The Modeling of Gas Bubbles Behavior under the Influence of Vibration in the Conditions of Impact of Aircraft's Overloads and Weightlessness Using the Algorithmization, Programming and Analysis

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ABSTRACT

A large number of manuscripts are devoted to the study of the behavior of gas bubbles in an oscillating fluid. Most of them are experimental and associated with the determination of the steady-state equilibrium levels of gas bubbles in a fluid filling a rigid and elastic vessel located on an oscillating base. Bleich H.H was the first who gave a theoretical description of behavior of air bubbles in a vibrating fluid under terrestrial conditions. Conducted experimental studies permitted to determine the possibility of gas bubbles control moving in a fluid using vertical vibration both on Earth and under conditions of a decrease of the acceleration of gravity. However, in conducted studies, the task of a theoretical description of gas bubblescontrol moving in a fluid using vertical vibration under microgravity conditions and calculation of the optimal control moving parameters under these conditions were not set. Determination of such parameters is necessary for the implementation of technological process for degassing fuel and special fluids in power supply and life support systems of spacecraft. The paper presents analysis of results of the conducted computer modeling of the developed model of the behavior of gas bubbles in the vibrating fluid under the acceleration of gravity change using the algorithmization with subsequent programming and simulation on computer screen the behavior of gas bubbles, confirmed during the flight tests aboard of flight laboratory IL-76K, showing the principal capability of the control moving of the gas phase in a gas-fluid mixture in conditions of microgravity using the controlled vibration.

Keywords: *Vibration; Modeling; Algorithmization; Programming; Simulation; Acceleration of Gravity Change.*

INTRODUCTION

Dynamic stability and stability of many phase systems have important significances for different technological operations both in the space and on the Earth. One of them is processing of valuable with perfect physical- mechanical properties foam materials, suspensions and so on. The control by external actions is necessary for the stabilization of many phase systems, for fulfilment of different technological processes. Depending on technological process and stated problem, external actions can be mechanical, vibrating, electric, and electromagnetic and so on. On the other side, in the space the opposite task appears: the separation of different phase, for example, degassing and cleaning of the fuel or metal, crystal melt. This task is reduced to the creation of the directional displacement of the separate components in many phase system (separation). One of the possible and rational methods of solution of this problem is also the use of external actions. In the theoretical plan, an investigation of the controlled technological processes, leads to the need to study the behavior of gas bubbles under different external physical influences. Majority of them relates to the determination of the steady equilibrium levels of gas bubbles in the fluid, filling the rigid and elastic vessel, which is located on the mobile base **[1-5]**.

Theoretical description of the air bubbles in the fluid under vibration given in **[1]**.

The author, examining vibration actions on the air bubbles in the incompressible, no viscous fluid, which is located in the flat rigid vessel, obtained the conditions for floating, sinking of the bubbles of air and their fluctuations around the equilibrium level (h_{eq}):

$\alpha N < 2$

$\alpha N > 2$ **[1]**

$\alpha N = 2$

where $\alpha = \frac{3hNg}{a^2(\lambda^2 - \acute{\omega}^2)}$ **[2]**

Here, h - the level, on which is located the bubble; $\acute{\omega}$ - the vibration frequency; Ng – the vibration acceleration of vibration stand; a - the radius of bubble; λ - the frequency of the small bubble vibration of a radius a. Assuming small bubble vibration near the equilibrium level and small deformations of bubble under the vibration acting, were obtained the equation of bubble motion in the fluid, the equation of the bubble deformations and the equation for the equilibrium level, near which the bubble is fluctuated. Subsequently, in **[2]** the theoretical studies of the behavior of gas bubbles in the vibrating fluid was continued for the case of elastic vessel, viscous fluid, large gas bubbles **[3]**.

The experimental studies in this area were represented in **[4, 5]**. The carried out experiments permitted to determine the controlled displacement of gas bubbles in the fluid using the longitudinal vibration in the diapason of frequencies from ***50*** to ***800Hz*** both in the Earth and due to the conditions of the acceleration gravity decrease **[6]**. However, in the conducted investigations was not established the purpose of determination of the optimum parameters of steady displacement and retention of gas bubbles in the vibrating fluid and theoretical calculation of these parameters for the conditions of microgravity. Determination of such parameters is necessary for the realization of degassing fuel and special fluids in the power supply and life support systems of space apparatus. The paper presents analysis of results of the conducted computer modeling of the developed model of the behavior of gas bubbles in the vibrating fluid under the acceleration of gravity change using the algorithmization with subsequent programming and simulation on computer screen the behavior of gas bubbles, confirmed during the flight tests aboard of flight laboratory IL-76K, showing the principal capability of the control moving of the gas phase in a gas-fluid mixture in conditions of microgravity using the controlled vibration.

MATERIALS

For the tests of early obtained theoretical conclusions about the behavior of gas bubbles in the vibrating fluid under the acceleration of gravity decrease the cylindrical vessel from organic glass (with the dimensions of the vessel: inside diameter - ***20 mm***, a height - ***110 mm***, weight - ***90 g***) and vibration stand VEDS-10A (frequency diapason ***40-500 Hz***) with vibration acceleration ***160 cm/sec***^{2} (or ***≈16 g***) were used. The tests were conducted aboard of the fly laboratory aircraft IL-76K.

