Hydroacoustical Speed Gauge for Marine Vessels

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유체음향을 이용한 선박 속력 측정장치

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요 약

이 논문은 최근의 선박에 있어서 절대선속을 측정하는 두 가지 방법-음향 도플러 선속계와 음향 상관 선속계에 의한-과 그 실현화에 관한 것이다. 또한, 이 논문에서는 두 선속계의 단점을 분석하여 개선방안을 제안하였으며, 이 연구의 결과는 향후 음향선속계의 개발에 기여할 것으로 본다.

Abstract

The paper deals with modern methods of measurement of ship's absolute speed and their realization: Doppler hydroacoustical logs and correlation hydroacoustical logs. Shortcomings of both log types are analyzed and ways of their improvement suggested.

On the basis of the study the perspectives of hydroacoustical logs development are determined herein.

Introduction

Speeds and intensity of cargo and passenger transits on the main sea routes have increased, number of different ship types and classes has also grown up.

New vessels have emerged such as ones with dynamic principles of support (on submerged

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wings, pads and ram wings), able to gather high speed (up to 100 knots and more). According to the valid qualification requirements vessels of 500 ton displacement and more should be equipped with speed gauges - logs.

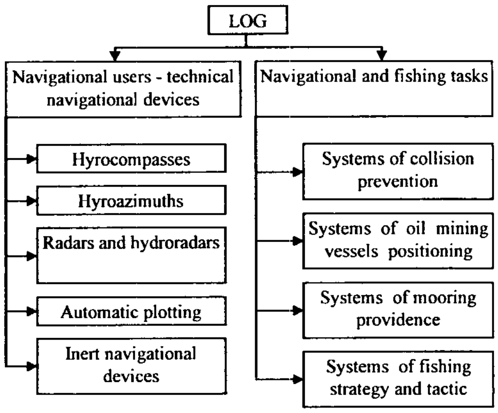
The volume of functional tasks given to hydroacoustical logs increases. As a rule HAL should measure the following values:

-longitudinal and transversal horizontal components of absolute speed vector;
-module of actual speed vector and crab angle;
-components of distance covered by ship with respect to sea bottom;
-keel depth;
-current speed;
-vertical component of speed vector when HAL is installed at underwater apparatus.

Range of speeds measured by log using longitudinal component is determined by maximum speeds of forward and backward motion of supposed log bearers. If transversal component is used this range does not exceed 010 knots. The above mentioned and other circumstances explain the deep interest to the following.improvement of HAL. List of users of information on ship's speed is shown in picture 1. An important part among the users aboard fishing vessels is played by systems for solution of strategic and tactical fishing tasks [Zhidkov E.M, Malyavin Y.N., 1995].

Wide and almost used possibilities for construction of new updated types of logs for marine vessels are given by usage of sound fields in sea water as recourses of information about ship's speed. Three approaches can be applied to solve this problem which are conditioned by features of different physical effects, accompanying distribution of sound waves received from a moving vessel.

The first approach is based on Doppler's effect which implies that frequency of echo-



Pic. 1 Users of information on ship's speed

signals, received by antenna on a moving vessel, is not equal to the frequency of emanated signal. Doppler's increase of frequency is in proportion to absolute speed of ship. This effect is a basis of Doppler's hydroacoustical log (DHAL) function [K.A. Vinogradov, V.N. Koshkarev, B.A. Osyukhin etc, 1990].

The second approach is supported by correlation connection between echo-signals from sea bottom received by hydroacoustical antennas spread in the bottom of vessel. Coefficient of mutual correlation of echo-signals is the speed function and carries information about absolute speed of vessel [A.A. Khrebtov, V.N. Koshkarev, B.A. Osyukhin etc., 1978].

The third approach is based on the fact that radial speed of sound wave distribution in moving medium is equal to geometric sum produced by sound speed in medium and medium speed itself. The principle can condition the construction of relative hydroacoustical log. In practice the second and third approaches are realized in correlation log (CHAL) [S.N. Pavlikov, A.S. Potapov, Y.I. Ubankin, 1994; V.M. Bukaty, V.I. Dmitriev, 1980].

