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PREFACE

Ladies and gentlemen, dear colleagues,

Welcome to Zlatibor, to the International Scientific Conference Heavy Machinery 2017.

This year the International Conference Heavy Machinery is held by the University of Kragujevac, Faculty of Mechanical and Civil Engineering in Kraljevo from 28 of June to 1 of July 2017.

It has gained a unique recognizable form for exchange of information, ideas and new scientific researches. The Conference is held in the year when the Faculty of Mechanical and Civil Engineering in Kraljevo celebrates the 58th year of university teaching in mechanical engineering and sixth year of university teaching in civil engineering.

For 24 years of its existence it has acquired specific and recognizable form in domestic and foreign scientific circles thanks to its scientific and research results.

The goal of the Conference is to make the research from the fields covered at the Faculty of Mechanical and Civil Engineering in Kraljevo available and applicable both within domestic and foreign frames. Also, our scientific workers will have the opportunity to learn about results of research done by their colleagues from abroad in the fields of transport design in industry, energy control, production technologies, and civil engineering through the following thematic sessions:

- Earth moving and transportation machinery,
- Production technologies,
- Automatic control, robotics and fluid technique,
- Machine design and mechanics,
- Railway engineering,
- Thermal technique and environment protection,
- Civil engineering and materials.

High scientific rating of domestic and foreign participants as well as the number of papers provide guarantees that the Conference is going to be very successful.

I wish to emphasize that this year we have a large number of papers, especially from abroad. The program also contains 104 invited papers in the plenary session. The invited lectures reflect the wide spectrum of important topics of current interest in heavy machinery. The sponsorship by the Ministry of Education and Science of the Republic of Serbia is supportive of efforts to promote science and technology in the area of mechanical and civil engineering in Serbia. We would like to express our sincere thanks to all members of scientific and organizing committee, reviewers, as well as to all participants including invited speakers for coming to Zlatibor to present their papers.

Thank you and see you at the next conference.

Kraljevo – Zlatibor, June 2017

Conference Chairman,

Prof. Dr Milomir Gašić, mech eng.

PLENARY SESSION

SESSION A: EARTH-MOVING AND TRANSPORTATION MACHINERY

SESSION B: PRODUCTION TECHNOLOGIES

SESSION C: AUTOMATIC CONTROL, ROBOTICS AND FLUID TECHNIQUE

SESSION D: MECHANICAL DESIGN AND MECHANICS

SESSION E: RAILWAY ENGINEERING

SESSION F: THERMAL TECHNIQUE AND ENVIRONMENT PROTECTION

SESSION G: CIVIL ENGINEERING AND MATERIALS

Research and Calculation of Rational Modes and Parameters of an Ultrasonic Cavitator

Iryna Bernyk[1*], Oleksandr Luhovski[1]
[1] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

In the executed researches it is accepted that the highest efficiency of transformation of electric energy into energy of acoustic vibrations and radiation in the work environment is subject to the approval of the resistance of the medium and the use of force apparatus. Implementation of the proposed approach is implemented reflect the changes in the rheological properties of the technological environment, by choosing the physical model and its mathematical description. Presented in the mathematical form of the stages of the cavitation process. The key parameters of cavitation bubbles in an acoustic field. The estimation of the cavitation process on the coefficient of the cavitation index and absorption coefficient in cavitating medium. The absorption coefficient is a measure of the efficiency of cavitation effect, the connection of this parameter with power density of shock waves.

Keywords: disperse medium, ultrasound, cavitation, rheology, intensity, impedance, absorption coefficient.

1. FORMULATION THE PROBLEM

Ultrasonic cavitation technology allows to intensify the technological processes, to increase the utilization of raw materials, to modify the original properties of the material, to create new substances and the environment to ensure environmental cleanliness and safety of production [1–11]. The process of turning electric energy into acoustic waves and its radiation in the working environment shall be carried out with the greatest efficiency, subject to the approval of the resistance of the medium and the use of force apparatus. Therefore, research aimed at improving the efficiency of cavitation technologies for the realization of different kinds of technological processes is the task urgent.

2. FORMULATION OF THE TASK

The aim of this work is to study the process of cavitation treatment of technological environments, the setting of parameters of influence and assess its effectiveness.

3. STATEMENT OF THE MATERIAL

Implementation of the proposed approach requires determining the change in rheological properties of the technological environment, which is the viscosity, plasticity and elasticity [2]. The procedure for accounting of these properties lies in the choice of the physical model with further mathematical description and assessment of the impact in the calculation of dependencies. From a physical point of view, the choice of model predefined the main characteristics of the deformation and stresses that occur during the technological influence and form the so-called stress-strain state.

