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Acoustic Fields and Microstreams Simulation in Ultrasonic Clearing Baths

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Introduction

High quality of electron-optical devices and systems in many respects defines functionality of difficult radio-electronic complexes, laser systems of detection, fiber-optical communication systems, medical equipment, cinemaphotoequipment and instrumentations. In these products cleanliness of a surface of optical details and electronic modules has great value. At any accuracy of processing the minimum quantity of extraneous substances on working surfaces does not allow to receive demanded optical and electric characteristics that conducts to marriage increase, equipment refusals while in service, to reception of doubtful data. The analysis of causes of failures of products shows, that their fourth part is necessary on a share of bad quality of clearing of surfaces [1]. Manual clearing by organic solvents led to a marriage significant amount, a traumatism, emissions of steams of solvents in atmosphere and to environmental contamination. The chlorinated hydrocarbons are toxic, possess cancerogenic and mutagen influence, form a smog and recycling of a waste by a burial place method demand. Hladons destroy an ozone layer and strengthen a hotbed effect. Environmental problems have caused heightened interest to processes and devices of ultrasonic clearing of electronic and electron-optical products. The problem of creation of new safe washing compositions on the basis of water solutions of the surface-active substances (SAS), capable to clear microrelief surfaces from pollution is rather actual.

Influence ultrasonic (US) of fields on liquid environments causes in them processes of cavitation, and also macro-and microstreams in volume of the liquid adjoining to the radiated surface of a bath. Close cavitation gas cavities it is accompanied by formation of shock microwaves which destroy not only oxide films and pollution on a processed surface of products, but also in certain degree change morphology of a surface [2]. Micro - and macrostreams in interfaces promote removal of pollution and acceleration of process of clearing of microrelief surfaces. An actual problem is optimization of parametres of an ultrasonic field in baths of group processing, an establishment of laws of physical and chemical processes of clearing profile and microrelief surfaces of optical and electronic modules in liquid washing environments at frequency and phase modulation US of a signal.

Simulation of ultrasonic field pressure distribution

Influence ultrasonic (US) fields on liquid environments causes in them processes of cavitation, and also macro-and microstreams in volume of the liquid adjoining to the radiated surface of a bath. Close of cavitation gas cavities it is accompanied by formation of shock microwaves which destroy not only oxide films and pollution on a processed surface of products, but also in certain degree change morphology of a surface [2]. Micro - and macrostreams in interfaces promote removal of pollution and acceleration of process of clearing of microrelief surfaces. An actual problem is optimization of parametres of an ultrasonic field in baths of group processing, an establishment of laws of physical and chemical processes of clearing profile and microrelief surfaces of optical and electronic modules in liquid washing environments at frequency and phase modulation US of a signal.

$$\frac{1}{\rho_0 c_w^2}\frac{\partial^2 p}{\partial t^2}=\frac{\partial}{\partial x}\left(\frac{1}{\rho_0}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\rho_0}\frac{\partial p}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{1}{\rho_0}\frac{\partial p}{\partial z}\right)=0; \quad (1)$$

where ρ_0 - density of the liquid environment; p - pressure; c_w - speed of distribution US in the environment; t - time; x, y, z - coordinates.

$$\mathbf{n}\cdot\left(\frac{\partial}{\partial x}\left(\frac{1}{\rho_0}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\rho_0}\frac{\partial p}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{1}{\rho_0}\frac{\partial p}{\partial z}\right)\right)=0, \qquad (2)$$

$$P_A = p_0 \sin(wt) + p_0 \sin([w \pm 100]t); \qquad (3)$$

$$P_B = p_0 \sin(wt + 4/6\pi) + p_0 \sin([w \pm 100]t + 4/6\pi); \qquad (4)$$

$$P_B = p_0 \sin(wt + 2/6\pi) + p_0 \sin([w \pm 100]t + 2/6\pi). \qquad (5)$$

At the initial moment of time equality of pressure was necessary to zero $p(x,y,z)=0$. The equation (1) dared taking into account boundary conditions (2-5) and by means of applied program COMSOL for various variants of an arrangement US of converters at the bottom of a bath [4]. Conditions of an impedance of a surface of the object shipped in a bath:

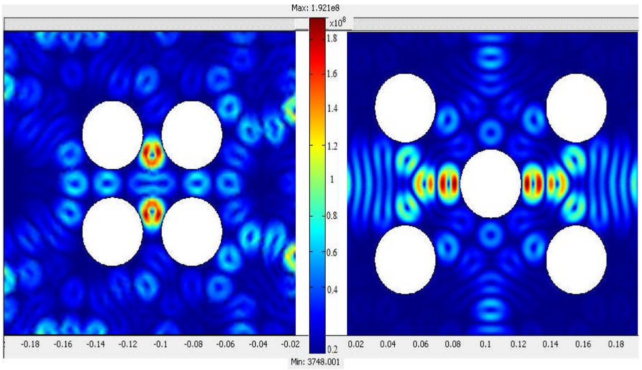
$$n(-(1/p_0)(vp - q)) - iwp/Z = 0 \ , \qquad (6)$$

where n – number of walls of a bath, reflexion q-factor, Z – acoustic impedance.

Condition of reflexion of fluctuations from a bath wall:

$$n(1/p_0(vp - q)) = 0 \ . \qquad (7)$$

Modeling in baths with the radiators distributed on the area has shown US of pressure, that the maximum amplitude of change of pressure US waves is observed at a surface of radiators and on the distances equal 4 λ. More uniform US the field on volume of a bath as a result of superposition of waves is created for an arrangement of radiators in knots of a lattice of triangular structure with length of the party, multiple $\lambda/\sqrt{3}$ (Fig. 1).



a b

Fig. 1. Distribution US pressure on the bath area with linear radiators arrangement (a) and triangular structure (b)

US of pressure in bath volume influences distribution presence at the liquid environment of firm bodies which certain degree reflect US waves. Stronger influence on distribution of pressure the cartridge with the details, located on distance, multiple λ from a bath bottom (Fig. 2). At the expense of reflexion from surfaces of details US pressure in adjoining layers of a liquid increases.

The important indicator is non-uniformity cavitation pressure in a bath. It should be minimum. At entering of the cartridge because of reflexions of waves from its surface non-uniformity cavitation pressure increases (Fig. 3).

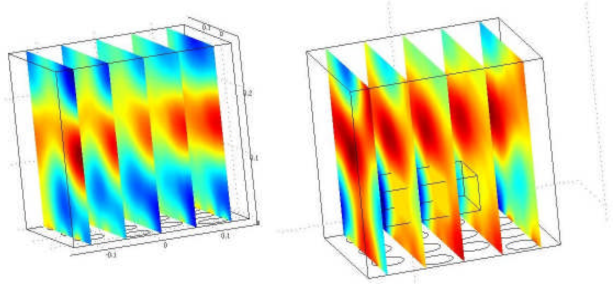


Fig. 2. Distribution US of pressure in a bath: without cartridge (1) and with the cartridge (2)

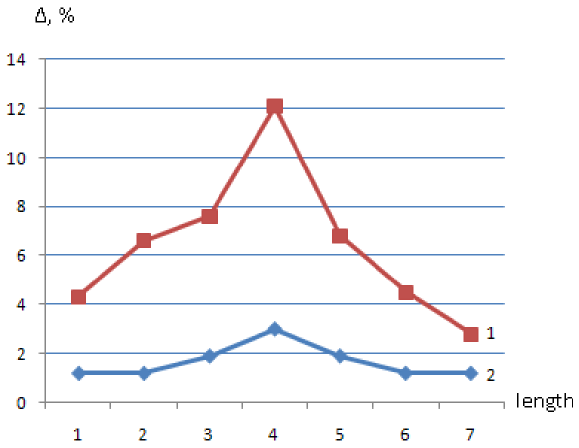


Fig. 3. Non-uniformity cavitation pressure in a bath with the cartridge (1) and without it (2)

Simulation of speed and direction acoustic micro streams

In the closed volume of the liquid environment limited to rigid walls, there is a standing wave, and near to the walls parallel to a direction to distribution of a wave, the gradient of speeds defined by a boundary condition of equality to zero of speed on a rigid surface is created. Indignation of a wave in view of surface presence extends on the distance equal to a thickness of an acoustic interface $\delta=(2v/\omega)^{\frac{1}{2}}$. At a direction of fluctuations on co-ordinate X and absence of walls the standing wave has to one component of speed $\vartheta_x^{(1)}=\vartheta_0 \cos kx \cos\omega t$. In the presence of rigid walls with co-ordinates $y=0$ и $y=2y_1$ In speed of a wave appears a component $\vartheta_y^{(1)}$. Values receive a component of speed as the decision of the first approach with a boundary condition $\vartheta=0$ at $y=0$ in interval of $0\le y\le y_1$ in a kind:

$$\vartheta_x^{(1)}=\vartheta_0 \cos kx\left[-\cos \omega t+e^{-\mu}\cos(\omega t-\mu)\right]; \ (8)$$

$$\vartheta_y^{(1)}=\vartheta_0\frac{k_\delta}{\sqrt{2}}\sin kx\left[\left(1-\frac{\mu}{\mu_1}\right)\cos\left(\omega t-\frac{\pi}{4}\right)-e^{-\mu}\cos(\omega t)-\frac{\pi}{4}-\mu\right]; \ (9)$$

where $\mu = y/\delta; \mu_1 = y_1/\delta$. The decision (9) is fair at performance of conditions $k\delta << 1; y_1 >> \lambda$.

As it is possible to consider a field of speeds of the first approach close to sinusoidal substitution of the decision (9) allows to receive expression for x component of an acoustic current:

$$\vartheta_x^{(1)} = \frac{\vartheta_0^2}{4c_0}\sin 2kx\left[\frac{1}{2}e^{-2\mu} + e^{-\mu}\cos\mu + 2e^{-\mu}\sin\mu + \frac{3}{4} - \frac{9}{4}\left(1-\frac{\mu}{\mu_1}\right)^2\right]; \qquad (10)$$

$$\vartheta_y^{(1)} = \frac{\vartheta_0^2}{8c_0}k\delta\cos 2kx\left\{\frac{1}{2}e^{-2\mu} + 3e^{-\mu}\cos\mu + e^{-\mu}\sin\mu + \frac{3}{2}\mu_1\left[\left(1-\frac{\mu}{\mu_1}\right) - \left(1-\frac{\mu}{\mu_1}\right)^3\right]\right\}. \qquad (11)$$

The decision (10 and 11) approximately satisfies to boundary conditions and is inapplicable in immediate proximity from a rigid wall. Far from this wall it is possible to neglect the small members containing $e^{-\mu}$, Therefore decisions (10) and (11) becomes simpler:

$$\vartheta_x^{(2)} = -\frac{3\vartheta_0^2}{16c_0}\sin 2kx\left[1-3\left(1-\frac{\mu}{\mu_1}\right)^2\right], \qquad (12)$$

$$\vartheta_y^{(2)} = -\frac{3\vartheta_0^2}{16c_0}ky_1\cos 2kx\left[\left(1-\frac{\mu}{\mu_1}\right)-\left(1-\frac{\mu}{\mu_1}\right)^3\right]. \qquad (13)$$

Rayleigh's current as well as Ekkart, is an interface current. Character of lines of a current, shows, that is average scale with alternating through $\lambda/4$ Whirlwinds with opposite directions of vector Ω. Axes of whirlwinds are located in points with co-ordinates:

$$x = \frac{(2n-1)\lambda}{8}; \quad y = 0.423y_1; \quad y = 1.577y_1. \qquad (14)$$

Because microstreams are most intensive within an acoustic layer, therefore for a finding of speed we will use (13).

As

$$\mu = y/\delta; \mu_1 = y_1/\delta \Rightarrow \frac{\mu}{\mu_1} = \frac{y}{\delta}\cdot\frac{\delta}{y_1} = \frac{y}{y_1},$$

that (13) will become:

$$V_y^{(2)} = -0.072\frac{V_0^2}{c_0}ky_1\cos 2kx. \qquad (15)$$

Considering, that

$$\vartheta_0 = A\omega = 2\pi fA; k = \frac{2\pi f}{c},$$

where $f = 44$ kHz, $\vartheta_0 = 1500$m/s; $A = 10\ldots30$µm; $x = 0$. Then the formula (15) will become:

$$V_y^{(2)} = 0.72\bullet\frac{4\pi^2 f^2 A^2}{c_0}\bullet\frac{2\pi f}{c_0}y_1\cos 2\frac{2\pi f}{c_0} = 2.7\bullet10^5 y_1, \qquad (16)$$

where y_1 - height of level of a liquid in a bath.

Dependences of speed of microstreams on frequency and for various level of a liquid are resulted on Fig. 4.