Doppler's Hydroacoustical Log

Doppler's method of measuring absolute speed of vessel with respect to sea bottom is based on determination of Doppler's shift in frequency of segment of tone signal reflected from bottom with respect to frequency of the signal emanated from board ship and calculation of speed according to equation:

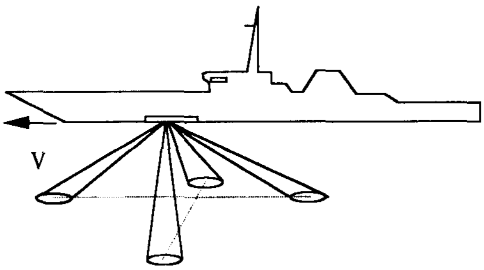
$$f_{\text{Д}} = f_{\text{пр}} - f_{\text{и}} = \frac{2 f_{\text{и}}}{C \cdot V_{\text{и}} \cdot \cos\alpha_{\text{и}}} - \frac{V_{\text{пр}} \cdot \cos\alpha_{\text{пр}} + V_{\text{и}} \cdot \cos\alpha_{\text{и}}}{2} \qquad (1)$$

where f - frequency of emanated signal; $f_{\text{Д}}$ - frequency of received echo-signal; $f_{\text{пр}}$ - sound speed in water; $V_{\text{и}}$, $V_{\text{пр}}$ - ship's speeds in the moment of emanation and reception respectively; $\alpha_{\text{и}}$, $\alpha_{\text{пр}}$ - angle of declination of property of log acoustical antenna in the moment of emanation and reception respectively.

To remove non-linear properties of the sequence two-ray Yanus system is used which compensate quadratic member of the above sequence. Four-ray systems also allow to determine transversal components of ships speed (Pic. 2).

In practice simplified method of speed determination is more widely used:

$$V = \frac{c \cdot f_{\text{Д}}}{4 f_{\text{и}} \cdot \cos\alpha} \qquad (2)$$



Pic 2 Operation principle of Doppler hydroacoustical log

Nowadays there is a varity of different industrial samples of Doppler hydroacoustical logs. Technical parameters of some of them are listed in Table 1.

Analyses of technical parameters of Doppler hydroacoustical logs built according to the method [A.A. Khrebtov, V.N. Koshkarev, B.A. Osyukhin etc., 1978] and listed in Table 1 allowed to determine their main shortcomings:

- log data depend on changes in speed of sound distribution along sound canal;
- insufficient reliability of log operation caused by small signal/noise ratio at the inlet of its receiver, possible loss of echo contact with sea bottom due to rolling, circulation, changes in reflection properties of sea bottom due to declination and absorption of acoustical energy and also caused by change of hydroacoustical canal properties (for instance, appearance of aeration around antenna or leap layer in vertical distribution of sound speed);
- measurement errors depend greatly on terms of fulfillment of lengths equality and homogenity of pathes for distribution of signal components in water in the limits of direction parameter width. The errors depend also on balance between reflective ability of bottom areas for bow and stern rays: if the balance is not preserved form of Doppler spectrum may be distorted and its maximum shifted;
- low functional stability and accuracy of measurement of small values in ship's speed conditioned by difficulties of measurement of small

Doppler shift values on the background of reverberation hinderance.

Thus, improvement of Doppler hydroacoustical logs should be carried according to the following trends:

〈Table 1〉 Technical Properties of Main DHAL

N	Properties, Log Type	Russian			Foreign		
		DHAL <Onega>	DHAL <LA-3>	DHAL <LA-4>	PADS <Sperry> USA	MX-610D <Magnavox> USA	Atlas Dolog 22 <Crupp Atlas Electronic> Germany
1	2	3	4	5	6	7	8
1	Range of measured speed, knot: longitudinal transversal	-10 ... 25	up to 40 ±4	-5 ... 50 ±5	-5 ... 25 ±5	±20 ±20	-5 ... 30 ±5
2	Errors in speed measurement, knot Errors in covered distance measurement, %	at V≤10kn. 0.05 kn. at V>10kn. 0.5 % 0.2 %	at V≤10kn ±0.15kn at V>15kn 0.1% 0.2 %	±0.7% from V 0.2 %	0.2 % 0.2%	0.2% 0.2%	0.2% 0.2%
3	Type of correction by change of sound speed	Frequency independent antenna	-	-		Thermistor	Frequency independent antenna
4	Range of working depths, m	3 ... 170	20 ... 5000	30...6000	30...6000	15...500	1...600
5	Number of rays formed by antenna	4	-	-	4	4	4
6	Working frequency: low frequency canal, kHz high frequency canal, MHz	255	25 100	24 - 26 96 -104	195 206	150	79
7	Width of direction property, degree: emanation reception	3	3° 5°	3° 5°	3° 5° , 11°	3° 5°	3°

1. Increase of accuracy. It is known that the attempt to reduce number of errors in measurement by increase of accuracy according to the simplified equation, for instance equation (2) does not give required results. The authors suggest to turn back to realization of method based on equation (1) and to increase accuracy of measurement of declination angle of direction parameter. It can be proved that ship' speed in the moment of reception of echo signal is determined by the formula:

$$= \frac{\dfrac{(f_{np} - f_{n}) \cdot (C - V_{n}\cos\alpha_{n})}{f_{n} - V_{n}\cos\alpha_{n}}}{\cos\alpha_{n}} \qquad \text{......................(3)}$$

2. Consideration of measurement errors. Unlike existing method of error determination [K.A. Vinogradov, V.N. Koshkarev, B.A. Osyukhin etc, 1990] the present paper suggests to compensate errors in ship's speed determination caused by change of sound speed by usage of combined method of speed determination which combines elements of both Doppler's and correlation

methods.

3. Expansion of usage terms. This trend implies fulfillment of certain procedures of automatic choice of optimum parameters (angle of direction parameter declination, emanation power, period and duration of impulses, period of accumulation and frequency of emanation) as well as modes of impulse and (or) continuous sounding.
4. Expansion of functional abilities. This trend includes testing hydroacoustical canals in order to choose optimum parameters and modes of log operation, automatic identification of navigational obstacles, signaling of the ship entrance into the sea area with given depth, determination of absolute and relative speed components (actual, longitudinal, transversal and vertical), measurement of current's speed at certain depth, calculation of ship's acceleration and leeway angle, determination of ground properties and calculation of the covered distance.

Correlation hydroacoustical log

In present time increased interest to correlation hydroacoustical logs (CHAL) is marked in the field of production of marine navigational devices in developed countries. Main technical parameters of modern CHAL are given in Table 2.

Various types of existing correlation hydro-acoustical logs require to be arranged according to common definitions in order to facilitate evaluation of their long-term usage.

1. By type and volume of initial information - gauges belong to correlation alarm navigational systems of the first class ("without memory") where information about navigation field is taken in one moving "spot" that is output signal of

