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APPLICATION OF WIDE BANDWIDTH SIGNALS FOR RECOGNITION OF SEA BEDDING

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SUMMARY

This article presents the results of research on the sea bedding using a measuring set generating wide bandwidth signals with linearly modulated frequency – chirp signals. The measurements were conducted in the Gdansk Bay region at locations where geological cores had been drawn.

INTRODUCTION

Wide bandwidth signals are becoming more and more the subject of research by hydroacoustics. Due to their advantages, they begin to compete with the monochromatic echo sounders and sonars in echo ranging and in the research of sea bottom. The application of time delay spectrometry method for the analysis of the signals reflected from the bottom gives the possibility to determine the bedding of different layers of bottom sediment.

1. MATHEMATICAL MODEL FOR WIDE BANDWIDTH SIGNAL ANALYSIS.

We generate a complex acoustic chirp signal of specified frequency bandwidth - Δf and duration - T. The method depends on an analogue multiplication of the received, reflected signal, which is a convolution of target's reflection impulse characteristics and the transmitted signal, by the replica of transmitted signal. The result is transformed into the digital form and subject to spectral analysis using the Fast Fourier Transform and then filtration by low pass close-fit filter. Time delay τ, resulting from the transition in the environment, causes the shift of frequency linearly proportional to the delay $\Delta f = \tau s$. Thus, in each case a delay is associated with a peak in the differential signal spectrum. The obtained differential signal spectrum determines the delay times of the echoes reflected from consecutive targets.

The generated chirp signal in the time domain can be expressed by the following function:

$$U(t) = \exp\left[i\left(f_0 + St^2/2\right)\right]N(t), \qquad (1)$$

where,
f0– beginning frequency,
S – speed of frequency shift (sweep),
N(t) – time window of T duration.
In actual research a rectangular window was used.

After the transition of the transmitted signal through the surveyed target (dispersing layer), that has a characteristic of impulse response h(τ), the received signal will have the following form:

$$V(t) = \int h(\tau)U(t-\tau)d\tau \qquad (2)$$

Assuming that the duration of the transmitted signal is very long, i.e. T⇒ ∞, from the formulas (1) and (2) we get:

$$\begin{aligned} V(t) &= \int h(\tau)\exp\left[i\left(\omega_0 t - \omega_0\tau + St^2/2 + S\tau^2/2 - St\tau\right)\right]d\tau = \\ &\exp\left[i\left(\omega_0 t + St^2/2\right)\right]\int h(\tau)\exp\left[i\left(-\omega_0\tau + S\tau^2/2 - St\tau\right)\right]d\tau. \end{aligned} \qquad (3)$$

The processing of the recorded signal can be analytically expressed as the multiplication in the time domain of the signal V(t) by $U^*(t)$ – function coupled with U(t) called the replica of the transmitted signal. As the result we obtain:

$$y(t) = V(t)\cdot U^*(t) = \int h(\tau)\exp\left[i\left(-\omega_0\tau + S\tau^2/2 - St\tau\right)\right]d\tau \qquad (4)$$

Then, the Fourier Transform is applied to the function coupled to y(t):

$$\begin{aligned} Y_\infty(\omega) &= \int y^*(t)\cdot\exp(-i\varpi t)dt = \iint h(\tau)\exp\left(i\left(\omega_0\tau - \frac{S\tau^2}{2}\right)\right)\exp(-i(\omega t - St\tau))dtd\tau = \\ &\int 2\pi\cdot\delta(S\tau-\varpi)\cdot h(\tau)\exp\left(i\left(\omega_0\tau - \frac{S\tau^2}{2}\right)\right)d\tau = \\ &\frac{2\pi}{S}h(\omega/s)\cdot\exp\left(i\omega\frac{\omega_0-\omega/2}{S}\right) \end{aligned} \qquad (5)$$

where δ(Sτ - ω) – Dirac delta function, that possesses the applied characteristic:

$$\int \delta(x-x_0)\cdot f(x)dx = f(x_0).$$

Thus, the required impulse characteristics of an object is defined by the following dependence:

$$h(\tau) = Y_\infty(\tau S)\exp\left(i\left(\frac{\tau S}{2} - \omega_0\right)\tau\right). \qquad (6)$$

In other words, $|Y(\omega)| = \frac{2\pi}{S}|h(\omega/S)|$ i.e. the method of time delay spectroscopy renders the impulse function of transition through different media, for example through a dispersing layer, singular target or sea. In order to calculate h(τ), it is necessary to multiply Y(ω) by the phase function.

