A. N. Kutsenko, S.P. Tarasov

ABOUT ACOUSTIC WAVES TRANSMISSION INTERFACE EFFECTS

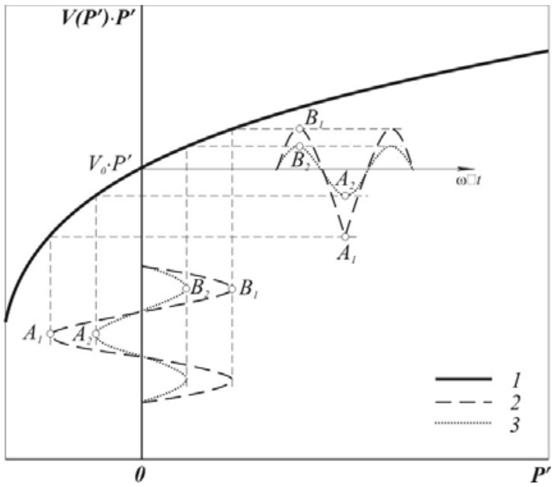
The Taganrog State Radio Engineering University
Russia, 347900 Taganrog, Nekrasovskiy 44
Tel.: (8634)-37-17-95
E-mail: egamt@fep.tsure.ru

Reflecting is investigated of simple plane pressure waves dropped to interface normally. Both mediums have different values of density, velocity of sound and non-liner parameter.

At the present time there are many works, which is devoted for studying effects of interfaces located in the nearfield of the sources for acoustic field. Parametric arrays working on the non-linear effects appeared at the wave of the finite amplitude propagation are being used in increasing frequency parallel with traditional sources. Described field theory of these arrays has studied adequately in order to predict their characteristics. However, when interfaces are being regarded near emitting surface, appearing non-liner effects, which are able to influence on the reflected field, aren't allow.

In the Ref. 1, the acoustic wave transmission across interface, where only non-linear parameter was varying and linear parameter (density and sound velocity) were being constant, was considered. It was shown that change of wave's frequency content occurred under reflecting. Under incidence to interface the level of reflecting second harmonic is 3 times less than level of second harmonic passed with signal together. General case – reflecting of plane Riemann waves incident normally to interface with different linear and non-linear parameters, in the context of the atmospheric acoustics, was considered in Ref. 2. Dynamics of various amplitude waves transmission across gas-gas interface. In this work, approaches presented in Ref. 2 will be used for hydroacoustics tasks.

Interface may be represented how quadripole having transfer characteristic determinant response character in the presence of the influence on this system. This transfer characteristic may be the function reflection coefficient value of incident wave amplitude value *V(P')* (Fig. 1). Further, reflection coefficient is the ratio of moment amplitude value of the reflected beam (not harmonics amplitude) to the moment amplitude value of the incident beam. Under transmission across quadripole (interface), non-linear transfer characteristic (curve 1) brings to onset in response (reflecting signal) harmonics, which aren't in incident wave. Thus, the reflecting coefficient, in classical conception, equals infinity for harmonics originated in quadripole (interface). It is given in Fig. 1. Reflecting wave's frequency content will insignificantly differ from incident wave frequency content under wavelet effect to interface. Amplitude rise of incident wave results in changing of response frequency content (curve 2). New harmonics are emerging in reflecting signal.



Fia. 1

We should set a problem of estimate sound pressure levels, when nonlinear dependence *V(P')* would result in changing of frequency content in reflecting wave.

Let simple wave, where disturbance is equal *P'*, is dropping to sharp interface with fluid or gas from water. Adjacent mediums will be described by constant linear parameters: equilibrium pressure P_0, density, and sound velocity c_0. State equation of these mediums is written in the form of Poisson's equation [3,4]:

$$P = \overline{P} \cdot \left(\frac{\rho}{\rho_0}\right)^n . \quad (1)$$

Here $\overline{P}$ is equilibrium pressure P_0 for gas, and for fluid – internal pressure P_* conditional cohesions; *P* for gas – pressure *P'* introduced by acoustic wave, for liquid the sum of pressure *P'* introduced by external action (this pressure includes equilibrium pressure and pressure introduced by acoustic wave) and internal pressure of fluid P_* $(P = P' + P_*)$; for gas: *n* - Poisson's adiabatic exponent equals the ratio of heat under constant pressure and volume $\gamma = {c_P}/{c_V}$, for liquid *n=Г* – the parameter characterizing deviation of adiabatic liquid compressibility from Hooke's law.