METHOD AND DEVELOPED DEVICES

The study of the gas bubbles dynamic behavior in the fluid and the control by the gas phase in the conditions, close to weightlessness, using the different types of the vibration are important for solving the number of the technological problems, connected to the needs of space technology (degassing special fluids and fuel). In connection with this, the task of the theoretical description of vibration impact on the air bubbles in the fluid was set taking into account of both the Earth's conditions and the conditions of close to the weightlessness. The theoretical description of the behavior of the air bubbles in the fluid under the influence of vibration in the Earth's conditions was given in the work **[1]**. The author, considering the vibration actions on the air bubbles in the incompressible, nonviscous fluid, which is located in the flat rigid vessel, obtained the conditions for floating, sinking and fluctuations of air the bubbles around the equilibrium level$\boldsymbol{h_{eq}}$ (1). Assuming the small bubble vibration near the equilibrium level and the small deformations of the form of bubble under the vibration action, the author, obtained the equation of the motion of bubble in the fluid, the equation of the deformations of bubble and the equation for the equilibrium level, near which the bubble oscillates:

$$\frac{d}{dt}[(a+3\Delta)\dot{\xi}] = 2(a+3\Delta)(\ddot{X}-ng_0) \qquad (3)$$

$$\Delta = \frac{\alpha}{3}\,Cos(\acute{\omega}t) \qquad (4)$$

$$h_{eq} = \frac{P_0}{\rho g\left[\frac{N^2\lambda^2}{2\nu(\lambda^2-\acute{\omega}^2)} - 1\right]} \qquad (5)$$

where ξ- the small movements of bubble near the level of $\boldsymbol{h_{eq}}$; $\boldsymbol{\nu}$ – the polytrophic constant; $\boldsymbol{g}$ - the acceleration of gravity; $\boldsymbol{X}$ - the oscillations of the table of vibration stand; $\boldsymbol{P_0}$ - the pressure above fluid air region.

In the study of the problems of mechanics in the weightlessness conditions or close to weightlessness, one of the first tasks is comparison, the estimation of the influence of different forces and the choice from them of those, which prevail over the rest. The forces acting on the vessel and the liquid in the vessel under these conditions can be divided into the following:

1) The external forces related to the aircraft or the space apparatus (remaining gravity of the Earth, the force of aerodynamic origin, geomagnetism, force, that controls of the orientation of space apparatus in space flight).
2) The force of the gravitational interaction with the elements of the construction of space apparatus and its content (self-gravitation).
3) The intermolecular forces - forces of surface tension.

Let us attempt to theoretically describe the behavior of gas bubbles in the fluid under the influence of vibration in the conditions of variable gravitational field.

Subsequently, disregarding the force of self-gravitation because of its smallness, we will consider the intermolecular force (force of surface tension) as the main force and the comparable with this force, the external to the space apparatus or the aircraft force, that can be expressed as force with the acceleration of $\boldsymbol{g = ng_0}$, where $\boldsymbol{n}$ - the amount of aircraft's overloads, $\boldsymbol{g_0 = 980\ cm/sec^2}$ - Earth's acceleration of the gravity. We will consider that the above fluid air pressure $\boldsymbol{P_0}$ is the constant (vessel is hermetically sealed), and rotary motion is absent. Then the system of the air bubble + fluid + vessel is completely described by three coordinates (figure 1). Let us place the origin of coordinate $\boldsymbol{Z}$ on the free surface of fluid. We need to find the expressions of kinetic and potential energies in order to obtain the Lagrange's equation for the considered system. Expression for the kinetic energy will be the same, what is obtained in **[1]**:

$$T = \frac{M}{2}\dot{X}^2 + 2\pi\rho_{fl}\,(a+\Delta)^3\,\dot{\Delta}^2 + \frac{\pi}{3}\rho_{fl}\,(a+\Delta)^3\,\dot{Z} - \frac{4\pi}{3}\rho_{fl}\frac{d[(a+\Delta)^3]Z}{dt}\dot{X} \quad (6)$$

where $\boldsymbol{M}$ - the common mass of system; ρ_{fl} - the density of fluid; $\boldsymbol{a}$ - the radius of bubble; $\boldsymbol{\Delta}$- the deformation of the form of bubble; $\boldsymbol{Z}$ - the displacement of bubble along the column of fluid.

Expression for the potential energy will consist:

1) From the potential of air in the bubble at the surface of fluid - $\frac{4}{3}P_0\,(a+\Delta)^3$; the potential of air in the bubble at any level - $\frac{4}{3\nu-1}\frac{P_1 a^{3\nu}}{(a+\Delta)^{3\nu-3}}$, where $\boldsymbol{P_1}$ - the pressure in the bubble at any depth in the absence of vibration, $\boldsymbol{\nu}$ - polytrophic constant.
2) From the surface tension's energy of fluid in the vessel and the surface tension's energy of the air bubble in the fluid that can be represented in the following form:

$W_1 = \pi\sigma_{12}\,(X^2+R^2)$ where $\boldsymbol{R}$ – the radius of vessel

$W_2 = 4\pi\sigma_{12}\,(a+\Delta)^2$

3) From the potential of the external forces:

$W_3 = -\,Mng_0X + \frac{4}{3}\pi n g_0 \rho_{fl} Z\,(a+\Delta)^3$

Sign "-" in the first term is caused by the fact, that $\boldsymbol{X}$ coordinate is counted from the bottom of vessel, i.e., it is opposite to the selected system of the origin of coordinate $\boldsymbol{Z}$.

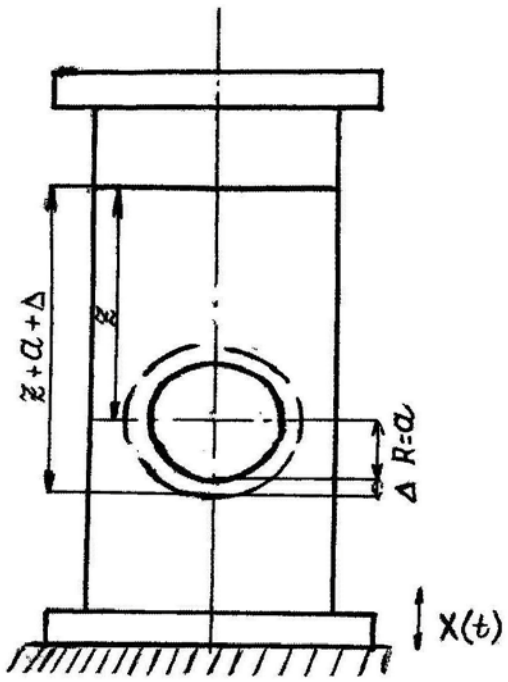

Fig. 1: Schema of the location of the "swarm" of air bubbles in the fluid in the vessel:
X - Displacement of the bottom of vessel;
Z - Position of the "swarm" of the air bubbles relative to the surface of fluid;
Δ - Deformation of the "swarm" of air bubbles.