The delay of the echo return and the frequency are related, allowing the calculation of the distance from the target.
Time delay spectroscopy has many advantages that make it very useful in the analysis of complex acoustical signals of linearly modulated frequency.
For the generated signal with linearly modulated frequency and bandwidth Δf and duration T we get the following benefits:

- Improvement of returned signal to noise ratio $\sqrt{\Delta f * T}$ times;
- In target's localization applications we get an improvement of vertical resolution, which in the time domain is approximately equal to 1/Δf;
- Vertical resolution = duration of impulse * speed of sound/2, where for
  the chirp signal
  the length of an impulse ≈ 1 / bandwidth;
- Improvement in the precision of an object's movement estimation;
- High dynamics (to 80 dB), which considerably improves the measuring capacity and its quality.

1. MEASURING SET

For the generation of linearly modulated frequency – chirp signals and registration of signals reflected from the bottom a measuring set was constructed. The set was described in the article "Complex signals with linearly modulated frequency for classification of sea bottom sediments" by K. Michałowski, D. Szulc. in the Proceedings of the Hydroacoustics Symposium – Jurata 1998.

2. EVALUATION POINTS

Basing on the geological chart of the Baltic Sea bottom (Chart No. 6 – Gdańsk) by National Geological Institute, two evaluation points were selected at which geological profiles were obtained. Evaluation point R 9/82 is located at the position φ = 54 ° 31' N λ = 018° 38' E. Geological profile at this point is presented on Fig. 1. Second evaluation point 1 ZG 54 is located at the position φ = 54 ° 31' N λ = 018° 38' E. Its geological profile is shown of fig. 2.

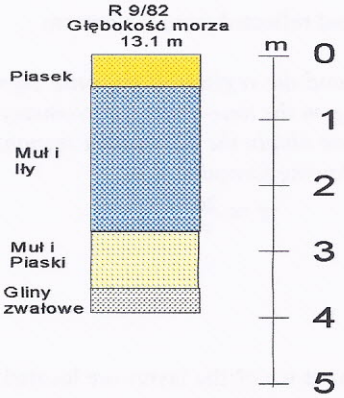

Fig. 1. Geological profile at R 9/82

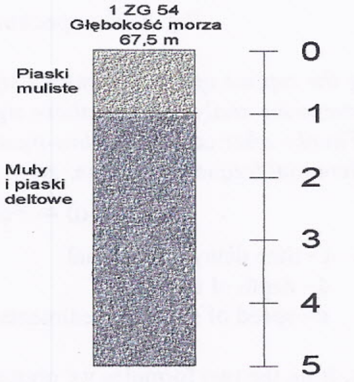

Fig. 2. Geological profile at 1 ZG 54

4. MEASUREMENTS AND PRESENTATION OF THE RESULTS

First evaluation point

Because of the limited sea depth (13.1 m.) transmitting and receiving transducers were lowered to the depth of 3 m. Parameters of transmitted signals:

- bandwidth 25 kHz – 37.5 kHz,
- signal duration t = 0.0155 s,
- sampling frequency fs = 200 kHz.

The following, returning signal V(t) was registered at this point:

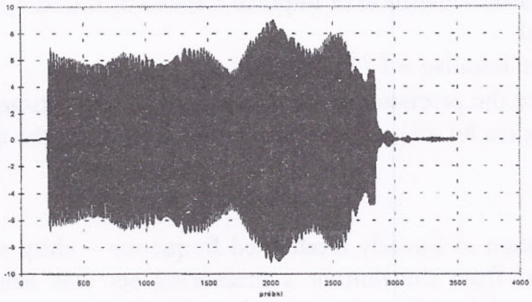

Fig. 3. Bottom reflection signal

The spectrum of the registered signal is presented on Fig. 4.

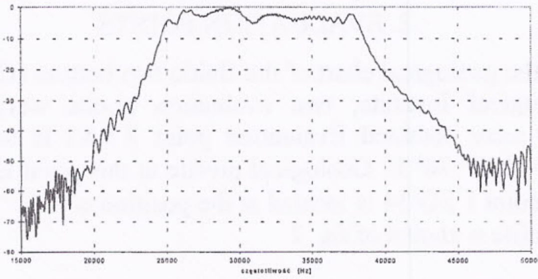

Fig. 4. The spectrum of a signal reflected from the bottom

Having the replica of the transmitted signal U(t) and the registered response signal V(t), we can come to the analysis of the above signal basing on the time-delay spectrometry method.