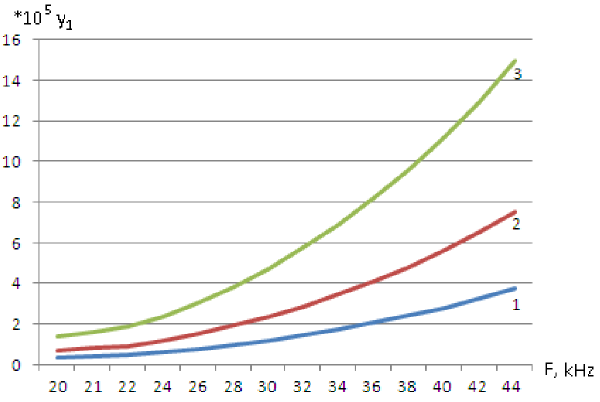


Fig. 4. Dependence microstreams speed on frequency: 1 - for λ, 2 - for 2 λ, 3 - for 4 λ

Microstreams in a bath have a direction from the centre, i.e. from a place of the greatest gradient of speeds US of fluctuations. In a direction of microstreams it is possible to define, that the most intensive fluctuations are observed between radiators (Fig. 5).

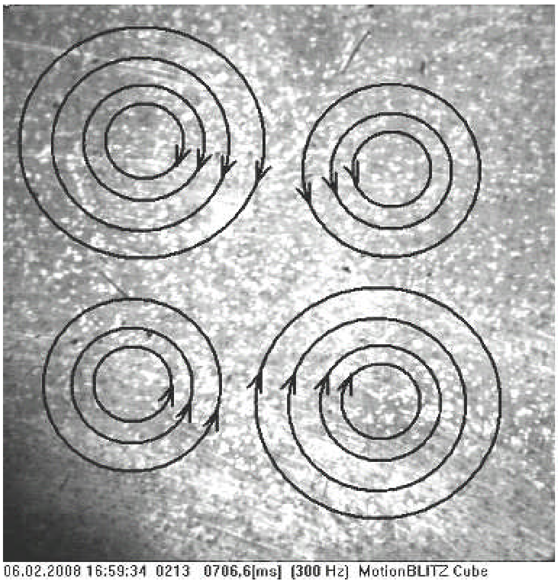


Fig. 5. Whirlwind microstreams in US baths

The sizes and speeds of microstreams from 10 to 20 mm/c depend on radiated capacity converters.

Thus, for effective clearing of electron-optical products it is necessary to create uniform distribution of pressure US a field and microstreams in volume of the liquid environment.

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Questions of simulation of ultrasonic pressure fields and microstreams in liquid environments of clearing baths with a various radiators arrangement are considered. The uniform field of ultrasonic pressure is created at an arrangement of radiators in the form of triangular structure. In the presence of the cartridge with details uniformity of distribution of ultrasonic pressure in baths worsens in 3-4 times. Speed and the sizes of whirlwind microstreams depend on power of radiators and their arrangement in a bath. Ill. 5, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

В. Л. Ланин, В. С. Томаль, В. И. Захаревич. Моделирование акустических полей и микропотоков в ультразвуковых ваннах очистки // Электроника и электротехника. – Каунас: Технология, 2009. – № 2(90). – С. 107–110.

Рассмотрены вопросы моделирования полей ультразвуковых давлений и микропотоков в жидких средах ванн очистки с различным расположением излучателей. Равномерное поле ультразвуковых давлений создается при расположении излучателей в виде треугольной структуры. При наличии кассеты с деталями равномерность распределения ультразвукового давления в ваннах ухудшается в 3–4 раза. Скорость и размеры вихревых микропотоков зависят от мощности излучателей и их расположения в ванне. Ил. 5, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

V. L. Lanin, V. S. Tomal, V. I. Zakharevich. Ultragarsinėse valymo vonelėse sukuriamų akustinių laukų ir mikrosrovių modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 2(90). – P. 107–110.

Analizuojami ultragarso slėgio laukų ir mikrosrovių valymo vonelių skystyje modeliavimas, kai naudojami skirtingi spinduoliai. Tolygus ultragarso slėgio laukas sukuriamas kai spinduoliai išdėstomi trikampio formos struktūra. Kai kasetė turi papildomų detalių, ultragarso slėgio pasiskirstymo vonelėse tolygumas pablogėja 3–4 kartus. Mikrosrovių sukūrių greitis ir dydis priklauso nuo spinduolio galios ir jų išdėstymo vonelėje. Il. 5, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).