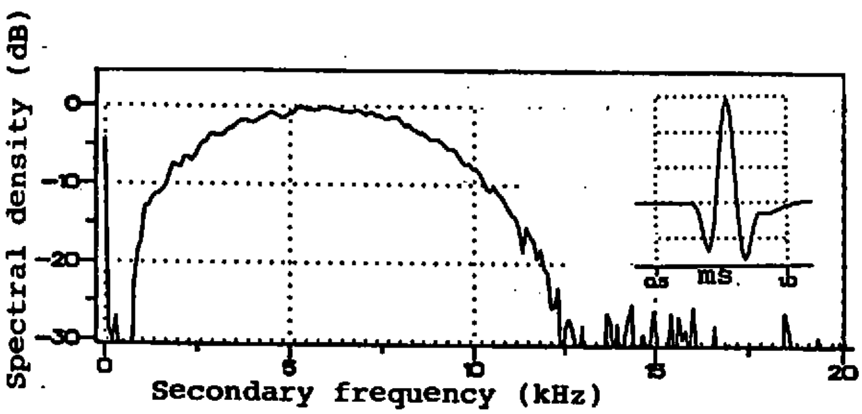

Figure 2. PS 040 Recorded Ricker wavelet and corresponding spectrum. The nominal secondary frequency is 5 kHz.

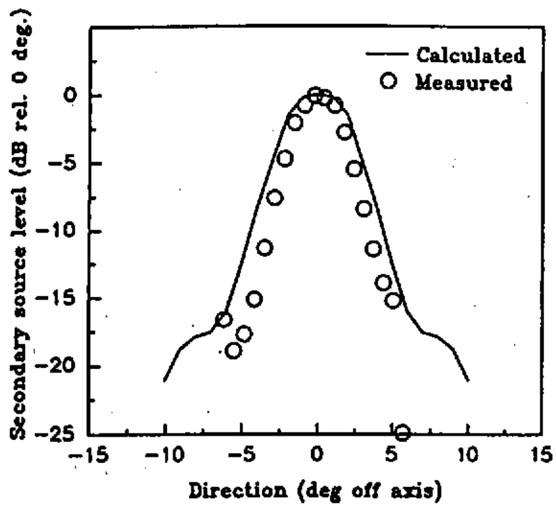

Figure 3. PS 040: Directivity at secondary frequency 5 kHz.

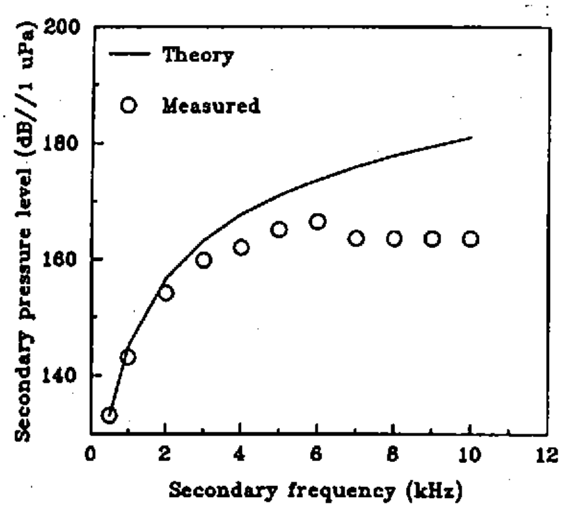

Figure 4. PS 040: Secondary pressure level at a distance of 90 m from the transducer. Electrical power input is 12 kW. corresponding to a primary source level of 240 dB//1 µPa 1 m. The wavelets are generated by pulsed CW modulations. The theoretical model does not account for the limited bandwidth of the primary signal generation process, which explains the falling off of the experimental values at higher difference frequencies.

