ACOUSTO HYDRODYNAMIC METHOD OF MEASURMENT OF FLUID CAVITATIONS THRESHOLD IN LIQUID

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The two constructions for measurement of cavitations threshold in fluid are presented. The elastic underwater jet's membranes as the model of uniflow and counter flow sensor are considered. The basic frequency of membrane's auto vibration depending on characteristics of fluid and geometric parameters of construction is calculated. The numerical calculations and experimental results are compared.

KEYWORDS

Cavitations threshold, uniflow and counter flow sensor, underwater jet's membranes, hydrodynamic radiator (HDR)

1 INTRODUCTION

Recently, in connection with environmental requirements and safety techniques in ultrason-ic and sound technologies used in biomedicine and in biomedical complexes, there has been a tendency to reduce the concentration of surface-active substances, to switch to distilled water and, more preferably, to neutral liquid (coal oils, toluene and other organic liquids). In the latter case, the liquid is also an insulator, and the main role in the technology of cleaning parts of biomedical equipment from various types of contamination, emulsification and dispersion is played by the mechanical effect of cavitation on the surface of a solid body [Dudzinskii 2017, Panda 2013a, Dyadyura 2016 & 2017]. But in a few corrosive mediums it's necessary to increase the shock waves intensity from the collapsed cavity pockets and to increase the acoustic field optimal frequency [Dashchenko 2004]. The first problem can't be uniquely solved by increasing acoustic pressure level. The cavitations threshold of the working fluid should be increased as well. For example, it can be achieved by the choice of the fluid type, its solid and fluid dirt cleaning, degassing and special processing [Kuznetsov 2020]. But in some technological processes the type of the working environment is always given, and it's not always possible to maintain purity and homogeneity of fluid properties. Another way is increasing hydrostatic pressure in the working reservoir. While using axial-symmetric hydrodynamic radiator (HDR), it gives, for example, the possibility to increase the frequency of its basic tone [Dudzinskii 2004, Manicheva 2007, Sukhodub 2018] simultaneously with increasing the acoustic signal level. But in this case, there is an opposite tendency: a certain value of the static overpressure decreases the cavitation effectiveness. Besides, in the course of time in the technological process the working fluid composition changes and it leads to the changes in its acoustic characteristics in the cavitations threshold in particular. That's why we have the problem of simple express analyses of this important for technologies physical quantity.

2 THEORETICAL AND REAL FLUID CAVITATIONS THRESHOLD

While examining the problem of cavity strength, is often refered to. In this work the ideal fluid tensile strength was calculated without cavitation nuclei in it. Theoretically the tensile strength for water was calculated of the order of *160MPa*, though maximally achieved cavitations threshold runs into only *28 MPa* [Zaloga 2019 & 2020] for special processing of some quantity of water. While watching the cavitation in real natural and laboratory conditions for usual water settled during a week, its strength runs into some atmospheres [Balara 2018, Duplakova 2018, Flegner 2019 & 2020, Monkova 2013, Murcinkova 2019, Baron 2016, Mrkvica 2012, Zaborowski 2007, Chaus 2018, Vagaska 2017 & 2021, Straka 2018a,b, Michalik 2014, Olejarova 2017, Rimar 2016, Panda 2013b, Sedlackova 2019, Kurdel 2014 & 2022, Labun 2017 & 2019, Pollak 2019 & 2020, Svetlik 2014]. A number of investigators suppose that the fluid cavitation strength appreciably influenced by the concentration and sizes of particles weighed in the fluid. In a number of experimental works, it was shown [Esche 1952] that the fluid strength decreases with the grows of air concentration and solid dirt in it. As to the dependence on the static overpressure, the cavitations threshold increases asymptotically to *1.4 MPa* [Panda 2011a].

