ESTIMATION SYSTEM FOR SONAR EFFICIENCY IN UNDERWATER TARGET DETECTION

V. IGNAT[1], FLORENTINA IGNAT[2]

This paper presents a new estimation system for sonar efficiency in underwater target detection.

1. GENERAL CONSIDERATIONS

Underwater target detection is influenced by the variation of physical factors of the medium in which the searching is taken place. This variations affects the sound propagation speed and also the distribution of this speed in the underwater space, this is what makes the detection of the underwater target a difficult problem, which imposes the usage of more than one type of sonar to assure a maximum probability of detection. The estimation system simulates the propagation of the acoustic sonar waves in the underwater medium and theirs concentration points and also the “shadow” areas. This way it can be established the depth of antennas of the sonars with immersed vibrator or the inclination angle of the beam, so as to obtain an optimum detection.

The initial input parameters are: the technical characteristics of the used sonars, the sound speed/depth diagram, the target strength, the sea hydrological parameters.

The previous implemented systems were solving the issue only in small sea water conditions, where the assumption that a cylindrical propagation exists could be made. Those systems haven’t totally satisfied the requirements because the propagation lows are different on some sectors, even for such water depth. The suggested and implemented system eliminates this inconvenience.

2. ACTION DISTANCE ESTIMATION FOR SONAR SYSTEMS

The action distance in a uniform infinite medium where the refraction of the acoustic rays is missing, doesn’t completely characterize the real possibilities of

[1] Naval Academy “Mircea cel Bătrân”, Constanța.
[2] Business & Decisions, Paris.

Rev. Roum. Sci. Techn. – Méc. Appl., Tome 54, N° 3, P. 169–174, Bucarest, 2009

sonars. From that reason, it was created a medium model with parallel layer structure and with constant values for the each layer sound speed gradient.

The acoustic ray theory on which the analyzed system is based, enable a way to easily obtain information about the sound space-propagation, information applied at sea acoustic level. If the medium is uniform, the output rays of the source S with direction to the receivers R_1, R_2, R_2, will be rectilinear (Fig. 1).

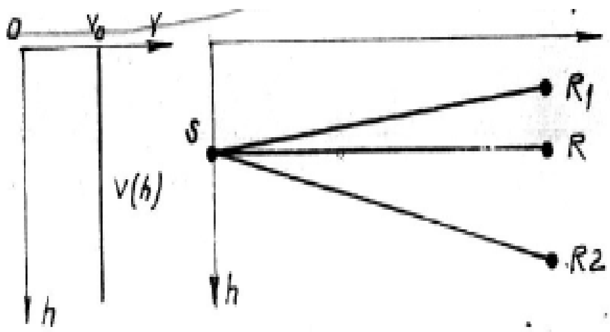


Fig. 1

If the medium is non-uniform, layered on *h* coordinate, the incidence angle of the acoustic ray is modified at each layer changing, according to relation (Fig. 2):

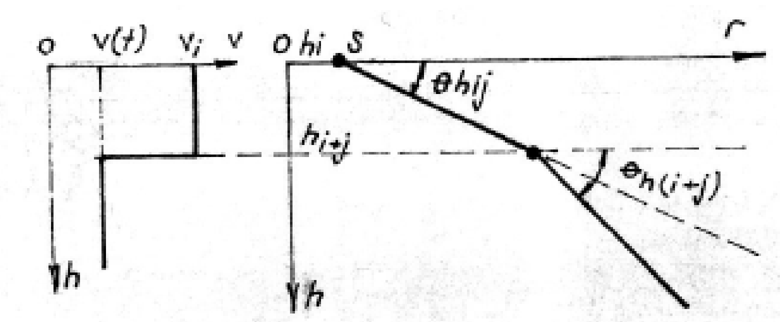


Fig. 2

$$\frac{\cos\left(\theta_{hij}\right)}{\cos\left(\theta_{h(i+1)j}\right)} = \frac{v_i}{v_{i+1}}, \tag{2.1}$$

where *i* is the index of the layer, and *j* is the index of the ray.

In the Fig. 3 there are shown some segments of ray trajectories in an infinite medium, for various dependences *v*(*h*).

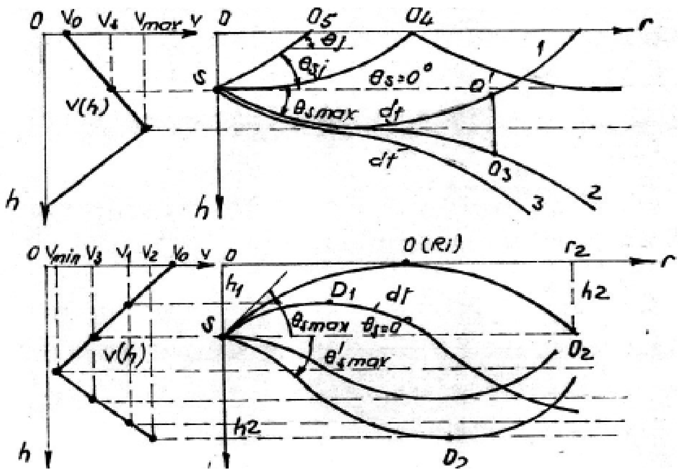


Fig. 3

2.1. THE ACOUSTIC RAYS COMPUTATION AND TRAJECTORY TRACING ALGORITHM

The active sonar equation is used to determine the sonar probable action distance. It connects the technical characteristics of detection equipment to the target parameters and the sound sea-propagation peculiarities. The action distance of the active sonar is given by the relation:

$$\mathrm{SL} + \mathrm{TS} - 2\mathrm{PL} - N + \mathrm{DI} = \mathrm{DT}, \qquad (2.2)$$

where: PL = propagation loss, in dB; N = noise level at the reception point, in dB; DI = directivity index of the receiving antenna, in dB; DT = detection threshold, in dB; SL = acoustic stress level generated by a sonar transmitter, in dB; TS = target strength, in dB.

The acoustic stress level is given by the relation:

$$\mathrm{SL} = 171.4 + 10 \log P + \mathrm{DIE}, \qquad (2.3)$$

where: 171.4 dB is the acoustic stress level generated by an acoustic source with power of 1 W; P is the acoustic power generated by the sonar's transmitter; DIE is the directivity index of the transmission antenna.

The noise level at the reception point (N) represents the intrinsic noise created by totaling the propeller and the ship mechanisms intrinsic noise with the hydrodynamic noise appeared at the ship movement. It's value is obtained from the graphics resulted from the measurements done at the antenna's position. The noise level presented in the graphics is in the band of 1 Hz. For that reason, in the sonar equation it must be introduced the intrinsic noise from the band-pass width of the NL receiver, given by the relation:

$$\mathrm{NL} = N + 10\lg W, \tag{2.4}$$

where W is the band-pass width of the intrinsic receiver.

The detection threshold depends on the signal processing level and on the receiver band-pass width. It is given by the relation:

$$\mathrm{DT} = \mathrm{d} - 10\lg Wt - 5\lg n \tag{2.5}$$

where: t is the span of the emitted impulse; W is the band-pass width of the intrinsic receiver; d is the uncovering coefficient which is determined depending on the detection and false alarm appearance probability; n the number of the reflected impulses from target.

2.2. THE PROPAGATION LOSSES

The sonar impulse emitted on the route transmitter – target – receiver is affected by a series of losses: the absorption in the medium, the dispersion in the medium, the reflections at the surface and from the bottom of the sea.

The propagation losses are given by one of the following 3 relation, depending on the proportion between H and the maximum distance fixed as distance scale:

$$H = \left[\frac{3}{8}(D + L)\right]^{\frac{1}{2}}, \tag{2.6}$$

where: D is the water depth in meters, D = the port waters depth set in the part of the software program which gives us the sound/depth variation, L is the wave channel depth in meters.

If $0 \le D_{\max} \le H \cdot 1000$ then the propagation losses are computed with the relation:

$$\mathrm{TL} = 20 \cdot \log r + \alpha \cdot r + A. \tag{2.7}$$

If $H \cdot 1000 \le D_{\max} \le H \cdot 8000$ the propagation losses are computed with the relation:

$$\mathrm{TL1} = 15 \cdot \log r + \alpha \cdot r + 5 \cdot \log H + A. \tag{2.8}$$

If $H \cdot 8000 \le D_{\max}$ from the relation 1, the propagation losses are computed with the relation:

$$\mathrm{TL2} = 10 \cdot \log r + \alpha \cdot r + 10 \cdot \log H + A, \tag{2.9}$$

where: α is the medium attenuation coefficient of the acoustic waves. It depends of the sonar work frequency:

$$\alpha = 0.036 \cdot f^{\frac{3}{2}}. \tag{2.10}$$

A is the propagation anomaly of the acoustic waves.

3. ESTIMATION SYSTEM FOR SONAR EFFICIENTCY

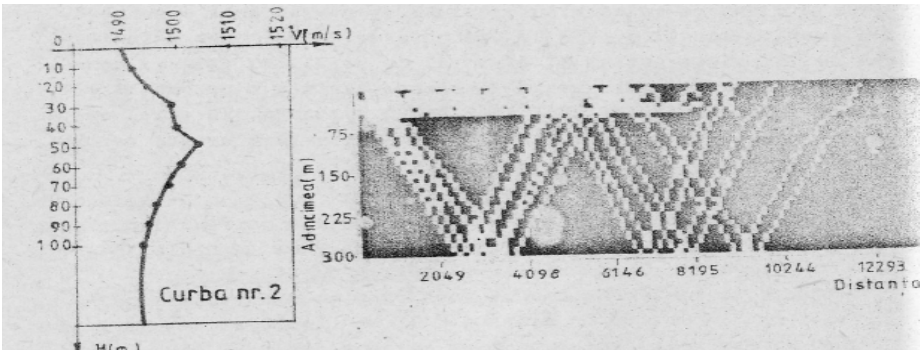
Based on the relations presented above, it was implemented a system which simulates the acoustic waves propagation in the marine medium, system with aid of which it can be appreciated the sonar efficacy in underwater target detection.