Coupling between pressure and vibrational speed inside simple wave was deduced , and it has the following form under fulfilment condition (1):

$$v = \pm \frac{2 \cdot c_0}{n-1}\left[\left(\frac{\rho}{\rho_0}\right)^{\frac{n-1}{2}} - 1\right] = \pm \frac{2 \cdot c_0}{n-1}\left[\left(\frac{P}{P_0}\right)^{\frac{n-1}{2 \cdot n}} - 1\right]. \qquad (2)$$

Using (2), it is easily to compose the transcendental equation, in case of continuity normal components of vibrational speed of particles inside wave ($v_{ПАД}$-v_{OTP}=$v_{ПР}$) and forces equality astride interface ($P'_f + P'_r = P'_p$):

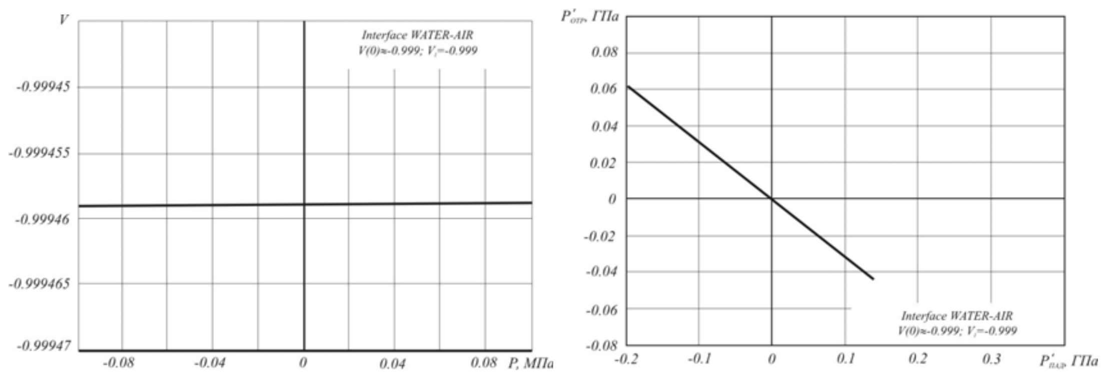
$$\frac{c_{01}}{n-1}\left[\left(1+\frac{P'_f}{P_1}\right)^{\frac{n-1}{2 \cdot n}} - 1\right] - \frac{c_{01}}{n-1}\left[\left(1+\frac{P'_r}{P_1}\right)^{\frac{n-1}{2 \cdot n}} - 1\right] = \frac{c_{02}}{m-1}\left[\left(1+\frac{P'_f}{P_2}+\frac{P'_r}{P_2}\right)^{\frac{m-1}{2 \cdot m}} - 1\right], \qquad (3)$$

Function *V(P')* ($P' = P'_f$) may be derived if equation (3) has solved. Exact solution of equation (3) find analytically impossibly. It is impossible to use the approximate methods for solution of this equation: iteration methods and graphic methods [5]. Equation (3) has been solved with iteration methods for interface fluid mediums, and for interface fluid-air (Fig. 2-4). There are relationships *V(P')* (Fig. 2 a) и *V(P')эP'* (fig. 2 б) for absolutely soft interface (fluid-air) in Fig.2. Apparently, that under heavy gradient of *ρэс* and *n* (or *m*) on interface *V* differs insignificantly from *P'*. It results in linear dependence *V(P')эP'* from *P'*. Gradient reduction of quantities indicated above reduce to relationship *V* from *P'* becomes nonlinear (Fig.3). It appreciably influences to relationship character *V(P')эP'* from *P'*. However, in both case (Fig. 2-4) under pressure amplitude is order $10^5 \Theta 10^6$ Pa relationship may be accepted linear. And we may respectively neglect nonlinear distortions introduced into reflected signal.