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Thus, the expression for the potential energy will take the form:

$$W=\pi\sigma_{12}(X^2+R^2)+\frac{4}{3}\pi P_0(a+\Delta)^3(P_0+ng_0\rho_{fl}Z)+\frac{4\pi P_1 a^{\gamma}}{3(\gamma-1)(a+\Delta)^{3\gamma-3}}++4\pi\sigma_{12}(a+\Delta)^2-Mng_0X \quad (7)$$

Defining the function of Lagrange as $L = T - W$ and by substituting in the Lagrange's equation, recorded for the generalized coordinates Δ and Z, will obtain the system of the differential equations that describe the behavior of the air bubble in the fluid under the influence of the vibration:

$$\frac{d(a+\Delta)^3\dot{Z}}{dx}=2(a+\Delta)^3(\ddot{X}-ng_0);$$

$$\ddot{\Delta}+\frac{3}{2}\frac{1}{(a+\Delta)}\dot{\Delta}^2-\frac{a^{3\gamma}P1}{\rho(a+\Delta)^{3\gamma+1}}+\frac{a(ng_0-\ddot{X})^{3\gamma}P1}{(a+\Delta)}Z-\frac{\dot{Z}^2}{4(a+\Delta)}=$$

$$=-\frac{P_0}{\rho(a+\Delta)}-\frac{2\sigma_{12}}{\rho(a+\Delta)^2} \quad (8)$$

Where $\rho = \rho_{fl}$.

Replacing variable $Z \rightarrow h + \xi$, where ξ - small displacements of air bubble near the equilibrium level h, obtain:

$$\frac{d(a+\Delta)^3\dot{\xi}}{dt}=2(a+\Delta^3(\ddot{X}-ng_0);$$

$$\ddot{\Delta}+\frac{3}{2}\frac{1}{a+\Delta}\dot{\Delta}^2+\frac{P_1}{\rho(a+\Delta)}(1-(\frac{a}{a+\Delta})^{3\gamma})+\frac{ng_0-\ddot{X})}{(a+\Delta)}\xi=\frac{\ddot{X}}{(a+\Delta)}h-\frac{2\sigma_{12}}{\rho(a+\Delta)^2}+$$

$$+\frac{\dot{\xi}}{4(a+\Delta)} \quad (9)$$

If consider Δ is a small, in comparison with a radius of a, then second term in the second equation of system (9) can be disregard, and the third to decompose in the Taylor series on the argument Δ, as result, we will obtain:

$$\frac{P_1}{\rho(a+\Delta)}(1-\frac{a}{a+\Delta})^{3\gamma}=\frac{3\gamma P_1\Delta}{\rho a^2}=\lambda^2\Delta$$

The terms, that contain ξ and $\dot{\xi}$ in the second equation of system (9) can be rejected, since it is considered that $h >> \xi$. Thus, the system of equations (9) is converted to the following form:

$$\frac{d(a+3\Delta)\dot{\xi}}{dt}=2(a+3\Delta)(\ddot{X}-ng_0)$$

$$\ddot{\Delta}+\lambda^2\Delta=\frac{\ddot{X}h}{a}-\frac{2\sigma_{12}}{\rho a^2} \quad (10)$$

Solving the second equation, taking into account that $\ddot{X}=Nng_0\,Cos(\acute{\omega}t)$, where N - The vibration acceleration of vibration stand, and $\acute{\omega}$ - the vibration frequency, we will obtain:

$$\Delta=\frac{\alpha}{3}aCos(\acute{\omega}t)-\frac{2\sigma_{12}}{\rho a^2\lambda^2} \quad (11)$$

Where, $\alpha=\frac{3Nng_0h}{a^2(\lambda^2-\acute{\omega}^2)}$ (12)

The equation (11) considers the influence of the forces of the surface tension $\frac{2\sigma_{12}}{\rho a^2\lambda^2}$ in contrast to equation (4), obtained in **[1]**.

Thus, if we consider the forces of surface tension, what is necessary for the conditions, close to weightlessness, and then the deformation of bubble (Δ) in the weightlessness conditions under the influence of vibration will be less than in the Earth's conditions. Substituting (11) to the first equation of system (10), after integration, we will obtain:

$\xi = \frac{ng_0}{a+3\Delta}\int[a(\alpha N-2)+\frac{12\sigma_{12}}{\rho a^2\lambda^2}]\, dt + \int\{2[a(N-\alpha)-\frac{6\sigma_{12}N}{\rho a^2\lambda^2}]\ Cos\ (\acute{\omega}t) + \alpha aNCos\ (2\acute{\omega}t)\}\ dt + const.$ ***(13)***

Since $\frac{1}{a+3\Delta}$ - is the periodic function and since Δ changes periodically, ξ will also be periodic function, if

$a(\alpha N-2) + \frac{12\sigma_{12}}{\rho a^2\lambda^2} = 0$ ***(14)***

Hence, using (3.1.12), we will obtain the general equation for the equilibrium level h_{eq}:

$h_{eq} = \frac{P_0}{\rho n g_0[\frac{N^2\lambda^2}{2v\left(1-\frac{6\sigma_{12}}{\rho\lambda^2a^3}\right)(\lambda^2-\acute{\omega}^2)}-1]}$ ***(15)***

The equation (15) passes to the equation for equilibrium level (5), if we n make equal ***1***, and by the force of surface tension (σ_{12}) disregard (Earth's case).

On the basis of equation (3.1.14), then the conditions for floating, sinking and fluctuations around the equilibrium level of gas bubble or the "swarm" of bubbles in the variable gravity, will take the following form:

$a(\alpha N-2) + \frac{12\sigma_{12}}{\rho a^2\lambda^2} < 0$ - bubble's floating;

$a(\alpha N-2) + \frac{12\sigma_{12}}{\rho a^2\lambda^2} > 0$ - bubble's sinking;

$a(\alpha N-2) + \frac{12\sigma_{12}}{\rho a^2\lambda^2} = 0$ -bubble's fluctuations around the equilibrium level.

