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Original Contribution

ACOUSTIC WAVES – SONAR EQUATION

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ABSTRACT: *The earliest methods used to directly measure water depth were the guide line (lead line) and drilling. Their simple principles of operation ensure their continued use for many centuries.*

KEY WORDS: *Acoustic waves, echo sounders, drilling.*

1. Introduction

Electromagnetic waves, which have excellent propagation in vacuum and air, are difficult to penetrate and do not propagate through liquids. Acoustic waves, both sound and ultrasonic, achieve good penetration and propagation through all elastic media, since these media can oscillate when exposed to pressure changes. Most of the sensors used to determine depth use acoustic waves [6].

2. Acoustic field and sonar equation

The sonar equation is used to investigate and express the detection ability and effectiveness of the sonar as a function of operating conditions [7].

The sonar equation for the sonar defines the signal or detects the echo as an echo excess (excess), (Echo Excess – EE),

(1) $$EE = SL - 2TL - (NL - DI) + BS - DT,$$

where SL – Source Level, TL – Transmission Loss, NL – Noise Level, DI – Directivity Index, BS – Bottom backscattering Strength force and DT – Detection Threshold. The intensity of acoustic waves *Ir* at a distance *r* from the transmitter is obtained from:

(2) $$I_r = \frac{p_r^2}{\rho.c} \text{ W/m}^2,$$

where p_r is the effective pressure at a distance r from the source, $\rho.c$ is the acoustic resistance (given the speed of sound 1500 m/s and the seawater density of 1026 kg/m3, the acoustic resistance is $\rho.c$ = 1.54.106 kg/m2s).

The *source level (SL)* gives the acoustic signal intensity level referring to the intensity of a plane wave with an average square pressure of 1 μPa, for a point located 1 meter from the center of the source (transmitter), i.e.

(3) $$SL = 10.\log_{10}\frac{I_1}{I_{ref}}.$$

Transmission loss (TL) includes losses of acoustic intensity due to geometry, i.e. scattering losses proportional to r^2 and losses due to absorption proportional to the absorption coefficient, depending on the physical and chemical properties of seawater and acoustic frequency. The loss of dispersion is due to the geometry of a cone-shaped beam (Fig. 1). Increasing the area leads to a decrease in power per unit area.

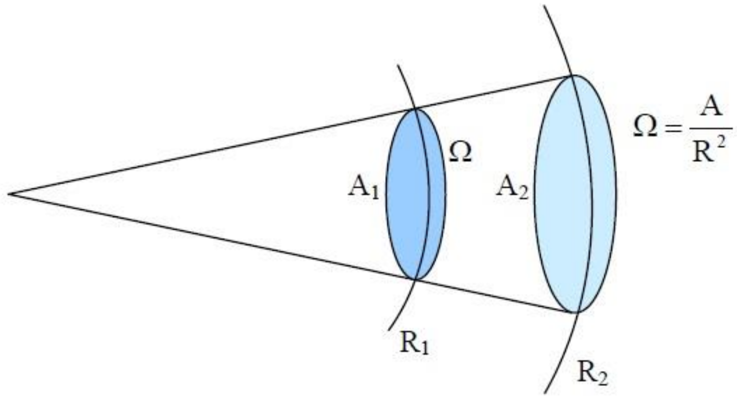

Fig. 1. Loss of dispersion due to beam geometry [3]

The power P of the acoustic pulse is equal to the intensity over the area:

(4) $$P = I_1.A_1 = I_2.A_2,$$

where $A_1 = \Omega.R_1^2$ and $A_2 = \Omega.R_2^2$, and Ω is the space enclosed by a conical surface – a solid angle. Therefore, the ratio of intensities can be represented by:

(5) $$\frac{I_1}{I_2} = \left(\frac{R_2}{R_1}\right)^2.$$

If the reference intensity at R_1 = 1 m, the distance at which the source level (SL) is determined, is taken into account, the logarithmic ratio of the intensities refers to the transmission loss due to propagation:

(6) $$10.\log_{10}\frac{I}{I_{ref}} = 10.\log_{10}\frac{1}{R_2^2} = -20.\log_{10} R_2 .$$

Therefore, the loss of transmission is given by:

(7) $$TL = 20.\log_{10} r + a.r ,$$

where r is the distance to the transducer, a is the absorption coefficient.