Equality of normal components vibrational speed of particles astride interface is usually supposed under boundary conditions consideration. It’s corollary of supposition medium continuity, where wave propagates. However, interface insertion is discontinuity of medium. Violation of condition equality of normal components vibrational speed is corollary of it, $v_{ПАД}$-v_{OTP}=$f(v_{ПР})$. Let this functional dependence is linear. Aspect ratio is *a*. Then equation (3):

$$\frac{c_{01}}{n-1}\left[\left(1+\frac{P'_f}{P_1}\right)^{\frac{n-1}{2 \cdot n}} - 1\right] - \frac{c_{01}}{n-1}\left[\left(1+\frac{P'_r}{P_1}\right)^{\frac{n-1}{2 \cdot n}} - 1\right] = a \cdot \frac{c_{02}}{m-1}\left[\left(1+\frac{P'_f}{P_2}+\frac{P'_r}{P_2}\right)^{\frac{m-1}{2 \cdot m}} - 1\right]. \qquad (4)$$

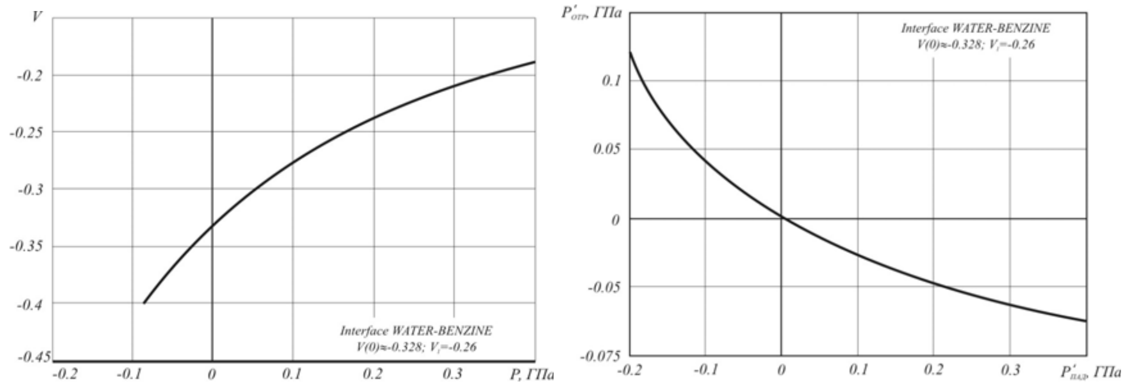
Solution of this equation is functional dependence *V(P',a)*. This dependence has been plotted for interface water-benzine (Fig. 5). Curve *V(P')* coincides practically with curve for case examined above under values *a* near one. Under value *a* decrease reflection coefficient converges to one without