In Aculichev's work [Dudzinskii 2004] the steam cavitations threshold for fluid was expressed by the amplitude value of the acoustic pressure P_{mc}, when cavitation appears

$$P_{mc} = P_0 - P_n + \left(\frac{\sigma}{r_0} + \frac{kT \cdot \ln(\nu A)}{4\pi r_0^3}\right) \cdot \left(1 + 2\cos\frac{4\pi + \varphi}{3}\right),$$

$$\varphi = \arccos\left[1 - \frac{2\sigma^3 / r_0^3}{\left(\frac{\sigma}{r_0} + \frac{kT \cdot \ln(\nu A)}{4\pi r_0^3}\right)^3}\right], \qquad (1)$$

where $P_0 = (P_{atm} + \Delta P_{st})$ – hydrostatic pressure in no disturbed fluid, P_{atm} – atmospheric pressure; ΔP_{st} – static overpressure in fluid; P_n – saturated steam pressure in bubbles over the radius r_0 at the temperature T, k – Boltzman's constant, σ – the surface tension coefficient ν – average wait-ing time of breaking continuum, A – constant factor. If $\nu = 1s$, many investigators have A over the range $10^{14}s^{-1}$ … $10^{36}s^{-1}$. That is why on the work [Panda 2011b, Valicek 2016] the average value $\nu A = 1025$ is used. On Syroteuk's [Dudzinskii 2001] work the fluid cavitations threshold is calculated according to the formula:

$$P_c = P_0 - P_n + \frac{2}{3\sqrt{3}}\sqrt{\frac{\left(2s/r_0\right)^3}{P_0 - P_n + 2s/r_0}}, \qquad (2)$$

where the fluid temperature influence is considered by the functional dependence $r_0(T)$ and the notation of physical values is the same as in expression (1).

Fig. 1 presents the water cavitations threshold experimental measurement at *t° = 30°C* (curve 1) which wasn't specially processed, and the results of the calculations according to Aculichev (curve 2) and Syroteuk (curve 3). Both models don't conform to the real value of the tap water strength over the range of static overpressure $\Delta P_{st}=[0;0.5]$ *MPa* not only quantitatively but also qualitatively. Actually, for the real water which has been precipitating for some weeks, the cavitation threshold depends nonlinearly on ΔP_{st}, asymptotically approaching the value *1.4 MPa* which corresponds to the data [Dudzinskii 2001 & 2004] despite that according to Aculichev and Syroteuk, the water strength will unlimitedly increase with static overpressure increase accordance with the linear law.

The cavitations threshold measurement by means of static and dynamic methods require much time. Besides, in most cases it's impossible to measure this physical quantity without shutdown the technological process. If to use a hermetic reservoir with hydrostatic pressure one should take a sample from the reactors is dangerous.

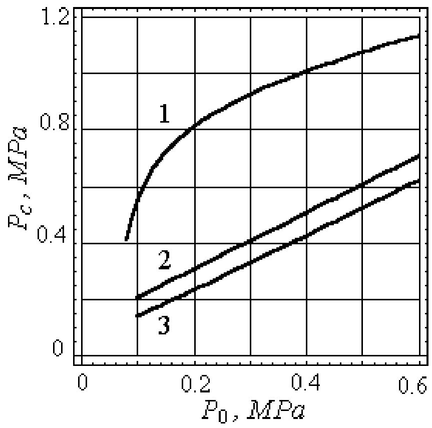

Figure 1. The water cavitations threshold dependence on hydrostatic pressure: 1 – Blake's results [Kornfeld 1951, Knapp 1974], 2 – calculation according to the formula (1), 3 – calculation according to the formula (2)

In the previous investigations the principal possibility of the work uniflow and counterflow types of axially symmetric hydrodynamic radiators (HDR) in the conditions of static overpressure [Dudzinskii 2004, Manicheva 2007] was shown. The aim of this work is a theoretical and experimental investigation of the dependence of the base harmonics frequency of elastic waves which are generated by HDR on the static overpressure in the hermetic working reservoir. It's necessary also to prove the possibility of using signal frequency for the cavitations threshold estimation in fluid.

3 THE INFLUENCE OF THE FLUID CAVITATION THRESHOLD ON THE COEFFICIENT OF ELASTICITY OF THE FLOODED AXIAL-SYMMETRIC JET MEMBRANE

The uniflow and counterflow radiators peculiarity is the absence of the of construction vibrating elements which determine their continuous lifetime [Dudzinskii 2006]. In the uniflow radiators the frequency of the base harmonics of the acoustic signal is given by the elastic flooded jet membrane 2 (cylindrical or conical form), which flows of the circular aperture nozzle 1 and is formed by the benched barrier 3 (Fig. 2). The sources of the sound generation are prime 4 and secondary 5 cavitaional vortexes which are periodically collapsed and generate highly intensive elastic waves. In the shadow photography of the given type of the HDR (Fig. 3) one can see a jet membrane and a prime circular vortex [Manicheva 2018, Bondar 2013].

