Vector-phase Measurements of Kinematic Parameters of Acoustic Field

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Abstract-**The possibility of kinematic parameters acquisition from acoustic field using vector-phase measurements of marine water was considered. The developed method includes measurement reception and localization of complex phase-manipulated signals in time. Such kinematic parameters as the phase and group velocities are calculated by way of reciprocal processing of acoustic pressure ranges and oscillation velocity (or pressure gradient) in the vector receiver. Concept of spatial-interference structure invariant of acoustic field presents the availability to apply notion "invariant velocity" as a kinematic parameter that possesses considerably lower spatial-temporal variability. Stringent solution of Helmholtz's equation for the pressure, oscillation velocity and energy stream, as Green's function, indicated that theoretical explorations were satisfactorily confirmed by the experimental data.**

I. INTRODUCTION

Last years the arisen interest to vector-phase measurements with application of oscillation velocity receivers (pressure gradient) is induced on the one side by qualitative improvement in constructing and production technology of such devices for measurement and on the other side by usage of non-traditional methods in the vector-phase instrumentation, namely processing of multi-component signals as on primary level, as on secondary one being linked with acquisition of final result of oblique measurement.

The presented report considers the methods of processing that include the stage of localization in time of irradiated signal acquired by channel-ranges of vector receiver and the next stage of secondary processing of the localized magnitudes in order to get kinematic characteristics of waveguide, such as phase and group velocities.

The procedure of localization in time consists of transmittance of complex phase-manipulated signal as m-sequence, reception of it by the vector receiver channel-range and reciprocal correlative processing of received signals (pressure and component of oscillation speed) with replica of irradiated signal. To our knowledge for such signals the function of uncertainty looks like a "needle" that is determined by a contour of envelope curve *(sinx)/x* and the envelope of autocorrelation function with the low level of lateral sidelobes.

After localization of measured magnitudes of sonic pressure P and oscillation velocity V look towards the source of beaming, we shall determine the phase velocity C_P

$$\frac{1}{C_p} = \frac{\rho |P| \cdot |V| \cos(P, V^*)}{|P|^2}.$$

Where ρ - density of medium, $*$ - designates complex conjugation. Local group velocity C_g we shall calculate by classical equation: $C_g = d\omega / dk,\ k = \omega / C_P,$ where ω - circular frequency, k - wave vector.

II. EXPERIMENT

The experiment with complex signals and vectorial receiver was accomplished at the hydrophysical scientific station of the Pacific Oceanological Institute of FEB RAS in close propinquity to the Cape Gamov. There were generated m-sequences being of 511 symbols length and equal to eight periods of career frequency 366 Hz. The signals were generated by piezoceramic transmitter (deepening to 39 m) deployed at the site with depth of 40 m.

The vector receiver presented as receiver of pressure gradient of inertial type was deployed at 200 m distance far from the source and at 3 m depth. Propagation conditions here are two-layers liquid with homogeneous contents and sound speed of 1500 m/s in upper layer, and 1800 m/s in the half-space, having ratio of the half-space to layer density to be equal to 1.6.

The following data are the sequel of an experiment processing in respect to the proposed method. Figure 1 demonstrates the resultant localization in time of sonic pressure signal for two moments of the phase-manipulated signal.

The arrivals of water wave (0.137s) and side (ground) wave (0.125s) are seen when being produced by a source accordingly geometrical shape of the experimental zone. Phase and group velocities determined for the same moments of beaming are presented in figures 2 and 3 like the normalized reciprocal magnitudes (slowness).

In figure 4 the regulating feature of ratio $C_pC_g = C_0^2$ is evident being quasi-invariant of wave process and having lesser variability comparing to initial values of C_p and C_g. Note the existence of invariant of spatial-interference structure "β" introduced in [1] and equaled to 1 in our case, as well the invariant velocity C_β identified in [2] as:

$$C_\beta \equiv \frac{(1+\beta) \cdot C_g \cdot C_p}{(C_g + \beta \cdot C_p)}$$

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Ratio between actual and imagined part of energy stream in researched process.

Figure 5 shows reaction of appropriate godograph for two moments of beaming in plane Im (p, V^*), Re (p, V^*).

The peculiarities of presented graphs in fig.5 include the next items: imagined part of the stream is non-zero, that evidences complicacy of the beaming source formed by actual source and imagined sources, ellipsoidal form of godograph has specific rip, that indicates changing type of wave movement, namely, arrivals of side wave and water arrivals are separated in time.