The main properties of the processed media are the basis of any material. There are three idealized models of materials: the ideal elastic body (Hooke); ideally viscous liquid (Newtonian); a perfectly plastic body (Saint-Venant) [3]. In real-world environments, which have a complex structure, can occur for all three rheological properties. To build the model they are interconnected in series or in parallel (tab. 1). Such models belong to the basic elastic-plastic body Saint-Venant, the viscoelastic body of the Kelvin-Voigt and Maxwell visco-plastic body Shvedov-Bingham and others, the use of which is determined by other properties.

The next step envisaged in the mathematical form of the stages of the process of cavitation: the formation of bubbles, their oscillation, the development and collapse. This process is accompanied by complex maso and heat transfer in the formed cavitation region.

The key parameter in the evolution of the gas and air bubbles in the acoustic field is the energy, the components of which are the pressure, time and speed of flow of the process of cavitation [5, 6]. Under the action of ultrasonic harmonic oscillation on environments, the amplitude of the sound pressure is determined in accordance with dependencies:

$$P_m = \rho_k c_k \omega A, \tag{1}$$

where: ρ_k and c_k – the density and speed of sound in cavitating medium; ω – the circular frequency of the sound wave; $k = \dfrac{\omega}{c}$ – wave number; A – the vibration amplitude of the radiator; $\rho_k c_k$ – the impedance of the medium, which determines the speed of oscillations for a given acoustic pressure.

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The propagation of ultrasonic waves associated with the transfer of energy. The energy density of sound waves, which falls per unit volume of the medium, can be expressed as:

$$E_э = p\upsilon^2/2 = 2\pi^2 pf^2A^2 \qquad (2)$$

The energy of ultrasonic waves that pass through unit area per unit time, it is customary to characterize the intensity of ultrasonic vibrations. When the plane wave is perpendicular to the surface, ultrasound intensity is associated with the amplitude of the sound pressure dependence:

$$I = 2\pi^2 pcf^2A^2 = P_M^2/(2pc) \qquad (3)$$

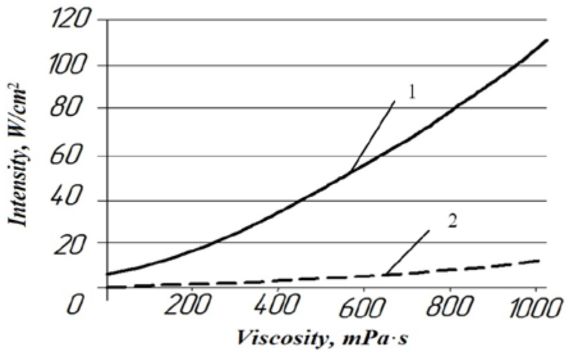
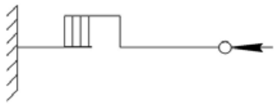
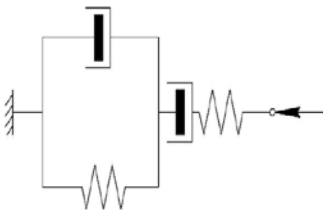
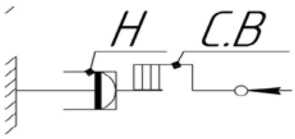
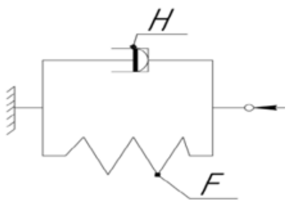
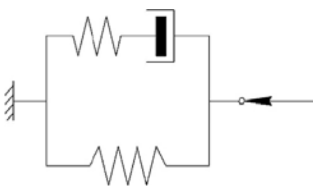
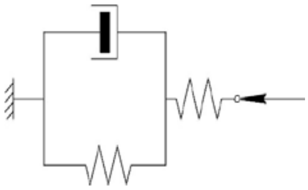
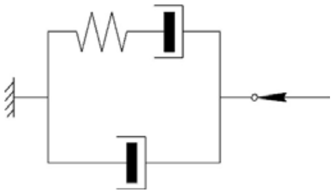
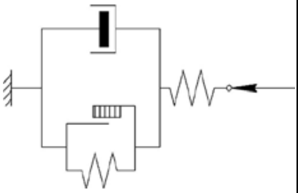
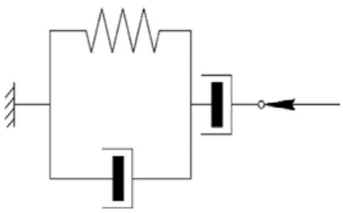
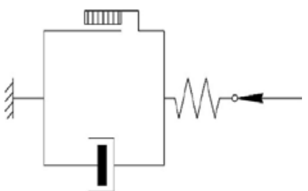
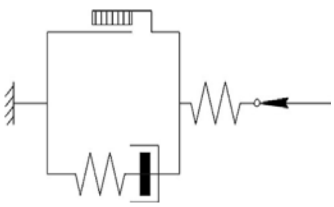