The *noise level (NL)* depends on the spectral noise level in the environment (N_0) and on the bandwidth of the transducer (transducer) at the time of reception (w),

(8) $$NL = N_0 + 10.\log_{10} w .$$

Noise in the ocean and seas is generated from several sources [6, 7], and they can be: waves, rain, seismic activity, thermal noise, living organisms and man-made. In addition to noise, it is also important to take into account the combined effects of acoustic energy created by different marine organisms, which can include surface waves, air bubbles, marine life, materials in suspension, etc. This impact is known as the Reverberation Level (RL) [2, 5].

Transducers usually have the ability to concentrate energy in a conical shape (Fig. 2).

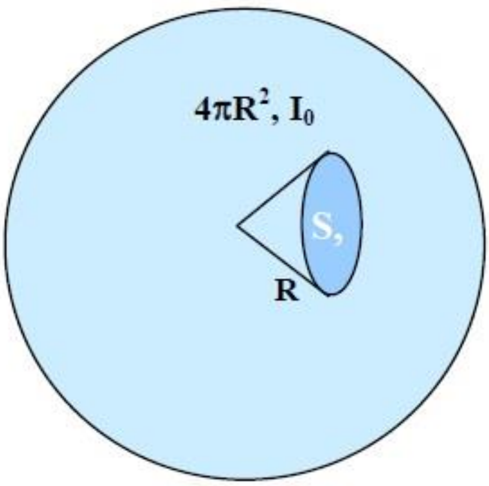

Fig. 2 [3]

Given the same power for all directional sources:

(9) $$P = I_0 . 4\pi R^2 = I.S .$$

The ratio of intensities is determined by:

(10) $$\frac{I}{I_0} = \frac{4\pi R^2}{S} ,$$

and the directionality index (DI) is obtained from:

(11) $$DI = 10.\log_{10} \frac{I}{I_{ref}} = 10.\log_{10} \frac{4\pi R^2}{S} .$$

For an array of length L and wavelength λ, (at $L >> \lambda$) the directivity index is determined by:

(12) $$DI = 10.\log_{10} \left(2L / \lambda \right) .$$

The acoustic energy that returns from the seabed is the energy used by sonar systems, as well as by remote means through which some properties of the seabed are deduced. Every particle on the seafloor can be likened to an energy reflector.

Seabed backscatter force (BS) is generally represented as the logarithmic sum of the backscatter force per unit area or backscatter index (SB), which strength depends on the reflective properties of the seabed and the effective instantaneous scattering region A, the seabed area that contributes to the backscatter signal:

(13) $$BS = SB + 10.\log_{10} A.dB .$$

The boundaries of the backscatter area are determined by the geometry of the beam, in particular by the beam width (of the transmitting beam) in the direction of the route in normal incidence or nadir, φ_T, and the beam width (of the receiving beam) in the direction of crossing at the lowest point, φ_R [4]. For directions outside the nadir, the backscatter zone is bounded by the beamwidth, φ_T, and the transmitted pulse length τ (Fig. 3).

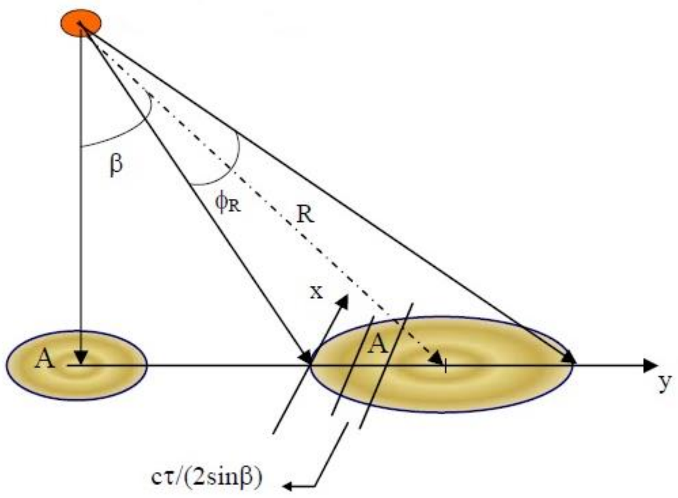

Fig. 3 [3]

The force of the reverse dispersion of the seabed can be given by:

(14) $$BS = \begin{cases} SB + 10.\log_{10}\left(\varphi_T.\varphi_R.R^2\right) \\ SB + 10.\log_{10}\left(\dfrac{c.\tau}{2\sin\beta}\varphi_T.R^2\right) \end{cases},$$

where the first expression is at a narrowing of the beam width and the second refers to the duration of the pulse, R is the inclination from the transmitter to the point on the seabed, c is the speed of sound, and β is the angle of the beam relative to the vertical.

