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## RESEARCH STAFF PROCESS OF INTERACTION AND TECHNOLOGICAL ENVIRONMENT IN DEVELOPED CAVITATION

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### ДОСЛІДЖЕННЯ ПРОЦЕСІВ ВЗАЄМОДІЇ АПАРАТУ І ТЕХНОЛОГІЧНОГО СЕРЕДОВИЩА В УМОВАХ РОЗВИНЕНОЇ КАВІТАЦІЇ

*Abstract. Approaches the definition and parameters of the model cavitation technology environment. Found that the technological environment, subdued cavitation processing, is a visco-elastic-plastic body and can be described by the model Bingham-Shvedova. Implemented is the idea to review the contact zone of interaction of the system "cavitation device – technological environment" by determining the balance of power system pressure and stress, surrounded by bubbles emerging in consideration of the fluid model as a system with distributed parameters. As the research is subject to various technological environments the cavitation is shown as viscous and plastic properties, considered taking into account the energy dissipation in cavitating environments, including the contact area on the laws change frequency independent and frequency dependent damping. This approach made it possible to reveal the physical nature of the interaction, receive analytical dependences to establish the basic parameters, including contact pressure and impedance in the contact area «cavitation machine systems – technological environment». Research results select the input impedance compensator length  $\lambda/4$  for maximum transfer conditions under which the impedance compensator system and coordination. When placing the device between the border and the environment auxiliary layer of material with the acoustic impedance ensured equality acoustic impedance device and transmission line equivalent. Then, a reflection of both boundary layer additionally installed waves are equal in amplitude, thus ensuring maximum transfer of energy to the flow of the process.*

*Keywords:* cavitation, ultrasound, technological environment, the contact zone, dissipation, wave resistance.

#### FORMULATION OF THE PROBLEM

The phenomenon of cavitation that occurs when exposed to an acoustic device manufacturing environment is widely used for accelerating various processes (dispersion, extraction, mixing, etc.). In chemical, food, construction and other industries [1 – 9]. Therefore, a study of this type of processing and search methods intensification of various kinds of processes is the task urgent.

The process of cavitation caused by a sharp variable characteristics of the velocity field and pressure cavities technological environment (water, suspensions, emulsions and others. Liquid medium), which are the key parameters of nucleation and cavitation. There are a number of [10 – 12] devoted to defining the nature and the numerical values of pressure in different parts of the cavitation bubbles and the ratio of the numerical values of pressure, for which there is slamming bubbles.

In this paper put forward the idea to review the contact zone of interaction of the system "cavitation device - technological environment" by determining the balance of power system pressure and stress, surrounded by bubbles emerging in consideration of the fluid model as a system with distributed parameters. This approach makes it possible to reveal the physical nature of the interaction, to develop proposals to improve the technology of process fluids.

#### RESEARCH ANALYSIS

Implementation of the proposed idea requires consideration of the physical and mathematical model of cavitating environment, which is in the form of bubbles. Cavitating environment in accordance with the ratio between the yield point  $\tau$  in pure shear and atmospheric pressure  $p_{atm}$  may be:

$$\begin{aligned} \text{hard plastic} - \frac{\tau}{p_{atm}} &\leq 1; \\ \text{liquid plastic} - \frac{\tau}{p_{atm}} &= 1; \\ \text{liquid} - \frac{\tau}{p_{atm}} &\geq 1. \end{aligned} \quad (1)$$

Consideration of wave phenomena in the cavitating medium can be measured by the ratio of time wave propagation  $t_w$  and oscillation period  $T$ .

Subject:  $t_w < T;$   
 $t_w > T.$  (2)

For the first condition (2) fluctuations in the process environment can be considered slow and neglected elastic wave. That is, in this case, acceleration and strain are determined solely by the arising technological environment.

In fulfilling the second condition (2) environmental movement is determined by elastic waves.

Because  $\tau = l/c$ , where  $l$  – the characteristic size medium in which the direction of application of force, and  $c^2 = \frac{E}{\rho}$ , where  $E$  – modulus,  $\rho$  – density of the medium, the same module density and technological environment require accurate account at all stages of cavitation process.