Figure 1: The change in the intensity of the cavitation processing of disperse media, depending on their viscosity: 1 – maximum intensity, 2 – min intensity

Table 1: Rheological models of simple and complex dispersed technological environments

 Hooke's (elastic)	 Newton's (viscous)	 Saint - Venant's (dryfriction)	 Maxwell's (elastic - viscous)
 Elastic - viscous Plasticmodel ((Buerger's)	 Prandtl's ((elastic - plastic)	 Visco - plastic	 Voigt 's ((elastic - viscous)
 Elastic - viscous ((Poynting - Thompson's)	 Elastic - viscous ((Kelvin's)	 Elastic - viscous ((Jeffreys)	 Visco - elastic - plastic ((Ishlinskoho)
 Elastic - viscous ((Mersich's)	 Elastic - viscous Plastic (Bingham's)	 Elastic - viscous plastic (Shvedov's)	

The change in the intensity of the viscosity (Figure 1) proves the necessity of taking into account dissipation in the determination of the parameters of the cavitation process.

In practice, an estimation of the cavitation process using the ratio of the index of cavitation K, which equals the time average volumetric concentration of bubbles:

$$K = \frac{\sum_i V_i}{V_p + \sum_i V_i}, \qquad (4)$$

where: V_p – the volume of fluid without bubbles, V_i – the average volume of cavitation bubble, i = 1, N, N – the number of bubbles.

Then the wave resistance of cavitation medium can be represented as:

$$\rho_k c_k = \rho_0 c_0 \left[\frac{1}{1 + \frac{K\beta_n}{\beta_0}} \right]^{1/2}, \quad (5)$$

where: $\rho_0 c_0$ – the wave resistance of the medium; $\frac{\beta_n}{\beta_0}$ – the ratio of compressibility of gas-vapor mixture in the bubbles to the compressibility of the fluid.

The dependence of the wave resistance of the medium from the cavitation index (Figure 2) shows that when the cavitation index of only 0.2% impedance and hence the amplitude of the current bubble sound pressure is reduced almost five times.

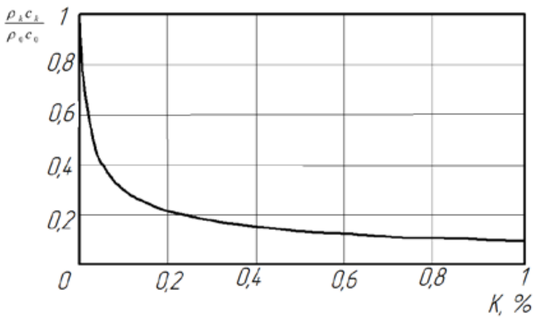


Figure 2: The dependence of the impedance changes of the medium from the cavitation index.

The bubbles, having a high compressibility, assume the external force in the sound wave, the same reducing the bulk modulus of elasticity of the medium of the E_c and the speed of sound:

$$c_k = \sqrt{\frac{E_c}{\rho_k}}. \quad (6)$$

An important parameter in the evaluation of process efficiency is the ratio of the velocities at the initial speed the process of cavitation cc, which varies from the origin of cavitation bubbles, their collapse c_k:

$$k_c = c_c / c_\kappa \quad (7)$$

The next process parameter is the absorption coefficient in cavitating medium $K_\bullet$. This parameter depends on the complex amplitude of acoustic pressure in the cavitation medium and the complex amplitude of the volumetric content of cavitation bubbles.

$$K_\bullet = -\frac{\omega}{c_0} \ln \frac{\rho_0 c_0 \bar{v}_1}{\bar{p}_1}, \quad (8)$$

where: ρ_0 – the equilibrium density of the medium, kg/m^3; p – the instantaneous pressure, PA; c_0 – the speed of sound in the liquid phase, m/s, $\bar{V}$ – instantaneous volume content of bubbles. Analysis of the dependence (8) shows that the absorption rate corresponds to the maximum efficiency of the cavitation process. In Fig. 3 shows the dependence of the absorption coefficient in cavitating liquids on the intensity effects for different viscosity ratios.