〈Table 2〉 Main Tactical and Technical Properties of Modern CHAL

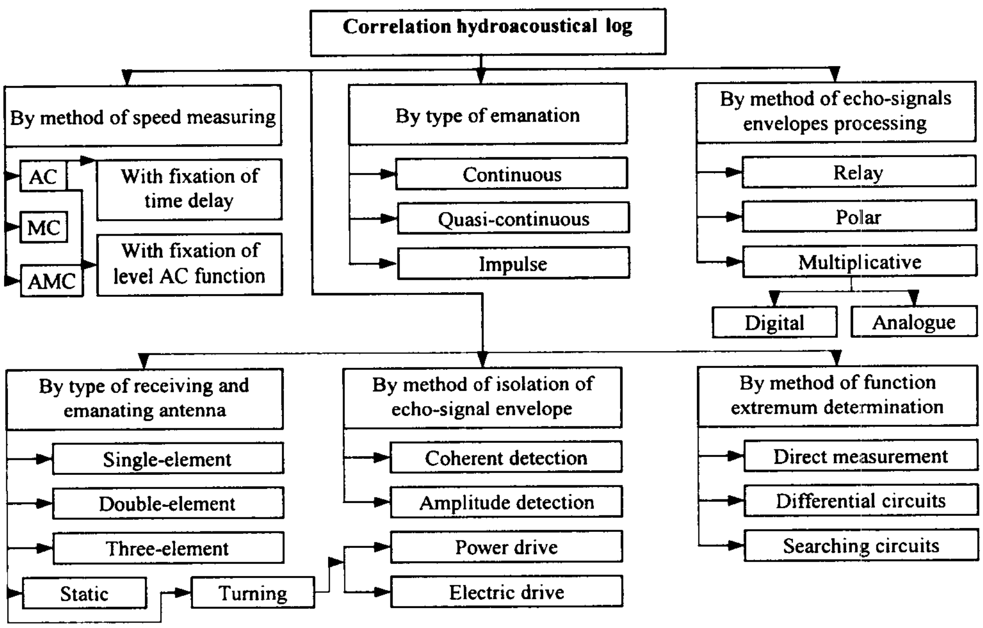
N	Properties, Log Type	SAL-84 <Consilium Marine>, Swiss	SAL-865 <Consilium Marine, Swiss	Quo Vadis <General Electric>, USA	MX-810 <Magnavox>, USA
1	Range of measured speed, knot: longitudinal component in measuring mode absolute speed relative speed transversal component	 8 ... 30 0 ... 30 0 ... 30	 - 8 ... 40 0 ... 40 ±8	 ±50 ±50 -	 ±30 ±30 ±10
2	Errors in speeds measurement, knot	at V≤20 kn 0.1kn at V>20 kn 0.5 %	at V≤20 kn 0.1kn at V>20 kn 0.5 %	at V≤10 kn 0.02kn at V>10 kn 0.2 %	at V≤10 kn 0.1 %
3	Errors in covered distance measurement, %	0.5	0.5	-	0.2
4	Working depth, m	2 ... 300	2 ... 300	up to 6000	5 ... 5000
5	Working frequency: low frequency canal, kHz high frequency canal, MHz	 150 4	 150 4	 12 -	 18 -
6	Range of measured depths, m	2 ... 300	2 ... 300	up to 6000	5 ... 5000
7	Errors of depth measurement, %	1	1	-	-
8	Width of XH, degree: transmitting antenna receiving antenna	 - -	 - -	 40 100	 40 100
9	Diameter of antenna, mm	92	122	-	305

indicator is a scale value.

2. By method of determination of ship's absolute speed - gauges belong to logs based on measurement of physical values, related to ship's speed by means of certain functional dependences.
3. By type of geophysical field in use - stationary field of natural origin (Earth field).
4. By method of navigational information reception - based on analyses of space profile of seas and ocean bottom surface.
5. By construction principle - gauge determines transport lag. Speed is determined by time delay, corresponding to maximum coincidence of signals of field parameters indicators scattered on a certain distance in motion direction.
6. By method of speed measuring - auto-correlation (AC), mutual correlation (MC) and mutual autocorrelation (MAC).

Increased interest to correlation hydroacoustical logs is caused by their advantages as compared to traditional Doppler hydroacoustical logs:

- independence of its work from changes of sound speed in water;
- lower influence of ship rolling because of better acoustical contact with ground due to wider parameter of antenna direction;
- less wave dimension of antenna;
- ability to measure ship's speed and keel depth simultaneously without forming additional (vertical) ray which allows to exclude echo sounder from device set;
- do not require temperature stabilization of master oscillator of emanation path;
- less sizes of antenna system which allow to set it in gate valve and change reception unit of log without docking;

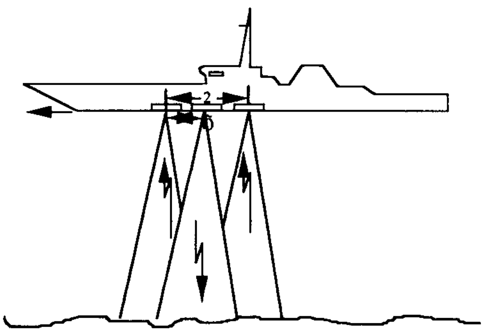


Pic. 3. Classification of correlation hydroacoustical logs

-lower power consumption and emanated power;
-comparatively smaller blind zone which allow to expand range of working depths below keel.

