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Target strength of krill

ABSTRACT: The method of target strength measurement adopted for the krill's target strength determination is proposed. The relation between the length of krill's individual and its target strength, obtained at the laboratory conditions, is presented.

Key words: Antarctic, krill

1. Introduction

The krill (*Euphausia superba* Dana) is one of the most important elements of the food chain in the Antarctic Seas. The researches of its life biology have been extensively carried on over years. Particulary in the seventies hydroacoustical methods of the abundance estimation were employed for this purpose. Hydroacoustical methods, however in spite of the others, require the apriori knowledge of the target strength *TS* of the investigated object. The first attempt of the krill target strength determination was carried out on the research vessel "Profesor Siedlecki" during. The Second Antarctic Expedition in 1977 (Kalinowski 1978) and were completed in the Institute of Telecommunication of the Technical University of Gdańsk.

First part of this paper is devoted to the definitions of the target strength *TS*, its second part discussed the target strength of the krill against its length measured at the laboratory conditions.

2. Method and results

2.1. The definition of the target strength

The target strength is a quantitive measure of the reflexive properties of an underwater object. It determines amount of the ultrasonic wave energy reflected by the object. Following Urick (1967) we define the target strength as:

$$TS = 10 \log \left.\frac{Ir}{Ii}\right|_{r=1\,\mathrm{m}} \text{ (dB)} \tag{1}$$

where:

TS — the target strength of the object,

Ii — the intensity of the plane wave falling on the object,

Ir — the intensity of the wave reflected from the object.

Both Ii and Ir are determined at the unit distance $r = 1$ m from the object at the direction of the falling wave.

The target strength TS depends on the relation between the linear dimensions of the object l and the wavelength λ. Three different ranges of the target strength dependence on the l and λ are distinguished (Forbes and Nakken 1972):

1° $\lambda \ll l$

It is so called geometrical zone where TS can be found by means of the geometrical optics laws.

2° $\lambda \gg l$

It is Rayleighs scattering zone where TS is approximately proportional to the sixth power of l and inversely proportional to the fourth power of λ

$$TS \cong A \cdot \frac{l^6}{\lambda^4} \tag{2}$$

where:

A — coefficient of proportionality

3° $\lambda \cong l$

It is the intermediate zone where TS depends on the object orientation and the ratio l/λ.

The target strength is also defined by means of so called effective cross-section σ of the target (Urick 1967). The effective cross-section is an equivalent surface which isotropically scatters energy of the falling plane wave with an intensity of the backscattered energy equal to the energy back scattered by the real object.

$$\sigma = \frac{Pr}{Ii} = 4\Pi \left.\frac{Ir}{Ii}\right|_{r=1\,\mathrm{m}}$$

where:

Pr — the energy scattered by the object,

Ii — the intensity of the plane wave falling on the object.

As above, the Ir and Ii are determined at the unit distance $r = 1$ m from the object at the direction of the falling wave.

It the case of sphere the relation between the effective crosssection and the geometrical surface depends on the walve of the radius a and the walve number $k = \frac{2\Pi}{\lambda}$ as follows (Urick 1967): 1° for

$$k \cdot a < 0.5$$
$$\frac{\sigma}{\Pi a^2} = 2.8\, k^4\, a^4 \tag{4}$$

2° for

$$k \cdot a > 5$$
$$\frac{\sigma}{\Pi a^2} = 1 \tag{5}$$

3° for

$$0.5 < k \cdot a < 5$$

the walve of the ratio $\frac{\sigma}{\Pi a^2}$ fluctuates.

The relation presented above are plotted in Fig. 1.