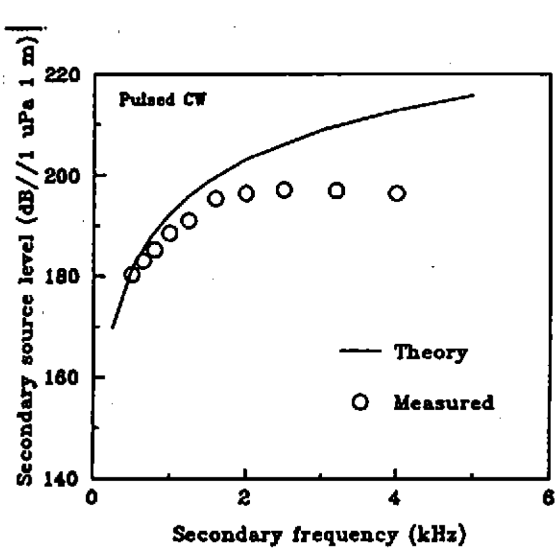

Figure 5. PS 018: Secondary pressure level at a distance of 90 m from the transducer. Electrical power input is 32 kW corresponding to a primary source level of 241 dB//1 µPA 1 m The reduced performance at higher difference frequencies is explained in the caption of figure 4.

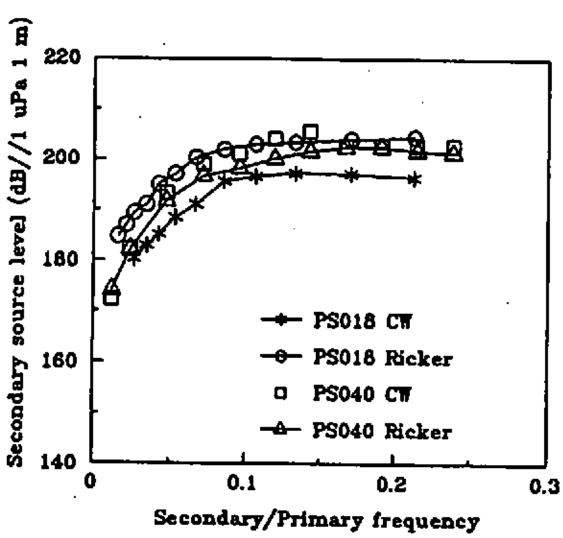

Figure 6. TOPAS: Secondary source level as derived from measurements at a distance of 90 m from the transducer. The PS 018 CW data are given as RMS values (-3 dB), while the other results are peak values.

The directivity is an important issue of the system. Figure 3 shows the result of a calibration test with PS 040 in Trondheimsfjorden. The theoretical curve shown is based on the simplifying assumptions of Moffet & Mellen [4]. It is seen that the experimental results are better than predicted by this theory. Note that the data shown is obtained along the shortest transducer axis, which is the along track axis.

With primary source levels at about 240 dB // 1 μPa 1 m, both versions of the transducer will be at the point of cavitation if they are operated close to the surface. The results shown in figure 4 were obtained with the PS 040 transducer mounted vertically on a quay front at a submergence of about 5 m. The secondary pressure level was measured on the transducer axis at a distance of 90 m from the transducer. Again the experimental results are compared to the Moffet & Mellen model [4]. We see that the model predictions are satisfactory for the low frequency end of the curve. At higher frequencies, the experimental results drops off, because of bandwidth limitations in the primary transmitter that are not accounted for in the theoretical model.

Figure 5 shows corresponding results obtained with the PS 018 transducer, while figure 6 gives the system performance for both versions, as to source levels obtained at the difference frequencies.

In the scanning mode, the system is electronically beam steered. The source levels and beam widths obtained at some beam directions are shown in figure 7.

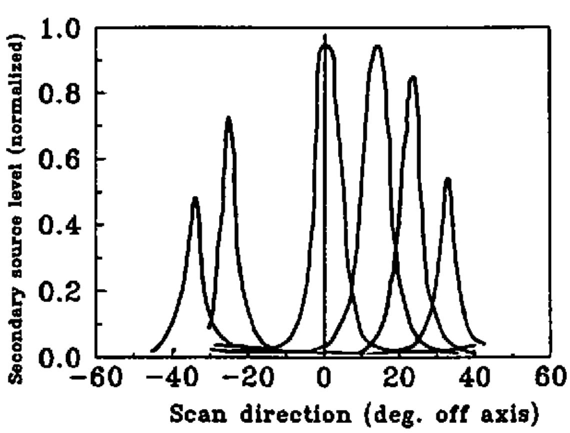

Figure 7. PS 040: Secondary source levels and beam widths at a number of scan directions. The nominal secondary frequency is 5 kHz.