Finally, after conducting low-pass filtering we obtain the sea bottom response signal in the differential frequency domain, given by the following formula:

$$\Delta\omega = \frac{S*\tau}{2} \qquad \tau = \frac{2d}{c}$$

where: t - time delay echo signal
d - depth of the layer
c - speed of sound in sediments

Finally, from the two formulas we obtain the depths at which the layers are located:

$$d = \frac{\Delta\omega * c}{2}$$

Diagram of the signal translated into the distance in the linear scale is presented on the following figure:

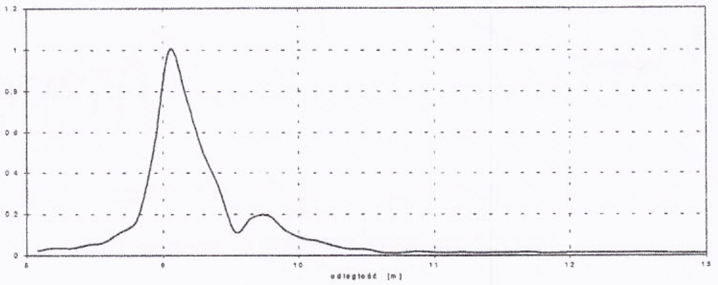

Fig. 5. Bottom response signal in a normalized linear scale

Second evaluation point:

At sea depths of 67.5 m transducers were lowered to the depth of 15 m.
Parameters of transmitted signals:

- bandwidth 23.1 kHz – 35.7 kHz,
- signal duration t = 0.041 s,
- sampling frequency fs = 200 kHz.

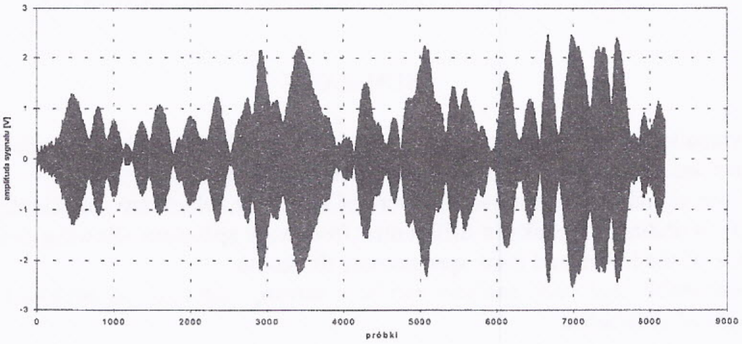

Fig. 6. Bottom response signal

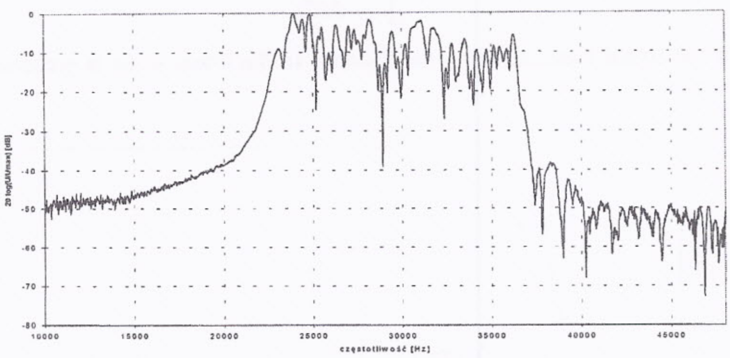

Fig. 7. Normalized spectrum of recorded signal

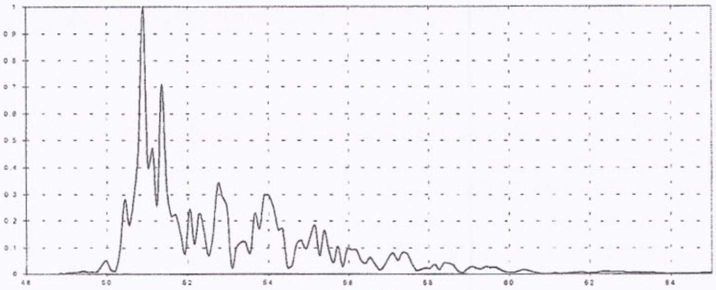

Fig. 8. Bottom response signal in normalized linear scale

SUMMARY

At each evaluation point, measuring cycles were established and the individual signals presented above are examples of the subsequent recorded groups.

Passing of the signal between adjacent layers of sediment, which are sufficiently distinguishable, results in distinctive peaks in differential frequency spectrum allowing determination of the existence of the layers and their approximate thickness.

It seems reasonable that such analysis can be a starting point for an attempt to classify the bottom layers of sediments.

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