In most real action cavitation protection between these criteria for dependence (2) that is usually necessary to take into account the elastic and inertial properties. It should be noted that dependence (2) does not take into account dissipative properties, because their influence is substantial in resonance as the regime most used for the treatment of process fluids.

To account for these properties are offered a number of models [13 – 18], which in one way or another law take into account the rheological parameters and characteristics.

In [18] proposed a generalized rheological model cavitating medium (Fig. 1). According to the block of A (Fig. 1, a) corresponds to a volume stretching the body, block B – pure shift in power is an auxiliary unit.

Generalized model qualitatively describes the behavior of dispersed environment in terms of cavitation, but its use in the equations of motion joint cavitation system and environment presents certain mathematical difficulties.

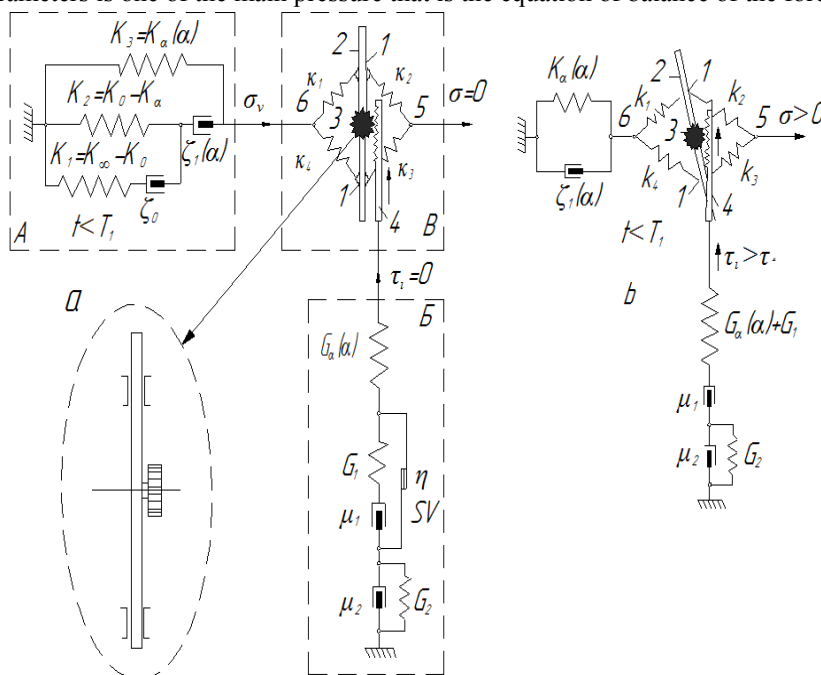
Assessing the reduced model should take into account that in general technological environment, subdued cavitation processing, is a visco-elastic-plastic body and can be described by the model Bingham-Shvedova.

**FORMULATION OF THE PROBLEM**

Analytical power describe the process of interaction between the working body of the apparatus that implements ultrasonic liquid dispersion effect on the environment. Methodology provides an assessment of existing models and phenomena that occur in the contact zone system "device environment." Achieving this can solve the problem of determination made by contact pressure under different laws that change dissipative forces and adopt the idea that the main parameter interaction process is the wave resistance.

**STATEMENT BASIC MATERIALS**

Research Methodology provides Consideration of conduct cavitation bubbles in the region and identification of parameters is one of the main pressure that is the equation of balance of the forces.



**Fig. 1. Generalized model cavitating environment:**  
 $k, G, l$  – coefficient of elasticity, shear and viscosity, respectively; 1...4 – elements of mechanical models that simulate the behavior of the environment in the transition.

By synthesizing the results of studies [17] it can be determined that the basic equations of static equilibrium bubbles having a spherical shape (Fig. 2) without the forces of viscous friction:

$$p = p_{vl} + p_g - \frac{2\sigma}{R}, \quad (3)$$

where  $p$  – external pressure surrounded by bubbles;  $p_{vl}$  – vapor pressure of the liquid;  $p_g$  – the partial pressure of gas;  $\sigma$  – the surface tension;  $R$  – radius of the bubble.