Generally, the experimental graphs are featured by great variability on kinematic parameters; there were noticed anomalous magnitudes of phase and group velocities which are regulated under introducing of the invariant ratio and stream of power.

III. DISCUSSION

Volumes are being determined by acoustic parameters of the marine water basin geometrical shape of frontiers, density and elasticity of the waveguide surrounding stuff (air, bottom). Research of the field of sonic pressure displays approximate state of real conditions inside of waveguide or closed volume. Actual description of acoustic field is possible to implement using simultaneously measurements of pressure, oscillation velocity and phase of elastic wave.

Simultaneous measurement of pressure in one point of space, as well instrumentation of oscillation velocity and phase between them would be noted as " vector – phase measurements". In real marine conditions it is very much complicated to measure precisely the actual acoustic parameters of marine water, bottom, frontiers of media acoustic separation in a waveguide and in any closed space.

Therefore, an error of measurement in marine medium equals to more than 20% on pressure and 40% on power capacity. Under such big value of error to compare the experimental and theoretical results could be reliable only by their properties.

Theoretical computation of acoustic field should be fulfilled using mathematical models which are in closest propinquity to the actual conditions.

To our supposition the marine medium might be imagined as endless flat waveguide only theoretically, because actually it is not a waveguide, but closed volume restricted by bottom, shoreline, frontier between air and water.

There fore in presented work the attempt to suppose marine medium as closed volume being an ellipsoid of rotation is considered. Meanwhile the theory expounded in (1,2) is used to admit calculation of harmonic source field that is situated in the closed volume under consideration.

Basing on this theory the propagation of arbitrary form periodical signal in marine medium is researched. Let ponder on harmonic source that works at some frequency "f".

The physical model of task is combination of point sources with distribution density "q" that are situated in the area restricted by surface "s" generating some potential "Φ" distribution on surface S. The sources are placed in the closed volume confined by surface S (Fig.6).

The mathematical model of task originated in Helmholtz's equation (1), which solution would be in accordance with congruous conditions along the frontier S (1a):

$$\Delta\Phi + k^2 \cdot \Phi = -4 \cdot \pi \cdot q(\overline{r_0}), \quad (1)$$

$$\left.\begin{aligned} \rho_1 \cdot \Phi_1\big|_S &= \rho_2 \cdot \Phi_2\big|_S \\ \frac{\partial \Phi_1}{\partial n}\Big|_S &= \frac{\partial \Phi_2}{\partial n}\Big|_S \end{aligned}\right\}, \quad (1a)$$

where: $q(\overline{r_0})$ – density of sources distribution,

Φ – potential of oscillation velocity,

ρ – normal to S boundary of separation,

κ – wave number.

The task of analysis for considered closed volume could be formulated as finding of the field generated by researched combination of the sources in observation point. In this case the field of potential is identified by the next equation:

$$\Phi(\bar{r}) = \int_V q(\bar{r}_0) \cdot G^{(+)}(\bar{r}_0, \bar{r}) dV, \quad (2)$$

where: $G^{(+)}(\overline{r_0}, \bar{r})$ – Green's function, i. e. afield of point sources located at the considered in medium plase that was indicated by radius – vector r_0 (sign «+» points to application of divergent waves in Green's function),

$\bar{r}$ – indicates to point of observation,

V – volume, where sources are situated.

Green's function of point source placed inside of closed volume in accordance with [1] should be computed in this way:

$$\left.\begin{aligned} G_1(MM_o) &= \frac{e^{i \cdot k_1 \cdot R_o}}{R_o} + K_o \cdot \frac{e^{-i \cdot k_1 \cdot R_o}}{R_o} \quad - int\,o \quad W \\ G_2(MM_o) &= \frac{e^{i \cdot k_1 \cdot R_{pr}}}{R_{pr}} \cdot K_п \quad - \quad off \quad W \end{aligned}\right\},$$

(3)

where: K – function depending only on angle coordinates (it means a coefficient of reflection of waves from separation frontier)

K – function depending on angle coordinates either (it means a coefficient of percolation of waves into the second half – space)

R_0 – distance between points of beaming and reception

R_{pr} – distance between some imaginable source and point of reception (detailed calculation of coordinates of imaginable source location is expounded in [1].