On the basis obtained equation (15) was developed the computer program, which numerically simulate the dependence of the equilibrium level on the amount of **g**-force(n)and of frequency of vibration ω that act on entire system, and simulated the behavior of gas bubble or of the bubbles "swarm" on the computer screen.

The equation (15) was converted to the new form, in which the dependence of the equilibrium level h_{eq} on the amount of g-force (n) and vibration frequency became explicit, since, λ^2 in the equation (15) equal $\frac{3vP_1}{\rho a^2}$, and $P_1 = P_0 + \rho_{fl}\, ng_0\, h_{eq}$.

For this purpose λ^2 was substituted as $\frac{3v\,(P_0+\rho ng_0 heq)}{\rho a^2}$ in the equation (3.1.15) and obtained equation was resolved relatively to the root of h_{eq}.

As a result, the equation for calculation of h_{eq} appears as follows:

$h_{eq} = (-1)\,(K_2/2K_1) - (\sqrt{K_2{}^2 - 4K_1K_3}\,)\,/\,2K_1$ ***(16)***

Where

$K_1 = 9\rho_{fl}{}^2 a\, n^3 g_0{}^3 (N^2 - 2);$

$K_2 = 6\rho_{fl}\, n\, g_0{}^2 (3P_0\, a\, (N^2 - 2) + 6\,\sigma_{12} + \rho_{fl}\, a^3\omega^2);$

$K_3 = 3ng_0\,(2P_0\,(6\sigma_{12} + \rho_{fl}\, a^3 + \omega^2) - 4\rho_{fl}\, a^2\, \sigma_{12}\, \omega^2 - \rho_{fl}\, a^3 P_0);$

$P_0 = \rho_{air}\, ng_0 L$

Here, ρ_{fl} - the water density, equal ***1 g/cm³***; a -the radius of bubble or "swarm" of the air bubbles; g_0 - the Earth's acceleration of gravity, equal ***980 cm/sec²***; N - the vibration acceleration of the vibration stand, equal ***150 m/sec²*** or ***15000 cm/sec²***; ω - the vibration frequency; $\boldsymbol{n}$ - the amount of $\boldsymbol{g}$-force; ρ_{air} - the air density, equal ***0.00019 g/cm³*** and $\boldsymbol{L}$ - the above liquid air column height in the vessel, accepted in the calculations as ***2 cm***.

The computer program, which numerically calculates in accordance to (16) the dependence of the equilibrium level h_{eq} on the amount of $\boldsymbol{g}$-force ($\boldsymbol{n}$) and frequency of vibration ω that act on the entire system: “swarm” air bubbles + fluid + vessel, was developed.

Here, the radius of air bubble or “swarm” of air bubbles $\boldsymbol{a}$, was equal ***0.55 cm***, the value of $\boldsymbol{g}$-force, was equal $\boldsymbol{29.40\ cm/sec^2}$ (or ***0.03un.***). As constants were ρ_{fl} - the water density, equal $\boldsymbol{1\ g/cm^3}$, g_0 - the Earth’s acceleration of gravity, equal $\boldsymbol{980\ cm/sec^2}$, $\boldsymbol{N}$ - the vibration acceleration of vibration stand, equal $\boldsymbol{150\ m/sec^2}$ or $\boldsymbol{15000\ cm/sec^2}$, ρ_{air}- the air density, equal $\boldsymbol{0.00019\ g/cm^3}$ and $\boldsymbol{L}$- the above liquid air column height in the vessel, accepted by ***2 cm***.

Figure 2 depicts the printout of the program’s constants and data input. Figure 3 depicts the printout of the program of the numerical simulation of the dependence of the equilibrium level of h_{eq} of air bubble or “swarm” of air bubbles, by a radius ***0.55 cm***, by the volume $\boldsymbol{0.7\ cm^3}$, on the frequency of vibration in the range of frequencies ω from $\omega = 18\ Hz$ to ***540 Hz*** by step of ***18 Hz*** under $\boldsymbol{g}$-force of $\boldsymbol{n}$, equal $\boldsymbol{29.40\ cm/sec^2}$ (or ***0.03 un.***)

For simulation of the behavior of air bubble or “swarm” of air bubbles in the vibrating fluid under aircraft’s overloads and microgravity on the personal computer screen the animation program, carried out on computer language Turbo C, was made.

To enter data into the animation program, in computer program, which numerically calculates in accordance to (16) the dependence of the equilibrium level heq on the amount of g-force (n) and frequency of vibration ω, that act on the entire system: “swarm” air bubbles + fluid + vessel, was provided record into file “VG0”total number (MI)of pairs of vibration frequencies and their corresponding equilibrium levels, the value of g-force(N1), volume ofair bubble or “swarm” of air bubbles (VOL), pairs of vibration frequencies and their corresponding equilibrium levels.

The sequence of starting of calculation program, of writing one file into a folder containing an animation program, reading data from one file with this program, and the synchronous animation of the behavior of air bubble or “swarm” of air bubbles in the vibrating fluid and of the trajectory of a flying laboratory IL-76K under aircraft’s overloads and microgravity on the computer screen was carried out by launching a virbo.bat file with the following contents:

@echo off
tbvibro - calculation program
tcvibro - animation program

The equation (15) shows that with $n \to 0$, $h_{eq} \to$ to the infinity, and since the column of liquid is limited by the bottom of vessel, then with $n \to 0$, we will obtain $h_{eq} \to L$, where $\boldsymbol{L}$ - the column of liquid height in the vessel.

Thus, the air bubble or “the swarm” of air bubbles, which is oscillated near the steady equilibrium level, under the influence of vibration, in the case of decreasing of the acceleration of gravity $\boldsymbol{g}$ from $g = 980\ cm/sec^2$ to $g = 0$ (or $n = 1$ ***un.*** to $n = 0$), has to descend in the direction to the bottom of vessel and reach it at $g = 0$.

Figure 4 demonstrates the frames (stills) of the developed animation computer program work, simulating the behavior of gas bubble in the fluid under the influence of vibration with a constant frequency of ***108 Hz***. and the constant vibration acceleration ***16***, in the conditions of the acceleration of gravity decrease from ***g = 980 cm/sec²*** (***n = 1un***) to ***g = 29.40 cm/sec²*** (***n = 0.03***).