See the counterflow HDR (Fig. 4). The flooded jet which goes out of nozzle 1 is formed in jet membrane 2 reflector with parabolic hole 3. In this case the jet membrane length is defined by the distance from the reflector end to the nozzle end. Prime 4 and secondary 5 toroidal vortexes are also present. In the photo of the counterflow HDR (Fig. 5) one can see the prime and circular vortexes. The principle of the sound generation is completely identical to the given above.

Geometrical parameters of the axial-symmetric radiator:

$r = 0.5\cdot(D_c+D_{max})$; *ℓ, h* – the diameter of the equivalent cylinder, the height and the thickness of the membrane, correspondingly (Figs. 2 and 4).

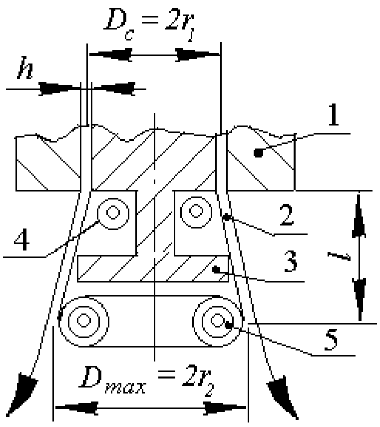

Figure 2. Uniflow HDR physical model

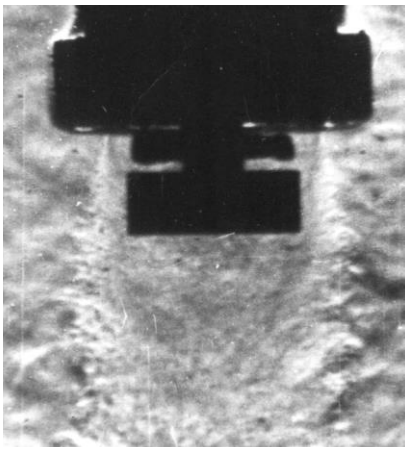

Figure 3. Uniflow HDR shadow photo of the prime vortex and jet membrane

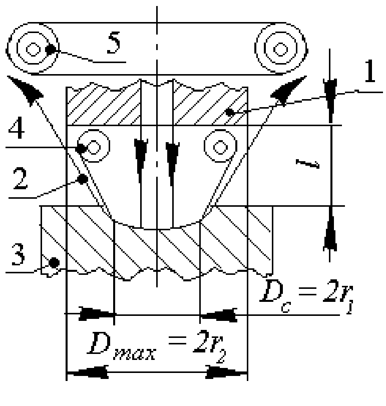

Figure 4. Counterflow HDR physical model

Hydrodynamic parameters: ρ, $æ_i$, P^* – density, parameters of adiabatic compressibility, intrinsic pressure, correspondingly, v – the jet velocity. One can show that at the optimal adjustment of the HDR the parameter ℓ is expressed by v. The middle length jet membranes (the height over the radius order of magnitude radius, i. e. $\pi r/\ell \sim 1$) for which the angle between the generatrix and the height is small were considered. That's why well use a cylindrical membrane with the first pinned and the second free base as a model. The jet membrane is deformed under the force uniformly distributed on its inner surface (the geometric parameters are considered to be known).

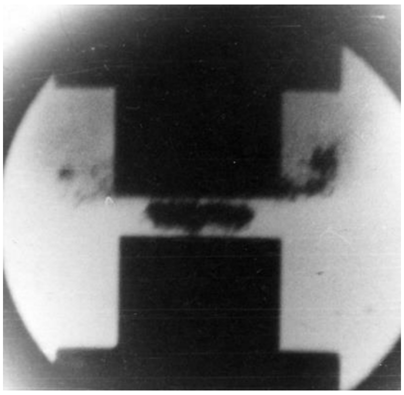

Figure 5. Counterflow HDR photo of the prime and secondary vortexes

The expression was obtained for the frequency of the base harmonics of the fluid jet natural oscillations by the method described in [Manicheva 2010, Dudzinskii 2006]:

$$f_0 = \frac{1}{2\pi \cdot r} \cdot \sqrt{\frac{12 + k_0^4 r^2 h^2}{12\rho} \cdot E}. \qquad (3)$$