Correspondingly [1] the K coefficients and K are found in this way:

$$K_{п} = \frac{\rho_1 \left[h_0^{(1)}(k_1 R_0|_S) + K_{отр.} h_0^{(2)}(k_1 R_0|_S) \right]}{\rho_2 h_0^{(1)}(k_2 R_{pr}|_S)},$$

$$K_o = \frac{\left(\begin{aligned} &\rho_1 c_1 \frac{\partial R_{pr}}{\partial n} h_0^{(1)}(k_1 R_0|_S) \cdot h_1^{(1)}(k_2 R_{pr}|_S) - \\ &- \rho_2 c_2 \frac{\partial R}{\partial n} h_1^{(1)}(k_1 R_0|_S) \cdot h_0^{(1)}(k_2 R_{pr}|_S) \end{aligned} \right)}{\left(\begin{aligned} &\rho_1 c_1 \frac{\partial R_{pr}}{\partial n} h_0^{(2)}(k_1 R_0|_{S_{ГР}}) \cdot h_1^{(1)}(k_2 R_{pr}|_S) + \\ &+ \rho_2 c_2 \frac{\partial R}{\partial n} h_1^{(2)}(k_1 R_0|_S) \cdot h_0^{(1)}(k_2 R_{pr}|_S) \end{aligned} \right)}, \quad (4)$$

here

$$h_0^{(1)}(k_1 R_0) = \frac{e^{ik_1 R_0}}{R_0},$$

$$h_0^{(2)}(k_1 R_0) = \frac{e^{ik_1 R_0}}{R_0}.$$

Oscillation velocity in the arbitrary point of space would be computed accordingly such equation:

$$\overline{V}(\overline{r},t) = -grad\Phi_n(\overline{r},t).$$

Pressure in the arbitrary point would be calculated in such way:

$$P(\overline{r}) = i\omega\rho\Phi(\overline{r}).$$

Group velocity of energy propagation (transfer of energy) in the space should be determined from the formula:

$$C_{gr} = \frac{I}{\langle\omega\rangle} \quad (5),$$

where:

$I = \frac{1}{T}\int_0^T P(\overline{r}) \cdot V(\overline{r})dt$ - intensity of power stream

(average magnitude for period $T = \frac{2\pi}{\omega}$, magnitude of power stream).

$\omega = \frac{1}{2}(\rho|V|^2 + \frac{P^2}{\rho c^2})$ - full density of energy.

Fig. 2-6 represents some results of numerical reckoning of the group velocity inside W volume.

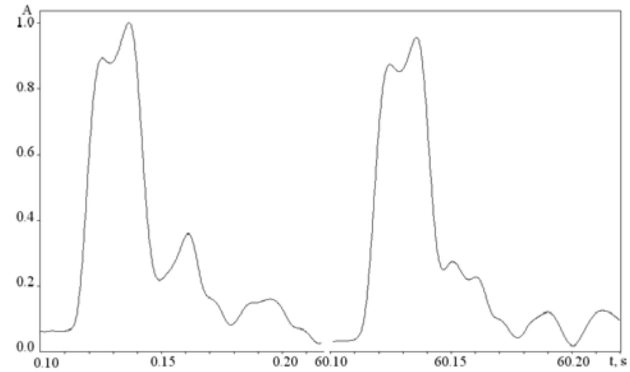


Fig.1.Dependence of pressure on time.

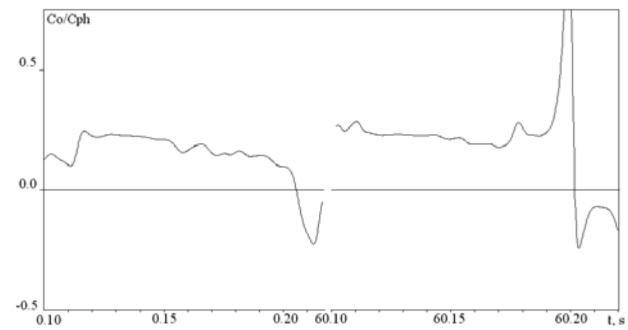


Fig.2. Dependence of phase velocity on time.