From the equation (15) it is seen, that, just as in the Earth case, with the decrease of the frequency of vibration (***ώ***), the equilibrium level (h_{eq}) increases (direction of equilibrium level is counted from the free surface of fluid to the bottom of vessel) and the "swarm" of bubbles descends, and with an increase of the frequency of vibration (***ώ***), equilibrium level (h_{eq}) decreases and the "swarm" of bubbles rises.

Consequently, just as the Earth's case, the "swarm" of bubbles in the fluid under the weightlessness conditions can be controlled by using a change of the frequency of vibration (***ώ***), and, obtained equation (15) makes it possible with the calculated accuracy.

Figure 5 demonstrates the frames-stills of the developed animation computer program work, simulating the raising of gas bubbles with an increase of the vibration frequency from ***216 Hz*** to ***414 Hz***, with the constants vibration acceleration ***16*** and the acceleration of gravity ***g = 29.40 cm/sec²*** (***n= 0.03 un.***).

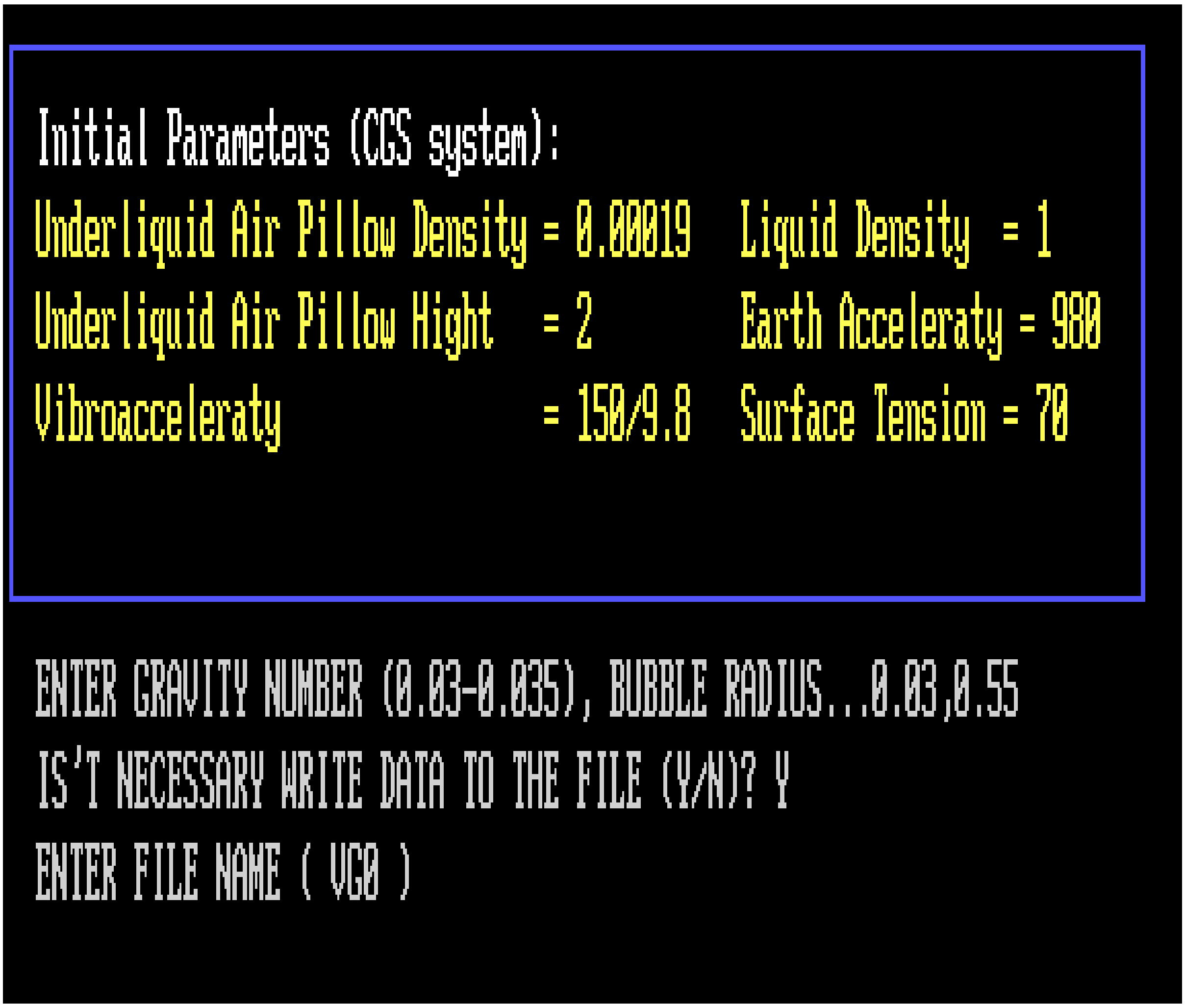

Fig. 2: Printout of the program data input

H Level	Frequentcy	Gravity	Volum
-0.3168	18.00	29.40	0.697
-0.6049	36.00	29.40	0.697
-0.9028	54.00	29.40	0.697
-1.2103	72.00	29.40	0.697
-1.5275	90.00	29.40	0.697
-1.8545	108.00	29.40	0.697
-2.1915	126.00	29.40	0.697
-2.5387	144.00	29.40	0.697
-2.8962	162.00	29.40	0.697
-3.2644	180.00	29.40	0.697
-3.6434	198.00	29.40	0.697
-4.0334	216.00	29.40	0.697
-4.4346	234.00	29.40	0.697
-4.8471	252.00	29.40	0.697
-5.2711	270.00	29.40	0.697
-5.7070	288.00	29.40	0.697
-6.1547	306.00	29.40	0.697
-6.6145	324.00	29.40	0.697
-7.0866	342.00	29.40	0.697
-7.5711	360.00	29.40	0.697