In formula (3): E – the flooded jet membrane coefficient elasticity, $k_0 = 1.5708/\ell$ for uniflow HDR and $k_0 = 1.8751/\ell$ for counterflow HDR – the parameters corresponding to the base harmonics of the membrane natural oscillations. As one would expect, the flooded jet membrane natural frequency is inversely proportional to its average radius and directly proportional to its square root of the coefficient of elasticity to the fluid density ratio. It is known that for the elastic body the oscillation frequency increases if its body size decreases, and it is directly proportional to the radical of the material elasticity to the body mass ratio [Krenicky 2020, Olejarova 2021]. Consider value E.

In the most of practical problems, where one should consider fluid compressibility, Tate model is used where fluid compressibility modulus is defined by the expression:

$$K = \sum_{i=1}^{n} æ_i \cdot \left(P_* + \Delta P_{cm}\right)^i, \qquad (4)$$

where ΔP_{st} is static overpressure as compared with the atmospheric pressure, P_* is the fluid inner pressure depends on the temperature, the coefficient $æ_1$ characterizes the fluid elastic properties deviation of Gook law as the first approximation and isn't practically changed in a wide range of temperature but depends on the inclusion concentration (small dispersed solid particles, cavitation flow etc.). For the most of fluids its value in the linear approximation [Kornfeld 1951] is over the range 4 … 12. The non-linear parameters $æ_2 >> æ_3 >> \ldots >> æ_n$. The problem of higher order non-linear parameters is equivalent to how much natural fluid corresponds to Tate fluid.

Then the modulus of the cylindrical elastic jet membrane in the case of Poisson's null coefficient assumes the form [Manicheva 2018]:

$$E = \frac{K}{3(1-2\nu)} = \frac{1}{3} \cdot \sum_{i=1}^{3} æ_i \cdot \left(P_* + \Delta P_{cm}\right)^i, \qquad (5)$$

where $\nu = 0$ – Poisson's coefficient. Suppose that axial-symmetric HDR in the active zone of sound generation create a developed cavitation, then in the last expression one should change the fluid inner pressure for its cavitations threshold ($P_* \rightarrow P_c$) [Manicheva 2018].

Taking into account expression (5), one can rewrite formula (3) for the base harmonic's frequency:

$$f_0^2 = \frac{12 + k_0^4 r^2 h^2}{144\pi^2 \rho r^2} \cdot \sum_{i=1}^{3} æ_i \cdot \left(P_* + \Delta P_{cm}\right)^i, \qquad (6)$$

To get "visible" solution substitute the water characteristics ($\rho = 10^3 kg/m^3$; $æ_1 = 7.1$; $æ_2 = 8 \cdot 10^{-6}$; $æ_3 = 10^{-11}$) and the parameters of the given uniflow HDR with circular nozzle and benched barrier ($k_0 = 187.51$; $r = 9 \cdot 10^{-3} m$). In the last expression. Cubic equation (6) has two complex roots (without physical sense) and one real root. If to ignore the infinitesimal components in the expression of this root, we'll finally have

$$P_c = -2.6667 \cdot 10^5 + \Delta P_{st} - \frac{6.2676}{D} + 2.6457 \cdot 10^{10} \cdot D,$$

$$D = \Big(4.0880 \cdot 10^{-15} + 2.5848 \cdot 10^{-20} \cdot \Big(f_0^2 + \sqrt{4.4818 \cdot 10^{10} + 3.1631 \cdot 10^5 \cdot f_0^2 + f_0^4}\Big)\Big)^{1/3}. \qquad (7)$$

In the formula (7) $P_c[Pa]$, $\Delta P_{st}[Pa]$, $f_0[Hz]$ and the numerical multiplier factors also have corresponding dimensions. If to substitute geometrical characteristics of another axial-symmetric HDR in equation (6) we'll get similar (7) formula with some other multiplier factors which can be used as well. Later it will be shown that there is no principal difference whether a uniflow or counterflow radiator is used.

4 THE ANALYSES OF EXPERIMENTAL RESULTS

The experiment was carried out using a uniflow radiator with circular nozzle and benched barrier (Figs. 2 and 3) and a counterflow radiator (Figs. 4 and 5). The working fluid was tap water settled for a month in a room with minimum temperature changes. Static overpressure was created in a small hermetic sound-conducting reservoir (high pressure polyethylene) inside of which one of the described above hydrodynamic radiators was placed. This reservoir was placed in a big tank with same water for the big fluid mass to prevent from its quick heating.