The system has two distinct parts, which interconnect:

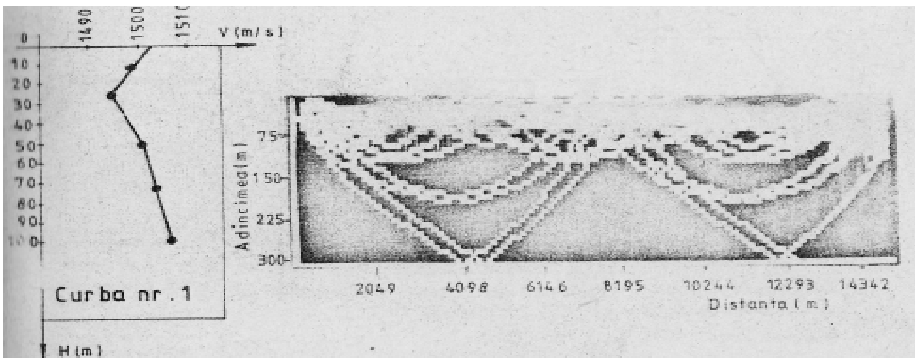
- the tracing system, for sound speed with the port waters depth profile;
- the prediction system, which indicates the way the acoustic waves are propagated in water, with the concentration zones and the acoustic shadow zones.

As example, on presents for a particular sonar type, the acoustic waves propagation way in water, for two distinct types of sound speed/depth profile.

The profile I of sound speed/depth variance. For an antenna immersion depth of 30 m, on observes forming a surface acoustic channel, and for an antenna depth of 75 m, a combination of surface acoustic channel and acoustic rays reflecting from the bottom of the port waters, with a lot of shadow zones where the submarine can not be detected (Fig. 4).



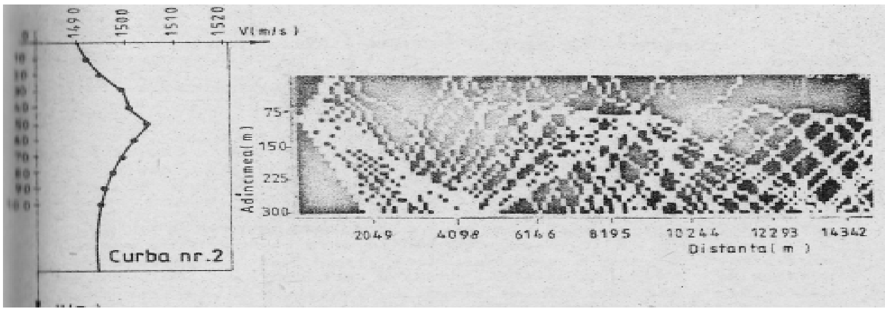
a



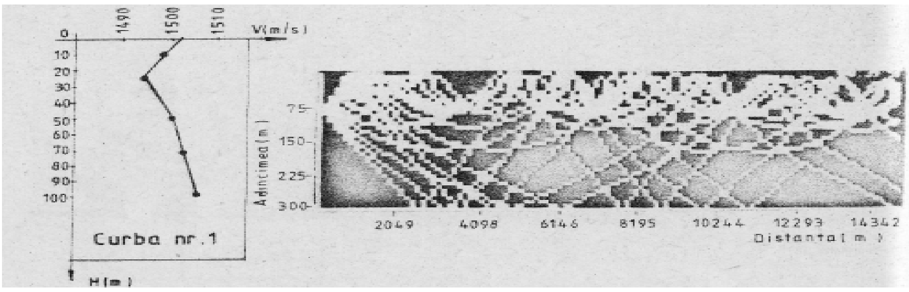
b

Fig. 4

The profile II of sound speed/depth variance. For a sonar antenna's immersion depth of 30 m, on observes a combination of surface acoustic channel and acoustic rays reflecting from the bottom of the port waters, with a lot of shadow zones where the submarine can not be detected, and for a depth of 75 m, a bottom acoustic channel stretching up to 15 km. The acoustic shadow zones are small but many, alternating with the acoustic ray concentration zones. As an effect, the target can be intermittently detected (Fig. 5).



a



b

Fig. 5

4. CONCLUSIONS

For an optimum detection of the immersed targets, it can be taken the following measures:

- the simultaneous usage of many sonar types: immersed, towed under keel;
- inclination at various angles for the sonar antennas mounted under the keel;
- the usage of multiple work frequencies, etc.

Received on 10 February 2009

REFERENCES

1. ROBERT J. URICK, *Principles of underwater sound*, McGraw-Hill, New York, 1983.