H Level	Frequentcy	Gravity	Volum
-8.0682	378.00	29.40	0.697
-8.5780	396.00	29.40	0.697
-9.1008	414.00	29.40	0.697
-9.6367	432.00	29.40	0.697
-10.1857	450.00	29.40	0.697
-10.7482	468.00	29.40	0.697
-11.3242	486.00	29.40	0.697
-11.9138	504.00	29.40	0.697
-12.5172	522.00	29.40	0.697
-13.1345	540.00	29.40	0.697

H Level	Frequentcy	Gravity	Volum
-8.0682	378.00	29.40	0.697
-8.5780	396.00	29.40	0.697
-9.1008	414.00	29.40	0.697
-9.6367	432.00	29.40	0.697
-10.1857	450.00	29.40	0.697
-10.7482	468.00	29.40	0.697
-11.3242	486.00	29.40	0.697
-11.9138	504.00	29.40	0.697
-12.5172	522.00	29.40	0.697
-13.1345	540.00	29.40	0.697

Fig. 3: Printout of the program of the numerical calculation of the dependence of theequilibrium level h_{eq} of the air bubble or "the swarm" of the air bubbles witha radius of 0.55 cm, by the volume of 0.7 cm^3, on the frequency of vibration in the range of the frequencies of vibration from ω = 18 Hz to 540 Hz with the step 18 Hz under the value aircraft overloads (g-force) n, equal 29.40 cm/sec^2 (or 0.03 un.).

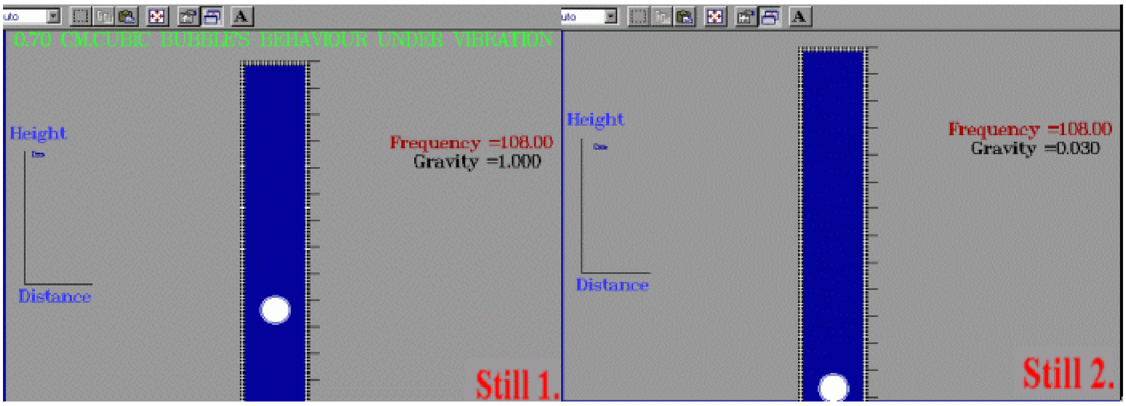

Fig. 4: The frames-stills of the developed animation computer program work, simulating the gas bubble behaviour in the fluid under the influence of vibration with a constant frequency of 108 Hz. and the constant vibration acceleration 16 in the conditions of the acceleration of gravity decreasefromg = 980 cm/sec² (n = 1un.) to g = 29.40 cm/sec^2(n = 0.03).

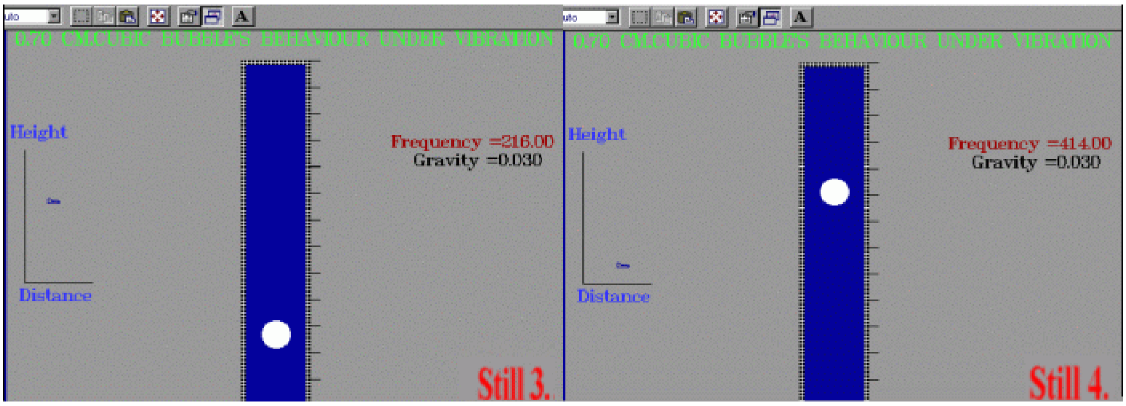

Fig. 5: The frames-stills of the developed animation computer program work,simulating the rising gas bubbles with an increase of the vibrationfrequency from 216 Hz to 414 Hz at the constants vibration acceleration16 and the acceleration of gravity g = 29.40 cm/sec² (n= 0.03 un.).

RESULTS

The flight tests were conducted aboard of flying laboratoryof the flying laboratory IL-76K**[7].** The obtained theoretical resultthat air bubble or "the swarm" of air bubbles, which is oscillated near the steady equilibrium level, under the influence of vibration, in the case of decreasing of the acceleration of gravity ***g*** from ***g = 980 cm/sec²*** to ***g = 0*** (or ***n = 1 un.*** to ***n = 0***), has to descend in the direction to the bottom of vessel and reach it at ***g = 0***was experimentally proved during the flight tests. Figure 6 illustrates the frames of filming of a results of flight tests that show the dependence of the positions of the equilibrium level of gas bubbles on the conditions of the acceleration of gravity decreasefrom ***g = 980 cm/sec ²*** to ***g = 0*** with the constant frequency of vibration ***108 Hz*** and the constant vibration acceleration ***16,*** corresponding tofigure 4. In the case of the acceleration of gravity increase, the "swarm" of bubbles must displace upward towards to the free surface of fluid, and if the amount of the acceleration of gravity reaches ***2 units***, then "swarm" must rise to the level two times higher. Figure 7 illustrates the frames of filming of a results of flight tests that show the dependence of the positions of the equilibrium level of gas bubbles on the conditions of the acceleration of gravity increasefrom ***g = 980 cm/sec²*** to ***g = 1323 cm/sec²*** with the constant frequency of vibration ***108 Hz***. and the constant vibration acceleration ***16***. The obtained theoretical result that the "swarm" of bubbles in the fluid under the weightlessness conditions can be controlled by using a change of the frequency of vibration (*ώ*), and, obtained equation (15) makes it possible with the calculated accuracy was experimentally proved during the flight tests of the flying laboratory IL-76K. Figure 8 illustrates the frames of filming, obtained as a result of the flight tests, that show raising gas bubbles with an increase of the vibration frequency from ***216 Hz*** to ***414 Hz***, at the constants vibration acceleration ***16*** and the acceleration of gravity ***g = of 29.40 cm/sec²*** (***n= 0.03 un.***), corresponding to figure 5.