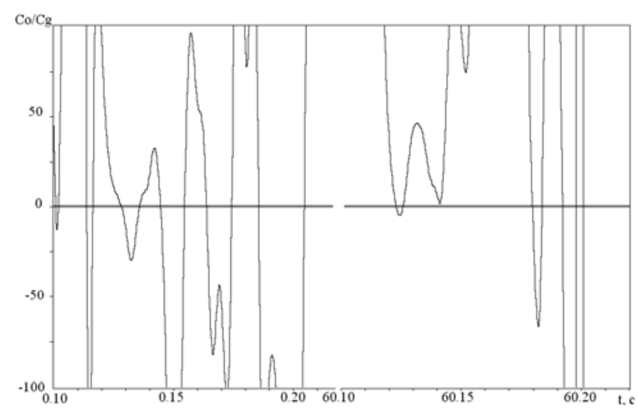


Fig.3. Dependence of group velocity on time

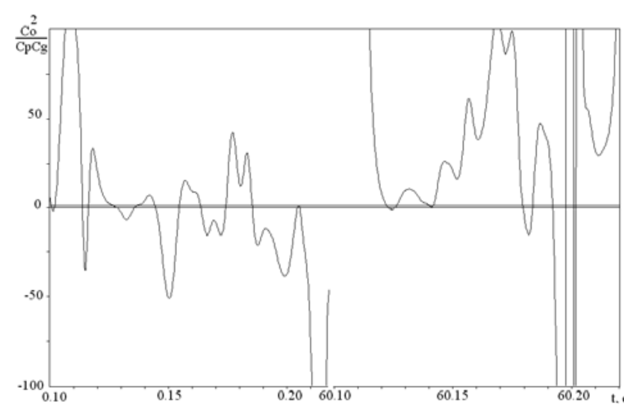
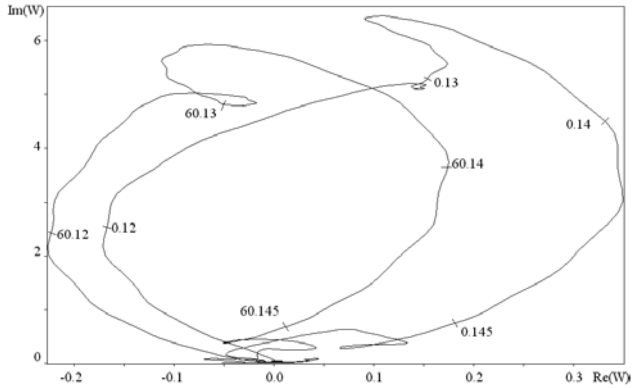


Fig.4. Dependence of multiplication of phase and group velocity on time



Fig,5.Relation between real and imagined part of power stream. Marks on curves respond to the moments of signal arrival in time.

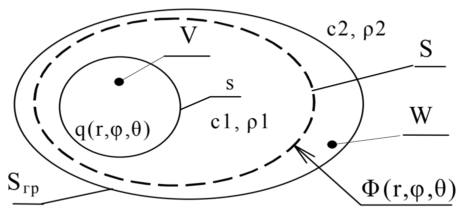


Fig.6.Geometrical scheme of task

IV. CONCLUSION

The analysis of theoretical computation of group velocity (fig. 7,8) admits to conclude the next.

In the shallow sea due to reverberation from bottom and percolation into the bottom of energy this sonic field energy disperses with different group velocity. The group velocity inside a volume can possess negative and positive magnitudes.

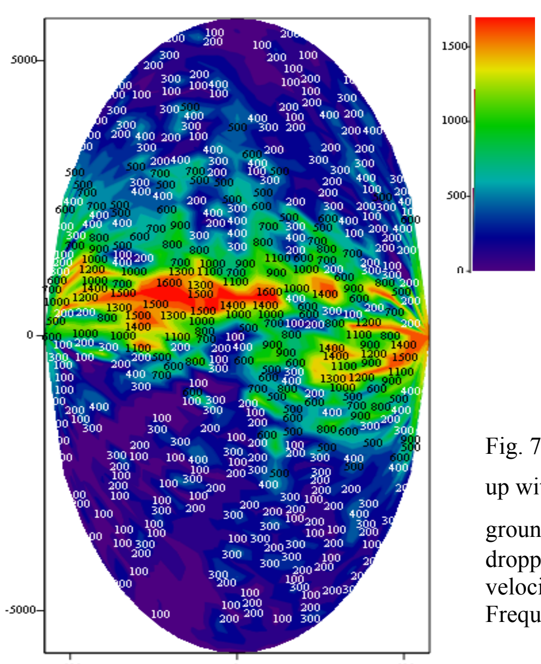
There should be remarked that in some spots of the closed volume (shallow sea) this group velocity may achieve those of phase velocity in the ground bottom. Distribution of energy stream inside of restricted volume looks like energy movement inside lens antennas. There fore in figures the restricted basin of the shallow sea we shall name term "lens" making appropriate sign of it.