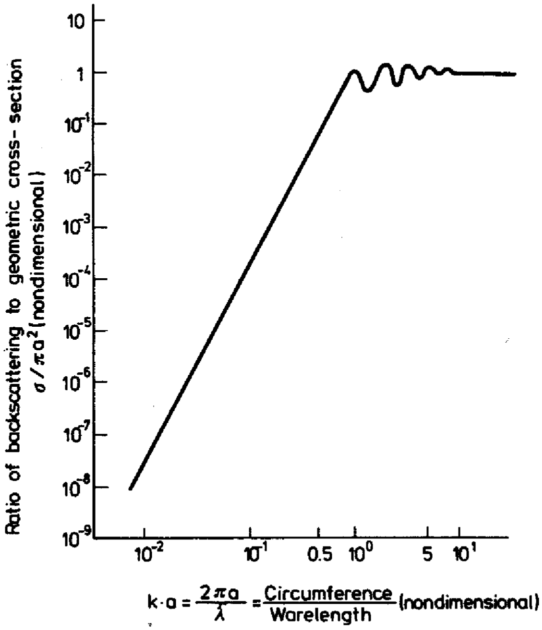

Fig. 1. Ratio of acoustic to geometric cross-sections of a fixed, rigid sphere of a radius a

2.2. Krill's target strength determination

There are several methods of the target strength determination given by Urick (1967). The comparative method briefly described below has been employed for the krill's target strength measurements.

Basically the comparative method consists in the comparison of the echo amplitude U_{rk} from the measured object, with the echo amplitude U_{rs} from the standard object with the apriori determined target strength TS_s. Both, measured object and the standart ought to be fixed at the same distance from transducer. Provided that the dimensions of the standart and the measured object are of the same order (what is particulary important in the intermediate zone) the target strenght of the measured object is given as:

$$TS_k = TS_s + 20 \log \frac{U_{rk}}{U_{rs}} \text{ (dB)} \tag{6}$$

where:

TS_k — target strength of the measured object,
TS_s — known target strength of the standart,
U_{rk} — echo amplitude from the measured object at the terminals of the receiving trasducer,
U_{rs} — echo amplitude from the standart at the terminals of the receiving transducer.

2.3. Krill's target strength measurement

Krill's target strength determination has been carried out in the measurement tank of the Institute of Telecommunication of the Technical University of Gdańsk. The dimensions of tank are 2×2×2 m. In order to attenuate undersired reflexions the bottom and walls of the tank are onvered with a coat made of synthetic hair. The reflexions from the surface are attenuated by means of the floating coat made of synthetic hair too, fixed to the plates of foamed polystyrene. Because of the geometry of the tank and the measurement set the pulse duration τ used for the measurement should fulfill some inequalities quoted below (Bruel and Kjaer 1977):

— Because of the reflexions between the receiving anu transmitting transducer

$$\tau \leqslant \frac{2}{c} \tag{7.1}$$

— Because of the reflexions from the bottom and the surface

$$\tau \leqslant \frac{\sqrt{h^2+d^2}-d}{c} \tag{7.2}$$

— Because of the reflexions from the walls

$$\tau \leqslant \frac{\sqrt{b^2+d^2}-d}{c} \tag{7.3}$$

and

$$\tau \leqslant \frac{a-d}{c} \tag{7.4}$$

— Because of the steady state of the receiver

$$\tau \geqslant \frac{3}{f_n} \tag{7.5}$$

where:

τ — pulse duration (ms),
c — propagation velocity of the acoustic wave in the water $\left(\frac{m}{s}\right)$,
d — the distance between the receiving and transmitting transducer (m),
h, a, b — dimensions of the tank (m),
f_n — frequency of operation (Hz).

The distance s between transducers and the target should not be less than the limit distance of the far field (Fraunhofer zone). For the circular transducer it leads to the inequality (Crawford 1973)

$$s \geqslant \frac{D^2}{\lambda} \tag{8}$$

where:

λ — the length of the wave,
D — the diameter of the transducer.

The relations (7) and (8) are plotted together on the common diagram in Fig. 2.