CONCLUSION

Thus, the analysis of results of the conducted computer modeling of the developed model of the behavior of gas bubbles in the vibrating fluid under the acceleration of gravity change using the algorithmization with subsequent programming and simulation on computer screen the behavior of gas bubbles, confirmed during the flight tests aboard of flight laboratory IL-76K, showed theoretical dependence of the position of the equilibrium level of gas bubbles in the vibrating fluid on the overloads in theinterval from ***n = 2 un*** to ***n = 0*** and the principal capability of the control moving of the gas phase in a gas-fluid mixture in conditions of microgravity using the controlled vibration.

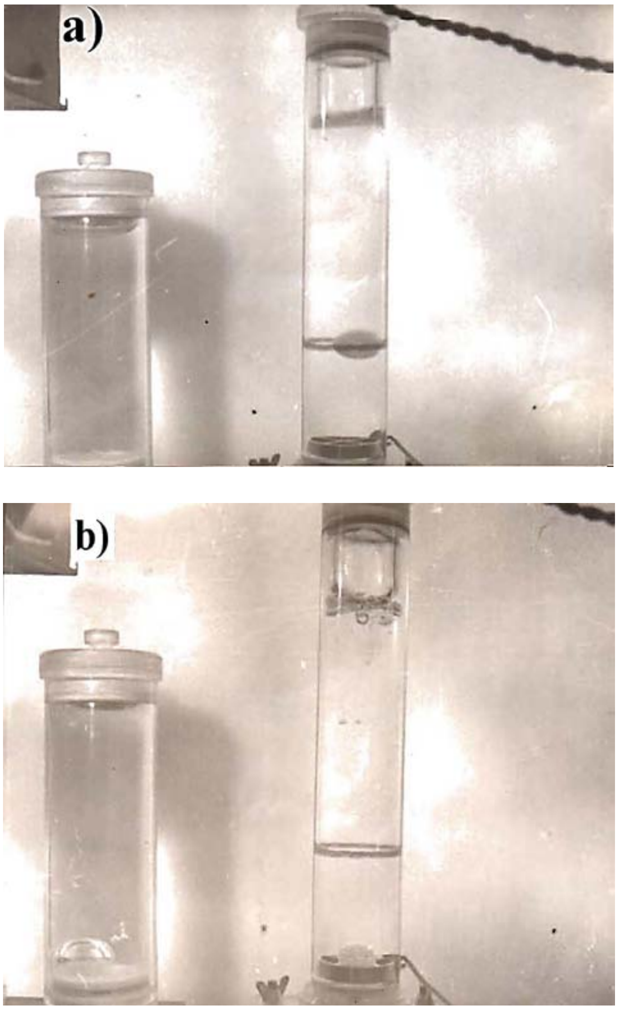

Fig.6: Frames of filming of results of flight tests that show the dependence of the Positions of the equilibrium level of gas bubbles on the conditions of decrease of the acceleration of gravity from g = 980 cm/sec² to g = 0 with the constant Frequency of vibration108 Hz and the constant vibration acceleration 16
a) - g = 980 cm/sec²; b) - g = 0