5.2 Field trials.

Results from the prototype system are available showing the penetration capability, resolution and demonstration of the 3-D seismic profiling. Tests have been performed over a one year period at various locations in Norway and UK. The results show a penetration capability similar to that of a boomer. The resolution is in the order of 10 cm or better. As an example of the seismic profiling capability a section from the Moray Firth is shown below, figure 8.

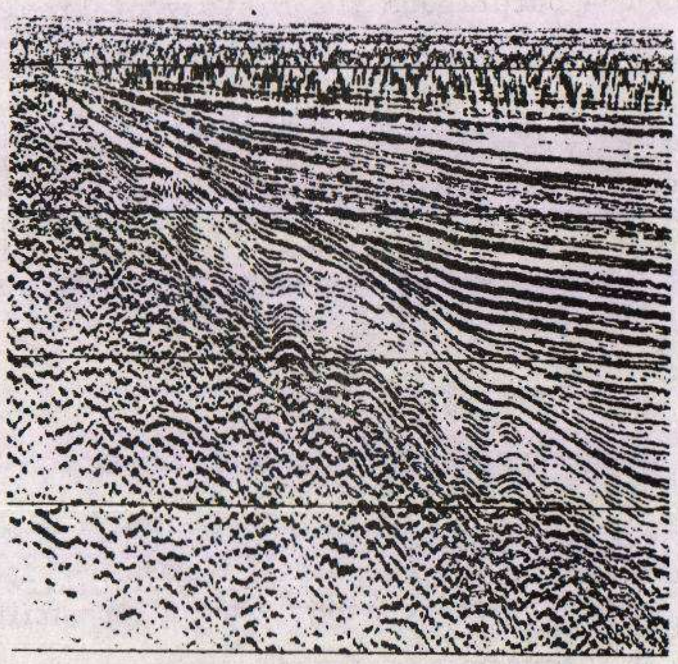

Figure 8. Seismic section, Moray Firth. 6.5 mSec/division.

The penetration shown is in the order of 50 m.

A demonstration of the 3-D seismic is shown in figure 9.

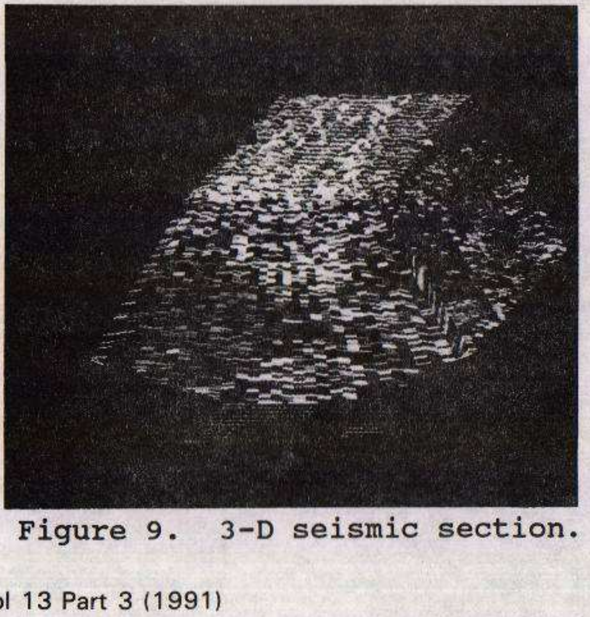

Figure 9. 3-D seismic section.

The figure shows a section into the seabed across the survey direction and on the outer edge the history of previous scans.

1. CONCLUSION

A novel system of seabed and sub-seabed inspection TOPAS has been described and some preliminary results have been given. The system using a parametric source gives simultaneously swathe bathymetry and 3-D seismic profiling. The performance for each application is comparable or better than that of existing equipment.

7. REFERENCES

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