The results of experimental research (fig. 1-5) structurally confirmed the theoretical computations and are close approximation to the actual conditions.

REFERENCES

1. Chuprov S.D., Maltsev N.E., Invariant of spatially frequency interference structure of acoustic field in layered ocean, *Docl. Acad. Nauk SSSR*, 257(2), 1981, pp. 475-479

2. Aksyonov S.P., Kamenev S.I., Kasatkin B.A., Some characteristics of acoustic field in the wedge lying on half-space, *Akust.Zh.*,32(5), 1986, pp. 585-590



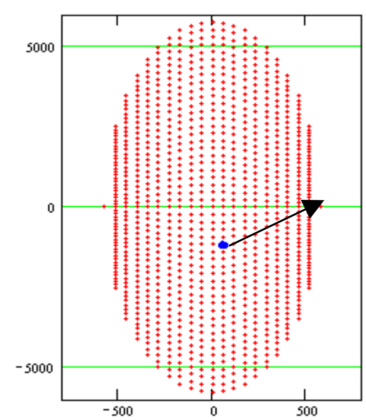


Fig. 7.Graph of the distribution of group velocity inside lens of elliptical shape filled up with water having parameters p=1000кg/ $м^3$, c=1500м/s. The outside of lens is ground with parametters p=2000 кg/ $м^3$, c=1700м/s. Angele of acoustic beam dropping onto the boundary of separation α=67 grades. Maximum values of group velocity in the lens equals: Cgr(max)=1651m/s., minimum values Cгр(min)=0.4/c. Frequency 260 Hz.

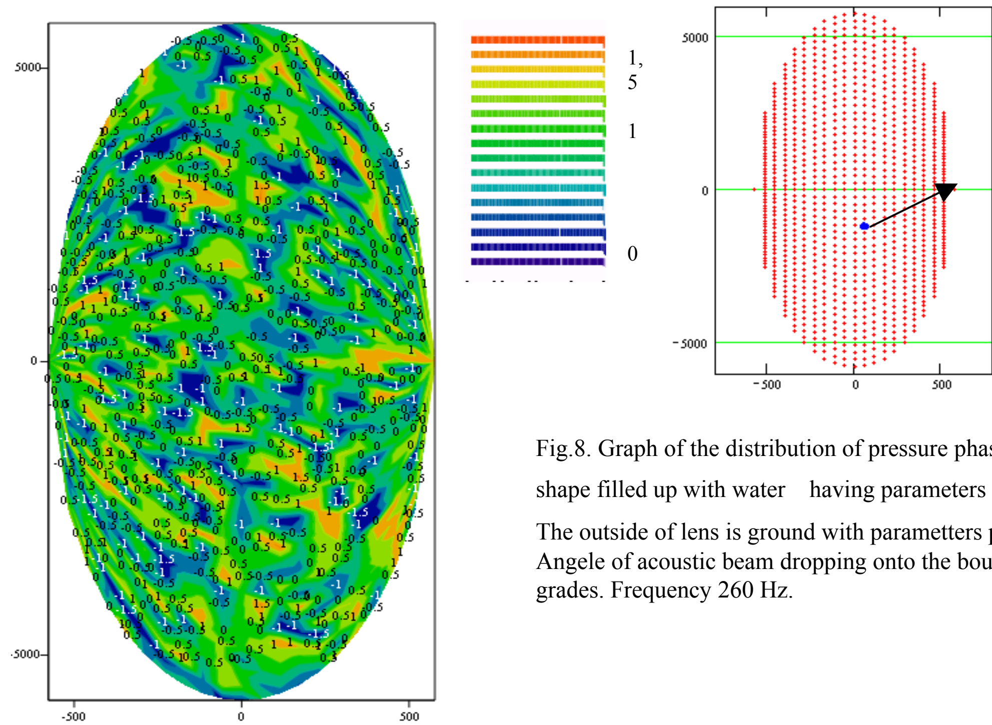


Fig.8. Graph of the distribution of pressure phase inside lens of elliptical shape filled up with water having parameters p=1000кg/ $м^3$, c=1500м/s. The outside of lens is ground with parametters p=2000 кg/ $м^3$, c=1700м/s. Angele of acoustic beam dropping onto the boundary of separation α=67 grades. Frequency 260 Hz.