Pressure  $p_{vl}$  and  $\sigma$  factor dependent on temperature. For example, water at  $t = 20^{\circ}\text{C}$   $p_{vl} = 2.35 \cdot 10^3$  Pa,  $\sigma = 7.35 \cdot 10^{-2}$  N/m, and at  $t = 40^{\circ}\text{C}$   $p_{vl} = 0.78 \cdot 10^3$  Pa. [17].

It is known [17] that the pressure associated with the volume and temperature Clapeyron equation:

$$p_g = BT / R^3, \tag{4}$$

where T – the absolute temperature; B – a constant that depends on the mass of gas bubbles in the middle.

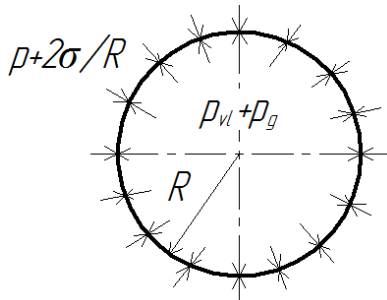


Fig. 2. Diagram vapor bubbles

Substituting (4) into (3) you can balance equation, which takes into account the effect of temperature. Lack of these equations is that force does not include viscosity, gas diffusion through the surface bubbles compressibility, inertia. An important aspect is to define the process of changing the radius of the bubble that needs clarification equation (3). There are other assumptions. So by the process of expansion or compression of the bubbles is isothermal, changing the gas pressure and the radius of the bubble accepted the law of Boyle-Mariotte [19].

Using the law under which (index "0" corresponds to the initial state of the bubble) of (3) can be transformed to a form which takes into account the change bubble radius:

$$p = p_{vl} + (p_0 + p_{vl} + \frac{2\sigma}{R_0}) \frac{R_0^3}{R^3} - \frac{2\sigma}{R}, \tag{5}$$

Actually equation (5) although it makes it possible to calculate the value of the unknown parameters, also has disadvantages.

There is an approach [20] where the law changes in the state of gas in bubble accepted adiabatic at which the condition is accepted that the bubble has a lot of gas and the movement of its walls is so fast that the heat dissipation in the fluid is considered as educating slow process:

$$p = p_g (\frac{R_0}{R})^{3\gamma} - \frac{2\sigma}{R}, \tag{6}$$

where  $\gamma$  - adiabatic index.

It should be noted that the general equation of the problem of movement bubbles are too complex, because in addition to clearly defining traffic conditions contact zone "machine-environment" the challenge consider yet one system "liquid-bubble" forming two distinct parts: the liquid with dissolved gas - water and the mixture bubbles of gas and vapor liquid - in the middle of the bubble.

Obviously, in this case to determine the motion of cavitation region should use gas and laws of thermodynamics, which consists of equations comprising equations: continuity, energy balance, diffusion, motion of fluid particles and gas, thermal conductivity and boundary conditions. The above equation albeit cumbersome, but their application for review of a linear process in solving particular difficulties are not.

In general we can say that the process of the birth and development of cavitation processes for certain conditions to determine their occurrence settings.

Thus, in [17] proposed definition dimensionless minimum radius  $R_{min}$  of the bubble as follows:

$$R_{min} / R_{max} = \frac{3\sigma}{1 + 3\delta - \delta^{1.6}}, \tag{7}$$

where  $R_{max}$  – the maximum radius;  $\delta = p_{sg} / p_0$  ( $p_{sg}$  – pressure in the middle of the bubble, which consists of the partial pressure of steam  $p_s$  and gas  $p_g$ );  $p_0$  – hydrostatic pressure.

Assuming that  $\delta \gg 1$  [17] dependence (7) is simplified:

$$R_{min} / R_{max} = 3\delta, \tag{8}$$

Average for the period of the density  $\rho_c$  and compression  $\beta_c$  determined according dependencies:

$$\begin{aligned} \rho_c &= \rho_l(1 - \kappa_c) + \rho_g \kappa_c; \\ \beta_c &= \beta_l(1 - \kappa_c) + \beta_g \kappa_c, \end{aligned} \tag{9}$$

where  $\rho_l, \rho_g$  – density of liquid and gas respectively;  $\kappa_c$  – cavitation coefficient [17]:

$$\kappa_c = \Delta V / V, \tag{10}$$

where  $\Delta V$  – volume cavitation bubbles; V – volume of liquid.