Radiators in all dimensions were toned to the maximum sound level at the account of adjusting optimum jet velocity at the nozzle exit [Knapp 1974]. Static overpressure in the working reservoir was measured by a manometer, the signal frequency – by a hydrophone and a spectrum analyzer (a frequency meter can be used in the regime of measuring time intervals – oscillations period).

In Fig. 6 the results of the cavitations water strength are given. Broken curve 1 shows the results obtained by Blake [Kornfeld 1951, Knapp 1974]; continuous curve – the calculation results according to formula (6). It's necessary to increase the flooded axially symmetric jet velocity by increasing pump discharge. As the uniflow HDR uses more discharge in in comparison with the counterflow HDR in the same conditions for the given type of radiator the hydrostatic pressure was limited by the range P_0 = [0.1;0.24] *MPa* [Manicheva 2021]. In the range above P_0 = [0.24;0.6] *MPa* a counterflow radiator was used. Round points are the experimental data with uniflow HDR with circular nozzle and benched barrier, square points – counterflow HDR.

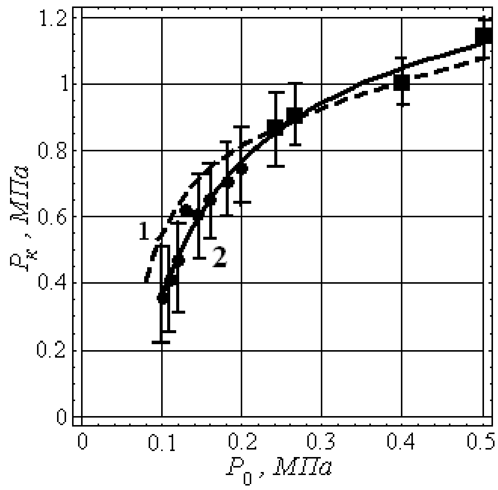

Figure 6. Tap water cavitations threshold dependence on hydrostatic pressure: 1 – Blake's results [Kornfeld 1951, Knapp 1974], 2 – calculation according to formula (6) methods [Manicheva 2021], • – experimental results with the uniflow HDR, ■ – experimental results with the counterflow HDR

As Fig. 6 shows, for the fluid cavitations threshold measurement the type of the axial-symmetric hydrodynamic radiator is of no importance. The error of the proposed method doesn't exceed 5%. The obtained dependence of the tap water cavitations threshold on hydrostatic pressure asymptotically approaches 1.4*MPa*, and it doesn't contradict the data of the works [Kornfeld 1951, Esche 1952, Knapp 1974]. One can also see that the theoretical and experimental results of the given investigations don't differ much from Blake's experimental results which were obtained by other methods.

CONCLUSIONS

The analytical dependence of the frequency of the acoustic signal base tone, generated by the axial-symmetric HDR on the geometric parameters of a jet membrane, fluid hydrodynamic parameters and hydrostatic pressure in the working reservoir, has been obtained of biomedical system.

It has been determined that the fluid strength nonlinearly depends on the hydrostatic pressure asymptotically approaches value of *1.4MPa*. In this case not only linear parameters but also the first two nonlinear parameters in the expression for the fluid adiabatic compressibility should be considered.

The possibility of a fluid cavitations threshold definition by means of measuring the hydrostatic pressure in the working reservoir and the acoustic signal basic harmonics frequency has been shown of biomedical system.

Acknowledgements

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REFERENCES

[Balara 2018] Balara, M., Duplakova, D., Matiskova, D. Application of a signal averaging device in robotics. Measurement, 2018, Vol. 115, No. 2, pp. 125-132.

[Baron 2016] Baron, P., Dobransky, J., Kocisko, M., Pollak, M., Cmorej, T. The parameter correlation of acoustic emission and high-frequency vibrations in the assessment process of the operating state of the technical system. Acta Mechanica et Automatica, 2016, Vol. 10, No. 2, pp. 112-116.

[Bodnar 2013] Bondar, A.A., Vitkov, V.V., Dudzinsky, Yu.M., Manicheva, N.V. Erosive activity in the near field of a jet hydrodynamic emitter. Electronics and communication, 2013, No. 2, pp. 91-96.