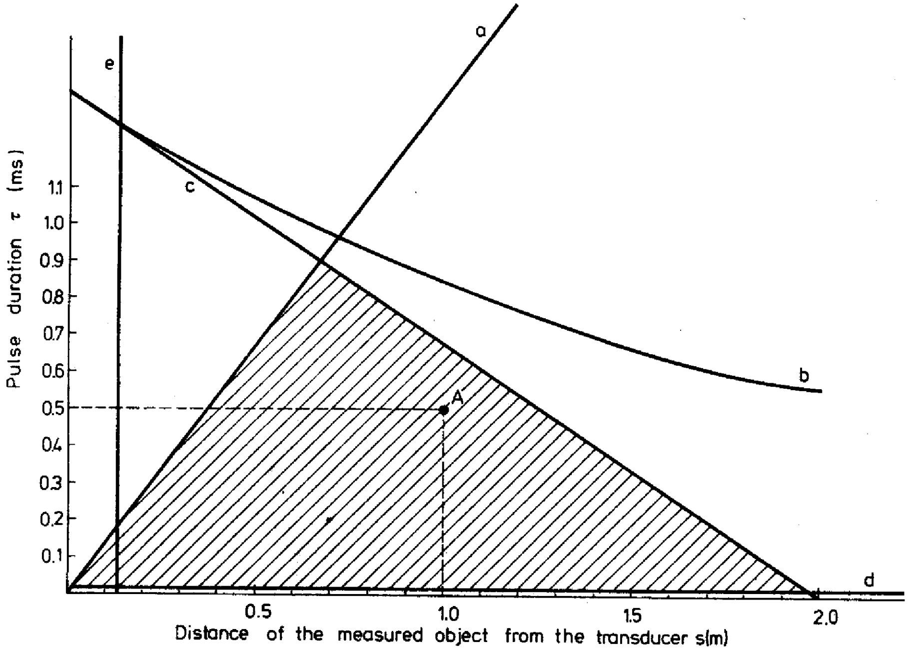

Fig. 2. Selection of a optimum measurement parameters at the measurement tank conditions a — curve illustrating equation 7.1, b — curve illustrating equations 7.2 and 7.3, c — curve illustrating equation 7.4, d — curve illustrating equation 7.5, e — curve illustrating equation 8, A (1, 0.5) working point.

Dotted area displays allowable range of the pulse duration τ and the distance s of the measured object from the transducer

Dotted area displays allowable range of the pulse duration τ and the distance of the measured object from the transducer.

For krill's target strength measurement two PZT circular transducers with the diameter $D = 35$ mm, operating at the frequency 159 kHz were used. The pulse duration was 0.5 ms. The distance between the measured object and the transducer was 1 m. As a standard object the glass sphere fulfilled with the air, with the diameter of 1 cm, was used.

3. Results

Fifty of formalin preserved individuals of krill of different body length were measured. As a result the relation between the target strength and the length of the body was obtained. Under assumption of the correlation coefficient equal to 0.8 this relation is given as:

$$TS_k = 2.3\,ML - 72 \text{ (dB)} \tag{9}$$

where:

TS_k — target strength of the krill (dB),

ML — length of the krill's individual (cm).

For an example:

The individual with length of 4.5 cm has $TS = -61.6$ dB, according to the equation (9).

4. Summary

This paper concerns the problems of target strength measurements. The method of measurement adopted for the krill's target strength determination is proposed. The resulting formula describing the relation between the length of the krill's individual and its target strength is presented. It is believed that the presented formula (equation 9) can be useful for estimation of the krill swarm density by means of the hydroacoustical equipment.

5. Резюме

Рассматривается вопрос измерений силы цели в лабораторных условиях. Представлено метод измерения силы цели крыля. Представлено уравнение (9) онисывающие зависимость силы цели от длины тела крыля. Эту зависимость можно использовать для вычислений плотности скоплений крыля с помощью гидроакустической аппаратуры.

6. Streszczenie

Opisano zagadnienie pomiaru siły celu w warunkach laboratoryjnych. Podano metodę pomiaru siły celu kryla. Przedstawiono równanie (9) opisujące zależność siły celu kryla od jego długości. Zależność ta może być wykorzystana do obliczania gęstości skupień kryla przy pomocy sprzętu hydroakustycznego.

7. References

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