Parameter  $\Delta V$  determined by the average size of cavitation bubbles and their number. As the size and number of bubbles during cavitation process of changing the formula (10) is very difficult.

The contact pressure is determined by consideration of the settlement scheme "cavitation machine – technological environment", which is reasonable represent discrete-continuous model under different laws scattering energy [21], the solution of which is as follows.

As the research subject to various technological environments that cavitation in the show as viscous and plastic properties, considered taking into account the energy dissipation in cavitating environments, including the contact area on the laws and changes frequency independent and frequency dependent coefficients damping.

For frequency independent model of energy dissipation in a technological medium of acoustic wave propagation equation is:

$$\frac{\partial^2 u}{\partial z^2} = \frac{\rho}{E^*} \frac{\partial^2 u}{\partial t^2}, \quad (11)$$

where  $\rho$  – density of the medium;  $E^*$  – the complex modulus.

Law deflected mode of technological environment described relationship:

$$\sigma = E\varepsilon + iE\varepsilon\gamma,$$

where  $i$  – the imaginary unit, indicating the rotation vector relatively hard elastic component  $E\varepsilon\gamma$   $E\varepsilon$  at an angle  $\pi/2$ , that inelastic component has direction, the opposite direction of speed;  $\gamma$  – loss factor, which assesses the level of energy dissipated in the environment in one cycle fluctuations.

If we take the general law of change of power:

$$F(t) = \sum_{n=-\infty}^{+\infty} F_n e^{in\omega t},$$

where

$$\omega = \frac{2\pi}{T}; n = \pm 1; \dots \pm 2; \dots F_n = F_n^* = \int_{-\tau/2}^{\tau/2} F(\tau) e^{-in\omega t} d\tau,$$

the solution of the original equation, according to the Fourier method can be represented by complex wave function:

$$u(z, t) = \sum_{n=-\infty}^{+\infty} (A_{1n} e^{k_n z} + A_{2n} e^{-k_n z}) e^{in\omega t}. \quad (12)$$

Moving  $u$  determined by the product of two functions, one of which depends on the argument  $z(z) = A_{1n} e^{k_n z} - A_{2n} e^{-k_n z}$ , and another – only by argument  $T_n(t) = e^{in\omega t}$ .

In the decision (12)  $A_{1n}$  and  $A_{2n}$  - constant due on boundary conditions:

at  $z = 0$

$$u(0, t) = \sum_{n=-\infty}^{+\infty} x_n e^{in\omega t}, \quad (13)$$

$x_n$  - Fourier decomposition in the movement of the working body;

at  $z = l$

$$\sigma|_{z=l} = 0. \quad (14)$$

Then, equating coefficients of the same harmonics, we obtain:

$$A_{1n} + A_{2n} = x_n;$$

$$A_{1n} e^{l(\alpha_n + i\beta_n)} - A_{2n} e^{l(\alpha_n + i\beta_n)} = 0,$$

where  $\alpha_n$  – coefficient that determines the extinction wave at n-th harmonic;  $\beta_n$  – coefficient effect on the same wave length.

From this value we find:

$$A_{1n} = \frac{x_n e^{-l(\alpha_n + i\beta_n)}}{e^{-l(\alpha_n + i\beta_n)} + e^{l(\alpha_n + i\beta_n)}}; \quad (15)$$

$$A_{2n} = \frac{x_n e^{l(\alpha_n + i\beta_n)}}{e^{-l(\alpha_n + i\beta_n)} + e^{l(\alpha_n + i\beta_n)}}. \quad (16)$$