[Chaus 2018] Chaus, A.S., Pokorny, P., Caplovic, E., Sitkevich, M.V., Peterka, J. Complex fine-scale diffusion coating formed at low temperature on high-speed steel substrate. Applied Surface Science, 2018, Vol. 437, pp. 257-270. ISSN 0169-4332.

[Dashchenko 2004] Dashchenko, A., Dudzinskii, Yu. Natural oscillations of a jet membrane under hydrostatic pressure. International Applied Mechanics, 2004, Vol. 40, No. 12, pp. 1385-1390.

[Dudzinskii 2001] Dudzinskii, Yu.M., Manicheva N.V., Nazarenko, O.A. Cavitation erosion at excess static pressure. Proceedings of the Odessa Polytechnic University, 2001, Vol. 3, No. 15, pp. 114-118.

[Dudzinskii 2004] Dudzinskii, Yu., Manicheva, N., Nazarenko, A. Optimization of parameters of a broadband acoustic source under static overpressure. Internat. J. of Fluid Mechanics Research, 2004, Vol. 31, No. 5.

[Dudzinskii 2006] Dudzinskii, Yu.M., Sukhar'kov, A.O., Manicheva, N.V. Power characteristics of the uniflow hydrodynamic sound source under the conditions of hydrostatic pressure. Internat. J. of Fluid Mechanics Research, 2006, Vol. 33, No. 2.

[Dudzinskii 2017] Dudzinsky, Yu.M., Manicheva, N.V., Zhukova, A.V. Strumine acoustic viprominuvacs for biotechnologies. Biomedical Engineering - Kyiv, Ukraine, 2017, No. 4, pp. 33-36.

[Duplakova 2018] Duplakova, D., et al. Determination of optimal production process using scheduling and simulation software. International Journal of Simulation Modelling, 2018, Vol. 17, No. 4, p. 447.

[Dyadyura 2017] Dyadyura, K.O., Sukhodub, L.F. Magnesium-based matrix composites reinforced with nanoparticles for biomedical applications. Proceedings of the 2017 IEEE 7th International