a b

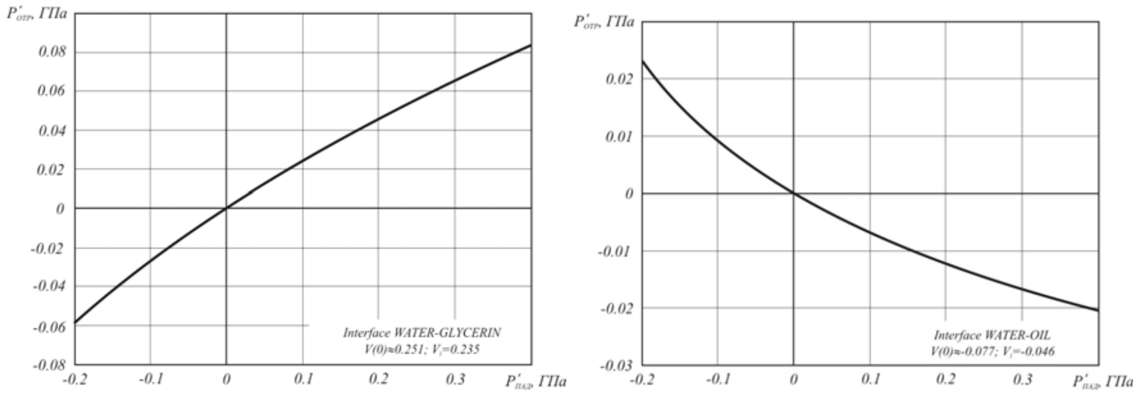
Fig. 2

dependence of amplitude incident wave. In case of interface is soft then reflection coefficient converges at first to zero next to one under decrease of coefficient a. Thus under decrease of coefficient a reflection coefficient value changes. In Ref. 6, experimental results are presented for iron plate located in nearfield parametric array and bubbles layer was generated with electrolysis on this plate. Number of bubbles and thickness bubbles layer were small in comparison with wave length. There was anomalous increase wave amplitude under reflecting from this interface in comparison with plate minus bubbles layer. Obviously, in case described in [6], nonlinear effects answers for increase reflection coefficient. It may be explained by decrease coefficient a value in the presence of bubbles layer on the plate surface in the context of approach described above. As may be seen from Fig.5, it's resulted to increase of reflection coefficient from interface.



a b

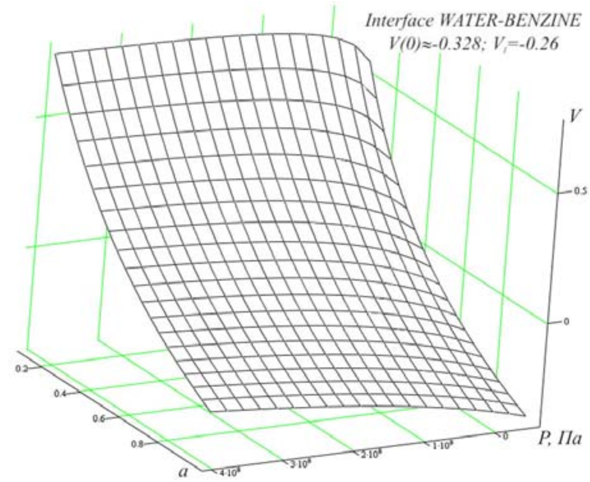
Fig. 3



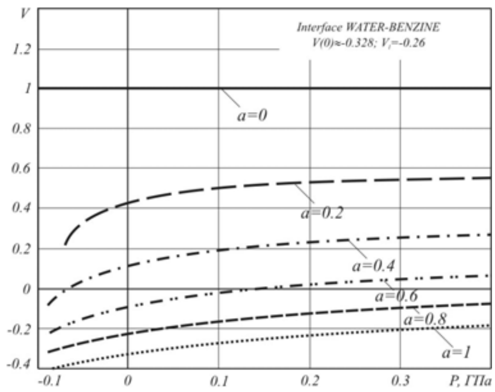
a b

Fig. 4

Nonlinear effects described above have contact interface solid-solid described in Ref. 7. fluid-solid (and it is possible on interface fluid- the coefficient a is analogue of pressing force of frequency content will be on interface fluid-solid physical nature how "flapping" nonlinearity of Changing contact square is possible on interface fluid). That is discontinuity on interface. Thus, solids contacts. Changing of reflected wave how under the case "flapping" nonlinearity.



a



b

Fig. 5

REFERENCES

1. E.N. Pelinovskii, V.E. Fridman Acoustic wave transmission through nonkinear boundary// Acoustical Physics 1983. №4. p. 569
2. Yu. V. Petukhov Effect of nonlinearity on pressure wave reflection at an interface of two media// Acoustical Physics, 1987 № 5 p. 930-932
3. O.V. Rudenko, S.I. Soluian Theoretical principles of nonlinear acoustics. Moscow, Nauka 1975 (In Russian).
4. L.K. Zarembo, V.A. Krasil'nikov Leading into nonlinear acoustics. Moscow, Nauka 1966, 520 p. (In Russian).
5. J.M. Walsh et. Al. Shock-wave compression of twenty-seven metals. Phys. Rev., 1957, v. 108, no. 2.
6. Yu.I. Kabaruhin Anomalous radiating of parametric sound source with a frontier bubbles layer// Acoustical Physics 1994 № 5 p. 846
7. I.Yu. Solodov, Chin An Vu «Claping» nonlinearity and chaos connected to oscillation of contactable boundary of solid bodies // Acoustical Physics 1993 № 5 p. 904-910