The absorption coefficient can be a measure of the effectiveness of the cavitation effect. Evidence of this conclusion to serve the relationship of the absorption coefficient with the specific power of the shock waves on the basis of consideration of local area processing medium volume ΔSΔx. So, using the law of conservation of energy, we find that the power density of the shock waves to be determined according to the expression:

$$P_{num} = \frac{\Delta Sl}{\Delta x \Delta S} = \frac{\Delta S(I - Ie^{-k\Delta x})}{\Delta x \Delta S} = \frac{(I - Ie^{-k\Delta x})}{\Delta x} = k\frac{I(1 - e^{-k\Delta x})}{k\Delta x} \approx kI, \quad (9)$$

where: ΔI – the change in the intensity of this wave as a result of absorption, W/m^2.

The expression for the work of the cavitator in contact area has the form [6]:

$$A_k = \pi m_c A_0^2 \omega^2 \mu \quad (10)$$

where: m_c – mass technological environment; A_0 – the amplitude of the contact zone; μ – wave coefficient, which takes into account the influence of the environment on the movement of the cavitator.

Average power cavitator P_{cp}:

$$P_{cp} = 0{,}5 m_c A_0^2 \omega^3 \mu \quad (11)$$

Expressions (10) and (11) are the values of the unknown parameters of the work and power of the cavitator, which are implemented in the contact zone of the cavitator and technological environment. The difference of the dependence (11) from the existing ones lies in the fact that in the known dependence [4, 8, 9] used the concept of added mass, which is supposedly attached to the surface of the cavitator. In fact, the mass of the environment is variable [6] and depends on acoustic parameters in (11) takes into account the wave factor μ.Under the conditions of pulsed energy transfer cavitator to the notion of vibration amplitude loses its definition, because the regime is not harmonic, but nonlinear.

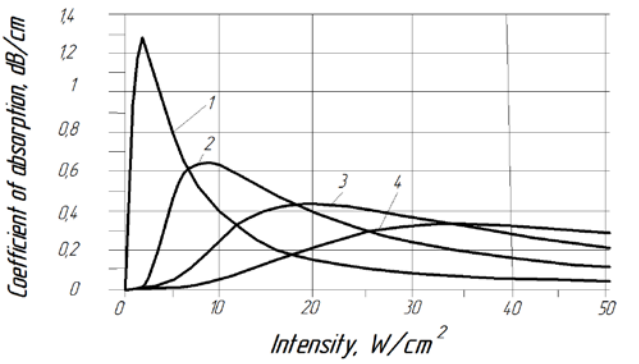


Figure 3: The dependence of the absorption coefficient in cavitating liquids on the intensity effects for different viscosity ratios: 1 - 1 MPa•s; 2 - 200 MPa•s; 3 - 400 MPa•s; 4 - 600 MPa•s

With this kind of movement is determined by the movement in the relevant time periods: $t_П = t_1 + t_2$ where t_1 – part of the period in a single move A_1, and t_2 – in A_2. Denoting $\alpha = t_1 / t_2$ и $\omega_{cp} = 2\pi / t_П$ – the average frequency of; F_1, F_2 – the amplitude of forces in the respective periods of oscillation of the contact zone.

Under these conditions, the expression of specific energy, per unit volume of the cavitation medium has the form:

$$\overline{E} = \frac{\Delta E}{V} = \frac{F \Delta x t_1}{\rho S \Delta x t_1} = \frac{F t_1 \omega_{cp}}{2\pi \rho S \alpha} \qquad (12)$$

In the formula (12) contains all the components of parameters of the dynamic action of the cavitation device and the characteristics of the technological environment. Given formula (1 – 12) are initial information for development of algorithm of calculation of the cavitation device, which implements a harmonious and non-linear law of actions on the technological environment. And the absorption coefficient is a measure of the efficiency of ultrasonic cavitation, because of (9) follows: the specific energy of shock waves generated per unit time, is equal to the product of the absorption coefficient and the intensity of the primary ultrasound waves. Therefore, the absorption coefficient defines the ratio of useful energy created in the form of shock waves are necessary for the realization of cavitation process energy.

4. CONCLUSIONS

1. An accurate description of cavitation processing technology of dispersed media depends on the choice of the model. The key parameter in the evolution of bubbles in an acoustic field is the energy, the components of which are the pressure coefficient of energy absorption, the time and speed of flow of the process.

2. We found that the characteristics of manufacturing environments, which can serve to define a rational model of technological process are: the load on the emitter, rheological properties and conditions influence the emitter.

3. The absorption coefficient is a measure of the efficiency of ultrasonic cavitation, i.e., determines the ratio of useful energy created in the form of shock waves are necessary for the realization of cavitation process energy.

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