Conference on Nanomaterials: Applications and Properties, NAP 2017, 2017, 2017-January, 04NB14.
[Flegner 2019] Flegner, P., Kacur, J., Durdan, M., Laciak, M. Processing a measured vibroacoustic signal for rock type recognition in rotary drilling technology. Measurement, 2019, Vol. 134, pp. 451-467.
[Flegner 2020] Flegner, P., Kacur, J., Durdan, M, Laciak, M. Statistical Process Control Charts Applied to Rock Disintegration Quality Improvement. Applied sciences, 2020, Vol. 10, No. 23, pp. 1-26.
[Jurko 2011] Jurko, J., Panda, A., Gajdos, M., Zaborowski, T. Verification of cutting zone machinability during the turning of a new austenitic stainless steel. In: Advanced Computer Science and Education Applications: International Conference CSE 2011, Heidelberg: Springer, 2011, pp. 338-345. ISBN 978-3-642-22456-0.
[Jurko 2012] Jurko, J., Dzupon, M., Panda, A., Zajac, J. Study influence of plastic deformation a new extra low carbon stainless XCr17Ni7MoTiN under the surface finish when drulling. Advanced Materials Research, 2012, Vols. 538-541, pp. 1312-1315.
[Jurko 2013] Jurko, J., Panda, A., Behun, M. Prediction of a new form of the cutting tool according to achieve the desired surface quality. Applied Mechanics and Materials, 2013, Vol. 268, No. 1, pp. 473-476.
[Krenicky 2020] Krenicky, T., Servatka, M., Gaspar, S., Mascenik, J. Abrasive Water Jet Cutting of Hardox Steels-Quality Investigation. Processes, 2020, Vol. 8, Issue 12, Art. No. 1652.
[Kurdel 2014] Kurdel, P., Labun, J., Adamcik, F. The Estimation Method of the Characteristics of an Aircraft with Electromechanic Analogue. Nase More, 2014, Vol. 61, No. 1-2, pp. 18-21. ISSN 0469-6255.
[Kurdel 2022] Kurdel, P., Ceskovic, M., Gecejova, N., Adamcik, F., Gamcova, M. Local control of unmanned air vehicles in the mountain area. Drones, 2022, Vol.54, No.6, pp. 1-18. ISSN 2504-446X.
[Kuznetsov 2020] Kuznetsov, E., Nahornyi, V., Krenicky, T. Gas Flow Simulation in The Working Gap of Impulse Gas-barrier Face Seal. Management Systems in Production Engineering, 2020, Vol. 28, No. 4, pp. 298-303.
[Labun 2017] Labun, J., Fabry, S., Ceskovic, M., Kurdel, P. Mechanical demodulation of aircraft antenna signal. In: 6th Int. Conf. on Air Transport (INAIR), Prague, 14-16 Nov. 2017. Elsevier, pp. 149-155. ISSN 2352-1465.
[Labun 2019] Labun, J., Kurdel, P., Ceskovic, M., Nekrasov, A., Gamec, J. Low Altitude Measurement Accuracy Improvement of the Airborne FMCW Radio Altimeters. Electronics, 2019, Vol.8, No.8., pp. 1-12.
[Manicheva 2007] Manicheva, N.V. Energy of submerged conical jet shells. In: Proc. of All-Ukr. Acoustic Symp. Consonance 2007, 25-27 September 2007. Kyiv, 2007, pp. 176-182.
[Manicheva 2010] Manicheva, N.V., Dudzinsky, Yu.M., Vitkov, V.V. Improving the efficiency of cavitation in a dual-frequency ultrasonic field. Engineering, 2010, No. 5, pp. 45-47.
[Manicheva 2018] Manicheva, N.V. Jet Acoustic Radiators for Biomedical Apparatus. Dissertation Thesis. National Technical University of Ukraine Igor Sikorsky Kyiv Polytechnic Institute. Kyiv, Ukraine, 2018, 207 p.
[Manicheva 2021] Manicheva, N., Dudzinskii, Yu., Titova, N., Zakharova, A. Determination of the nonlinear parameter and internal pressure in a liquid by the acoustic method. Proc. of Odessa Polytechnic Univ., Odessa, Ukraine, 2021, Issue 1(63), pp. 88-94.
[Michalik 2014] Michalik, P., Zajac, J., Hatala, M., Mital, D. and Fecova, V. Monitoring surface roughness of thin-walled components from steel C45 machining down and up milling. Measurement, 2014, Vol. 58, pp. 416-428, ISSN 0263-2241.
[Monkova 2013] Monkova, K., Monka, P., Jakubeczyova, D. The research of the high speed steels produced by powder and casting metallurgy from the view of tool cutting life. Applied Mechanics and Materials, 2013, Vol. 302, pp. 269-274.
[Mrkvica 2012] Mrkvica, I., Janos, M., Sysel, P. Cutting efficiency by drilling with tools from different materials. Advanced Materials Research, 2012, Vols. 538-541, pp. 1327-1331. ISSN1022-6680.
[Murcinkova 2019] Murcinkova, Z., Vojtko, I., Halapi, M., Sebestova, M. Damping properties of fibre composite and conventional materials measured by free damped vibration response. Advances in Mechanical Engineering, Vol. 11, No. 5, 1687814019847009.
[Olejarova 2017] Olejarova, S., Dobransky, J., Svetlik, J., Pituk, M. Measurements and evaluation of measurements of vibrations in steel milling process. Measurement, 2017, Vol. 106, pp. 18-25.
[Olejarova 2021] Olejarova, S. and Krenicky, T. Water Jet Technology: Experimental Verification of the Input Factors Variation Influence on the Generated Vibration Levels and Frequency Spectra. Materials, 2021, Vol. 14, 4281.
[Panda 2011a] Panda, A., Duplak, J., Jurko, J. Analytical expression of T-vc dependence in standard ISO 3685 for cutting ceramic. Key Engineering Materials, 2011, Vols. 480-481, pp. 317-322.
[Panda 2011b] Panda, A., Duplak, J., Jurko, J., Behun, M. Comprehensive Identification of Sintered Carbide Durability in Machining Process of Bearings Steel 100CrMn6. Advanced Materials Research, 2011, Vol. 340, pp. 30-33.
[Panda 2013a] Panda, A., Duplak, J., Jurko, J., Behun, M. New experimental expression of durability dependence for ceramic cutting tool. Applied Mechanics and Materials, 2013, Vols. 275-277, pp. 2230-2236.
[Panda 2013b] Panda, A., Duplak, J., Jurko, J. Pandova, I. Roller Bearings and Analytical Expression of Selected Cutting Tools Durability in Machining Process of Steel 80MoCrV4014. Applied Mechanics and Materials, 2013, Vol. 415, pp. 610-613.
[Pollak 2019] Pollak, M., Kascak, J., Teliskova, M., Tkac, J. Design of the 3D printhead with extruder for the implementation of 3D printing from plastic and recycling by industrial robot. TEM Journal, 2019, Vol. 8, No. 3, pp. 709-713.
[Pollak 2020] Pollak, M., Torokova, M., Kocisko, M. Utilization of generative design tools in designing components necessary for 3D printing done by a robot. TEM Journal, 2020, Vol. 9, No. 3, pp. 868-872.
[Rimar 2016] Rimar, M., Smeringai, P., Fedak M., Kuna S. Technical and software equipment for the real time positioning control system in mechatronic systems