Besides, method of hydroacoustical correlation measurement of ship's speed with respect to sea bottom allows to use complex signals which improve accuracy of determination of speed distance down to bottom due to strongly pronounced narrow peak of correlation function at zero value of argument. This helps to increase reliability of its work under circumstances of strong hindrance. Usage of lower frequencies in correlation hydroacoustical logs as compared to Doppler hydroacousticall logs and vertical sounding provides stable contact with ground at leap layer in vertical distribution of sound speed.

Correlation methods of ship's speed measuring are characterized by average quadratic relative errors evaluated by formula:



Pic. 4. Principles of correlation hydroacoustical log operation

$$\sigma = \frac{\lambda \sqrt{\frac{\lambda}{\theta}}\ K}{\theta\ d\ \sqrt{VT}} \qquad (4)$$

where λ - waves length of emanated signals;
θ - parameter width of antenna direction;
T - time of approximation;
K - coefficient depending on construction method of correlation device.

The formula (4) shows that with increase in approximation time, frequency of emanation and width of direction parameter the errors decreases.

Thus, increase in accuracy and reliability of correlation methods of ship's speed measuring with respect to sea bottom is provided by determination of area of working parameter of correlation function envelope with maximum slope value, chosen method of correlation measurement and principles of device construction which allow to get maximum accuracy under given conditions.

Conclusion

Analyses of DHAL and CHAL given in Tables 1,2 results in the following conclusions:

-errors in speed measurement and range of measured speeds are almost equal with DHAL and CHAL;
-CHAL requires less emanation power at the same working depth;
-CHAL reading do not depend on sound distribution speed in water and do not require special compensation devices;
-CHAL work is stable at ship's rolling and ground declinations;
-angles of ground declination do not influence error value of speed measuring by CHAL;
-less dimensions of CHAL antenna systems allow to install them in gate valves which fact increases maintenance properties;
-absence of considerable scattering of emanating and receiving antennas in CHAL prevents turning of antenna axis at ship's hull deformation when sailing in heavy seas;

-CHAL has less blind zone in working depth.

Analyzed modern methods of ship's absolute speed measurement allow to draw to the conclusions on their long-term properties, such as information accuracy, reliability at low mass and dimension values. Each of the analyzed above speed gauges has its own advantages and shortcomings which reveal under different sailing conditions. The situation is possible when there is no certain gauge able to provide the whole set of requirements in a wide range of operation conditions.

Analyses of existing DHAL and CHAL allow to determine perspectives of their development:

1. Creation of navigational hydroacoustical complex with multi-antenna system with blocks of correlation processing of echo-signals envelope and isolation of Doppler's frequency shift. Shaper of emanated signal changes declination angle of sound ray from 60 to 90 degrees. Inclined emanation is used to determine distance to upcoming obstacle (hydroradar mode) and to determine longitudinal component of ship's speed. At the same time vertical emanation allows to determine depth (echo-sounder mode) and all the elements of speed triangle. In joint processing of information on value of longitudinal component of ship's speed measured by Doppler's and correlation methods sound speed in water is determined from moving objects. Received information on sound speed in water may be used in future to correct echo-sounder, hydroradar and DHAL readings [B.G. Abramovich, 1992].
2. Formation of complex of ship's speed gauges based on different methods of ship's speed measurements. A good example of the complex may be given by hydro-acoustical Doppler and correlation logs, hydroacoustical correlation log and speed canal of inert navigational system as well as by unity of the three devices. Operation mode is chosen on the basis of information on external conditions (ship's rolling, meteorological conditions, aeration of water mass etc.) and depends on state of measurement canals according to data on built-in control systems. Redundancy of information received from complex system would allow to increase accuracy and reliability of output parameters due to joint processing of information given by speed gauges making a part of the system.

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