Pressure device environment fluctuations (contact area), after corresponding changes:

$$p(0, t) = \rho l A_1 \omega^2 \sqrt{\chi_{1n}^2 + \chi_{2n}^2}, \quad (17)$$

where  $A_1$  – amplitude contact zone;  $\chi_{1n}$  and  $\chi_{2n}$  – wave ratios:

$$\chi_{1n} = \frac{\alpha_n \operatorname{sh} 2\alpha_n l + \beta_n \sin 2\beta_n l}{l(\alpha_n^2 + \beta_n^2)[ch 2\alpha_n l + \cos 2\beta_n l]}; \quad (18)$$

$$\chi_{2n} = \frac{\alpha_n \sin 2\beta_n l - \beta_n \operatorname{sh} 2\alpha_n l}{l(\alpha_n^2 + \beta_n^2)[ch 2\alpha_n l + \cos 2\beta_n l]}. \quad (19)$$

Wave equation based frequency dependent energy dissipation in the technological environment will be as follows:

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial z^2} + \frac{4\eta\partial}{3\rho\partial t} \left( \frac{\partial^2 u}{\partial z^2} \right), \quad (20)$$

where  $c$  – velocity of waves;  $\eta$  – viscosity.

In the case of harmonic vibrations occurring during ultrasonic impact, amplitude is:

$$u = u(x) \sin \omega t. \quad (21)$$

Substituting expression (21) to (20) we obtain a second order differential equation with constant coefficients, whose decision is:

$$u(x) = A_1 \cos k_p x + A_2 \sin k_p x, \quad (22)$$

where  $k_p$  – complex continuous wave propagation that with the influence of viscous given by:

$$k_p = k - i\psi = \frac{\omega}{c} - i \left( \frac{2\eta\omega^2}{3\rho c^3} \right) \quad (23)$$

Then the expression for the amplitude will look like:

$$u = (A_1 \cos k_p x + A_2 \sin k_p x) \sin \omega t. \quad (24)$$

Differentiating expression (24) by the time we get the expression for speed:

$$v = \omega (A_1 \cos k_p x + A_2 \sin k_p x) \cos \omega t. \quad (25)$$

After differentiating expression (25) by the time we get an expression for determining acceleration. The integral of the acceleration of the coordinate given Newton's second law will be equal to the pressure of sound waves:

$$p(x) = -\frac{\rho\omega^2}{k_p} (A_1 \sin k_p x - A_2 \cos k_p x). \quad (26)$$

Thus, as in this case there is a standing sound wave, you can exclude from Members, depending on the time. Continuous integration with defined initial and final conditions of wave propagation in a layer of liquid. As an initial value provided useful vibrational velocity on the radiating surface of the ultrasonic transducer. Assume the limit distribution transformer – a layer of liquid on the origin, that  $x = 0$  and thus,  $v = v_0$ . When  $x = h$  is a limit distribution of liquid – gas, which according to the accepted assumptions wave reflection coefficient is unity, and as  $\rho_l c_l \gg \rho_g c_g$ , are on the verge of unit sound pressure.

Substituting the boundary conditions obtained in the equation (24) and (25), we obtain expressions for the permanent integration:

$$\begin{aligned} A_1 &= \frac{v_0}{\omega}; \\ A_2 &= \frac{v_0}{\omega} \cdot \frac{\sin lx}{\cos lx}. \end{aligned} \quad (27)$$

Substituting the obtained boundary conditions (13, 14) in equation (26), we obtain an expression for the pressure in the reservoir environment depending on its thickness:

$$p(x) = \frac{v_0 \rho \omega}{k_p} \frac{\sin k_p (l-x)}{\cos k_p l}. \quad (28)$$

The practical interest is the development of cavitation in the layer, which directly borders the surface of ultrasound transducer. Omitting the intermediate transformation, we obtain the amplitude pressure:

$$p = v_0 \rho \omega \left| \frac{\sin k_p l}{k_p \cos k_p l} \right| \quad (29)$$

or based on the formula (26):

$$p = v_0 \rho \omega \sqrt{\frac{(\sin kl \cos \psi l)^2 - (\cos kl \sin \psi l)^2}{(k^2 + \psi^2) [(\cos kl \cos \psi l)^2 + (\sin kl \sin \psi l)^2]}}. \quad (30)$$

The resulting expression makes it possible to determine the amplitude of the ultrasonic pressure wave depending on the coefficient  $k$ ,  $\psi$  coefficient of resistance and layer thickness  $l$  for different technological environments.