with pneumatic artificial muscles. Key Engineering Materials, 2016, Vol. 669, pp. 361-369.
[Sedlackova 2019] Sedlackova, A.N., Kurdel, P., Labun, J. Simulation of Unmanned Aircraft Vehicle Flight Precision. In: Int. Sci. Conf. on LOGI - Horizons of Autonomous Mobility in Europe, Ceske Budejovice, 14-15 November 2019; Elsevier, pp. 313-320. ISSN 2352-1465.
[Straka 2018a] Straka, L., Hasova, S. Optimization of material removal rate and tool wear rate of Cu electrode in die-sinking EDM of tool steel. Int. J. of Adv. Manuf. Technol., 2018, Vol. 97, No. 5-8 , pp. 2647-2654.
[Straka 2018b] Straka, L.., Hasova, S. Prediction of the heat-affected zone of tool steel EN X37CrMoV5-1 after die-sinking electrical discharge machining. In: Proc. of the institution of mechanical engineers part B - Journal of engineering manufacture, 2018, Vol. 232, No. 8, pp. 1395-1406.
[Sukhodub 2018] Sukhodub, L., Dyadyura, K. Design and fabrication of polymer-ceramic nanocomposites materials for bone tissue engineering. J. of Nano- and Electronic Physics, 2018, Vol. 10, No. 6, 06003.
[Svetlik 2014] Svetlik, J., Baron, P., Dobransky, J., Kocisko, M. Implementation of Computer System for Support of Technological Preparation of Production for Technologies of Surface Processing. Applied Mechanics and Materials, 2014, Vol. 613, p. 418. DOI: 10.4028/www.scientific.net/AMM.613.418.
[Vagaska 2017] Vagaska, A., Gombar, M. Comparison of usage of different neural structures to predict AAO layer thickness. Technicki Vjesnik-Technical Gazette, 2017, Vol. 24, Issue 2, pp. 333-339. DOI: 10.17559/TV-20140423164817.
[Vagaska 2021] Vagaska, A., Gombar, M. Mathematical Optimization and Application of Nonlinear Programming. Studies in Fuzziness and Soft Computing, 2021, Vol. 404, Issue 2021, pp. 461-486. DOI: 10.1007/978-3-030-61334-1_24.
[Valicek 2016] Valicek, J., et al. Mechanism of Creating the Topography of an Abrasive Water Jet Cut Surface. In: Machining, joining and modifications of advanced materials. Series: Advanced Structured Materials, 2016 Vol. 61, pp. 111-120. Springer Verlag, Singapore. ISBN 978-981-10-1082-8.
[Zaborowski 2007] Zaborowski, T. Ekowytwarzanie. Gorzow, 2007, 100 p.
[Zaloga 2019] Zaloga, V., Dyadyura, K., Rybalka, I., Pandova, I. Implementation of Integrated Management System in Order to Enhance Equipment Efficiency. Management Systems in Production Engineering, 2019, Vol. 4, pp. 221-226.
[Zaloga 2020] Zaloga, V., Dyadyura, K., Rybalka, I., Pandova, I., Zaborowski, T. Enhancing efficiency by implementation of integrated management system in order to align organisational culture and daily practice. Management Systems in Production Engineering, 2020, Vol. 28, No. 4, pp. 304-311.

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