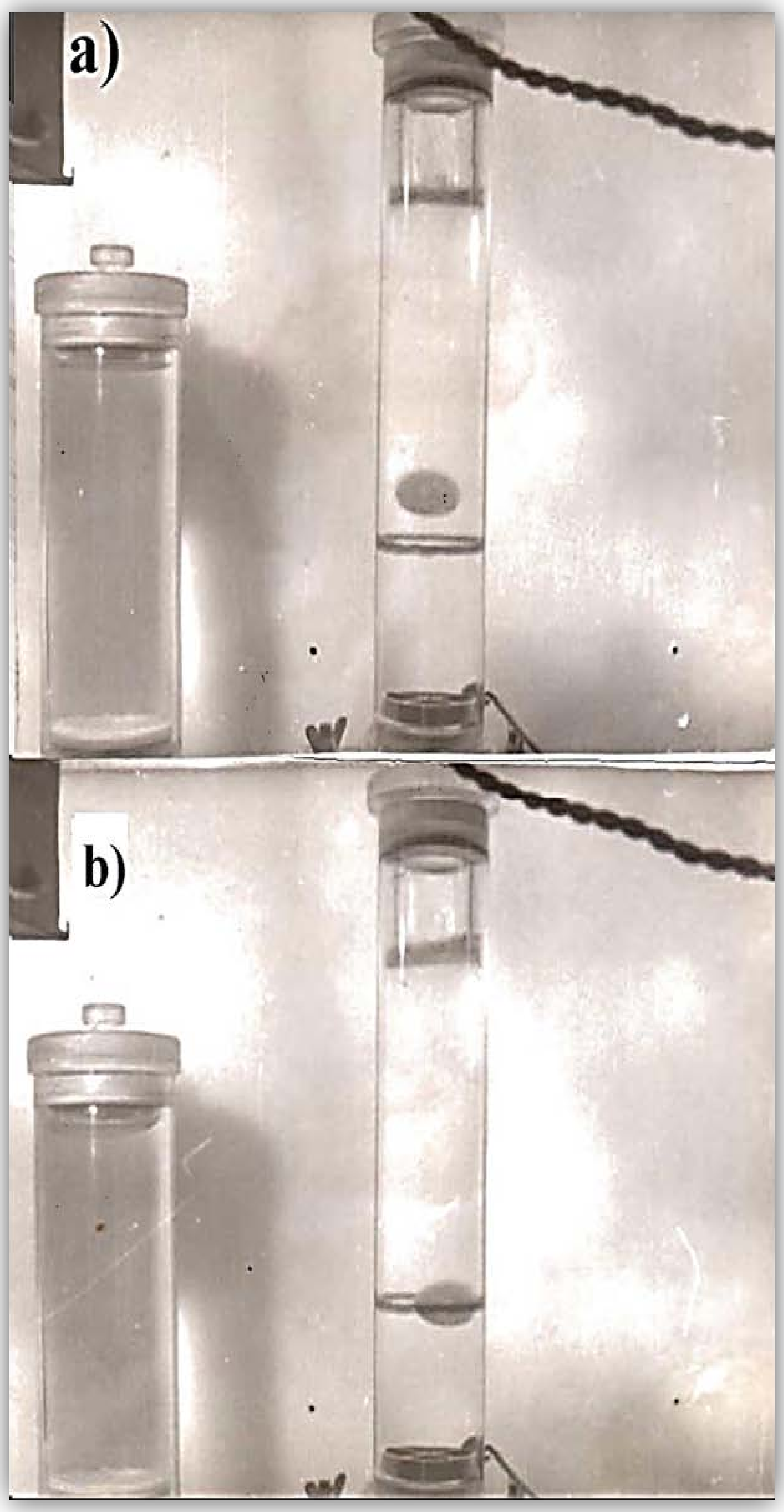

Fig. 7: Frames of filming of a results of flight tests that show the dependence of the positions of the equilibrium level of gasbubbles on the conditions of an increase of the acceleration ofgravity from g = 980 cm/sec² to g = 1323 cm/sec² with theconstant frequency of vibration 108 Hz. and the constantvibration acceleration 16. a) g = 1323 cm/sec² (n = 1.35 un), b) g = 980 cm/sec² (n = 1 un).

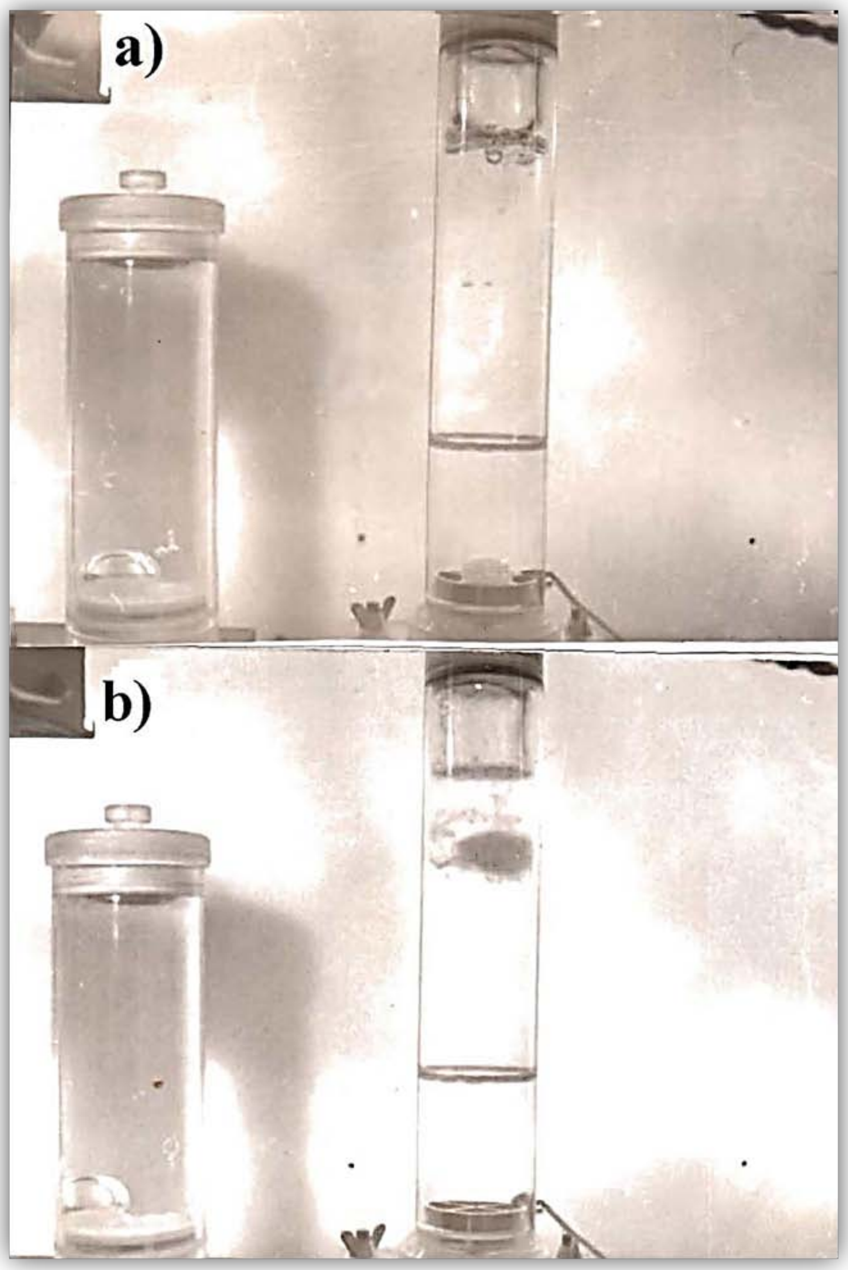

Fig. 8: Frames of filming, obtained as a result of the flight tests that show raising gas bubbles with an increase of the vibration frequencyfrom 216 Hz to 414 Hz, at the constants vibration acceleration 16and the acceleration of gravity g = of 29.40 cm/s ² (n= 0.03 un.). a) ώ = 216 Гц, b) ώ = 414Гц.

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