An important parameter that is dependent (30) is wave propagation speed  $c$  and density  $\rho$ , which seem characteristic impedance as defined modes without cavitation and cavitation depends on the rheological properties of a particular technological environment.

Consider the process of acoustic waves from the device to the manufacturing environment. We assume that the plane wave  $X$  axis of the apparatus to the border with the environment of distributed acoustic impedance  $Z_m$ , and the environment on the border with the device on the same axis  $X$ , as a result of this resistance, there is a wave resistance  $Z_{en}$ . It is clear that apart from the wave that is transmitted to the environment, there is on the verge of a contact device with medium wave which moves in the opposite direction. Thus is formed a complex wave field, which can provide the transmission coefficient and the reflection wave in the form:

$$\begin{aligned} K_{ref} &= p_{m.ref} / p_{m.inc}; \\ K_{tr} &= p_{m.inc} / p_{m.ref}. \end{aligned} \quad (31)$$

By analogy with the decision of the equation of motion (13) can be written expressions for the incident and reflected waves of pressure and speed:

$$\begin{aligned} p(x) &= p_{m.inc} e^{-ik_1 x} + p_{m.ref} e^{ik_1 x}; \\ v(x) &= v_{xinc} e^{-ik_1 x} + v_{xref} e^{ik_1 x}. \end{aligned} \quad (32)$$

where  $k_1 = \omega_1 / c_1$ , – wave number;  $i$  – imaginary unit.

Applying the condition of continuity of motion parameters in the contact zone system "machine – environment" (no discontinuity):

$$\begin{aligned} p_m &= p_{en}; \\ v_m &= v_{en} \end{aligned} \quad (33)$$

get:

$$\frac{p_{m.inc}}{Z_m} - \frac{p_{m.ref}}{Z_m} = \frac{p_{m.tr}}{Z_{en}}. \quad (34)$$

Dividing the left and right of the amplitude of the acoustic pressure  $p_{m.inc}$  and using (32) we obtain expressions for the coefficients of reflection and transmission waves:

$$\begin{aligned} K_{ref} &= (Z_{en} - Z_m) / (Z_{en} + Z_m); \\ K_{tr} &= 2Z_{en} / (Z_{en} + Z_m). \end{aligned} \quad (35)$$

The condition determining the impedance to maximize its passage may realize by entering the border compensator system and environment, which serves as the load impedance and reflection of acoustic waves only in the area of the device. This load impedance must be equal to the characteristic impedance environment:  $Z_k = Z_{en}$ .

Using the solution (24) replacing  $x = l$ , where  $l$  – the length of the device which is distributed wave, we get resistance in the section ( $x = -l$ ):

$$Z_s(x = -l) = \frac{p_m(-l)}{v(-l)} = Z_m \left[ \frac{e^{ik_1 l} + k_{ref} e^{-ik_1 l}}{e^{ik_1 l} - k_{ref} e^{-ik_1 l}} \right]. \quad (36)$$

In view of (31)

$$Z_s = -l = Z_m \frac{Z_{en} \cos k_1 l + i Z_m \sin k_1 l}{Z_m \cos k_1 l + i Z_{en} \sin k_1 l}. \quad (37)$$

If we assume that between the device and the environment is set equalizer length  $l = \lambda / 4$ , where  $\lambda$  – wavelength compensator, we get the following relationship:

$$k_1 l = (2\pi / \lambda) / (\lambda / 4) = \pi / 2. \quad (38)$$

Substituting (38) to (37) we obtain an expression for determining the input impedance:

$$Z_s(\lambda / 4) = Z_m^2 / Z_{en}. \quad (39)$$

Therefore, choosing the input impedance compensator length  $\lambda/4$  condition obtain maximum transmission at which the impedance compensator system and coordination. Indeed, having the border system and auxiliary layer material environment with the acoustic impedance can ensure equality acoustic impedance device and transmission line equivalent. Then, a reflection of both boundary layer additionally installed waves are equal in amplitude and counter-phase move in the direction that will lead to their mutual compensation. A shift between phases of movement for  $180^\circ$  provided path difference between the waves bounds by a half wavelength. Equal amplitudes provided rational choice impedance compensator.