The backscatter coefficient (SB) is usually partially dependent on the angle of incidence, with the largest variation being near the nadir and usually following the Lambert dependence at larger angles of incidence [1, 7]. It is usually defined:

- SB = BS_N , for normal frequency (β = 0º);
- SB = $BS_0.\cos^2\beta$, for inclined frequency (β > 10-25º).

Typically, BS_N is about 15 dB and BS_O is about 30 dB. These values can vary within ± 10 dB or even more depending on the type and roughness of the seabed.

The *detection threshold (DT)* is system-dependent with a parameter that establishes the lowest level above which the sonar can detect the returning rays.

The state of the depth measurement technique has been assessed by a working group according to standard S-44 as follows:

- *Single beam echo sounders (SBES)*. They have reached an accuracy of less than a decimeter in shallow water.
- *Multifunction echo sounders (MBES – Multibeam echo sounders)*. This technology is developing rapidly and offers great potential for accurate and complete exploration of the seabed if used with appropriate methods and provided that the resolution of the system is suitable for the correct detection of navigational hazards.
- *Aerial laser sounding (ALS)*. This is a new technology that can offer significant benefits in studies in shallow and clear water. Aerial laser systems can measure depths of up to 50 m or more.

3. Conclusion

Despite these new technologies, single-phase echo sounders (SBES) with traditional equipment are still used in hydrographic surveys worldwide. These sonars are also evolving from analog to digital recording, with greater and higher accuracy and with specific characteristics that allow a greater variety of purposes to be achieved.

The use of digital sonars together with motion sensors, global satellite positioning systems (GNSS) and data acquisition software are combined to optimize performance with corresponding reductions in the personnel needed to perform a hydrographic survey.

MBES have become a valuable tool for determining depth when complete soundproofing of the seabed is required. An increasing number of national hydrographic offices have adopted MBES technology as a methodology of choice when collecting bathymetric data for the production of new nautical charts.

Aerial laser probing (ALS) systems have the highest levels of data collection and are particularly suitable for surveys near shore and shallow water. However, the high costs of data collection and processing do not allow for wider use for the time being.

References:

[1] de Moustier, C. “Signal Processing for Swath Bathymetry and Concurrent Seafloor Acoustic Imaging”, Acoustic Signal Processing for Ocean Exploration, J.M.F. Moura and I.M.G. Lourtie Eds., pp. 329 – 354., 1993.

[2] Ivanov S. „Spatial data models“. Journal scientific and applied research. Volume 20. Shumen 2021. University Publishing House "Ep. K. Preslavski". ISSN: 1314-6289. pp 40 - 46.

[3] International Hydrographic Organization, Manual on Hydrography, Publication C-13, May 2005, (Corrections to February 2011), Chapter 1, 2 and 3.
[4] Kirilova, K., Yanchev K. “About the choice of parameters when representing the normal earth as a reference frame in Geodesy”, Journal scientific and applied research, лицензиран в EBSCO, USA. Volume 24, 2023, pp. 11-16, ISSN: 1314–6289.
[5] Niyazi-Yusuf, M., „Inaccuracies in area objects transferred from the map of the restored property to the cadastral map“, Journal scientific and applied research, Vol. 23, Konstantin Preslavsky University Press, Shumen, ISSN: 1314-6289, p. 39-47, EBSCO, USA.
[6] Stoykov, E. "Technical means and systems for performing hydrographic measurements", University Publishing House "Bishop Konstantin Preslavski", Shumen, 2019, 177 pages, ISBN 978-619-201-334-9.
[7] Urick, R. Principles of Underwater Acoustics, McGraw-Hill, Toronto, 1975.