## CONCLUSIONS

1. Consider the physical and mathematical models of the environment and the process of their transformation over time.

2. Revealed that the technological environment, subdued cavitation processing, is a elastic-visco-plastic body, which can be described model Binhama-Shvedova.

3. Established parameters that affect the value of contact pressure, among which is the dominant resistance.

4. Analytical dependence for determining the resistance of the equalizer, which enable to reconcile the wave resistance of the system with maximum energy transfer to the technological process of cavitation processing environment.

**Анотація.** Розглянуто підходи до визначення моделі та параметрів процесу кавітації технологічного середовища. Виявлено, що технологічне середовище, підкорене кавітаційній обробці, представляє собою пружно-в'язко-пластичне тіло і може бути описане моделлю Бінгама-Шведова. Реалізована ідея розгляду контактної зони взаємодії системи «кавітаційний апарат – технологічне середовище» на основі визначення рівноваги силового тиску апарату і напружень, виникаючих в оточенні бульбашки з розглядом моделі рідини, як системи з розподіленими параметрами. Оскільки дослідженню підлягають різні технологічні середовища, які в процесі кавітації проявляють як в'язкі, так і пластичні властивості, розглянуто врахування розсіювання енергії в кавітуючому середовищі, у тому числі в контактній зоні за законами зміни частотнезалежних і частотнозалежних коефіцієнтів дисипації. Такий підхід дав можливість розкрити фізичну сутність взаємодії, отримати аналітичні залежності для встановлення основних параметрів, в тому числі контактної тиску і хвильового опору в контактній зоні системи «кавітаційний апарат-технологічне середовище». Запропоновано вибирати значення вхідного опору компенсатора довжиною  $\lambda/4$  для отримання умови максимальної передачі, за якою хвильовий опір апарату і компенсатора узгоджені. Розташовуючи між границею апарату і середовищем допоміжний шар матеріалу з таким акустичним опором, забезпечується рівність акустичного опору апарату і еквівалентної лінії передачі. Тоді, відбиття від обох границь додатково встановленого шару хвилі будуть рівні за амплітудою, забезпечуючи таким чином максимальну передачу енергії на протікання технологічного процесу.

Ключові слова: кавітація, ультразвук, технологічне середовище, контактна зона, дисипація, хвильовий опір.

**Аннотация.** Рассмотрены подходы к определению модели и параметров процесса кавитации технологической среды. Выявлено, что технологическая среда, подчинённая кавитационной обработке, представляет собой упруго-вязко-пластическое тело и может быть описано моделью Бингама-Шведова. Реализована идея рассмотрения контактной зоны взаимодействия системы «кавитационный аппарат - технологическая среда» на основе определения равновесия силового давления аппарата и напряжений, возникающих в окружении пузырька с рассмотрением модели жидкости, как системы с распределёнными параметрами. Поскольку исследованию подлежат различные технологические среды, которые в процессе кавитации проявляют как вязкие, так и пластические свойства, рассмотрены с учётом рассеяния энергии в кавитирующей среде, в том числе в контактной зоне с законами изменения частотнонезависимых и частотнозависимых коэффициентов диссипации. Такой подход дал возможность раскрыть физическую сущность взаимодействия, получить аналитические зависимости для установки основных параметров, в том числе контактного давления и волнового сопротивления в контактной зоне системы «кавитационный аппарат – технологическая среда». Предложено выбрать значения входного сопротивления компенсатора длиной  $\lambda / 4$  для получения условия максимальной передачи, по которой волновое сопротивление аппарата и компенсатора согласованы. Размещение между границей аппарата и среды вспомогательного слоя материала с таким акустическим сопротивлением, обеспечивает равенство акустического сопротивления аппарата и эквивалентной линии передачи. Тогда, отражение от обеих границ дополнительно установленного слоя волны будут равны по амплитуде, обеспечивая таким образом максимальную передачу энергии на протекание технологического процесса.

Ключевые слова: кавитация, ультразвук, технологическая среда, контактная зона, диссипация, волновое сопротивление.

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