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INFLUENCE OF THE UNIFORM OUTFLOWING ON ANGULAR MOTION OF RESERVOIR WITH LIQUID UNDER IMPULSE EXCITATION

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Problem of dynamics of cylindrical reservoir, partially filled by ideal incompressible liquid, on pendulum suspension under external impulse loading is investigated within the framework of model of combined motion. The system reservoir–liquid with a free surface, being initially at rest, is subjected to external impulse excitation of rectangular profile during the 1st second of motion. We assume that dimensionless liquid filling depth H (related to the radius R of the reservoir) changes according to the given law: $H = H_0 + t\Delta H$, where t – time period, ΔH – constant outflowing speed. Local effects of the outflowing are neglected. Mathematical model of the system reservoir-liquid is an assembly of kinematic (1) and dynamic constraints, initial conditions and equations of motion.

$$\Delta\varphi = 0,\ \Delta\vec{\Omega} = 0 \ \text{ в } \tau;\ \frac{\partial\varphi_0}{\partial n} = 0,\ \frac{\partial\vec{\Omega}}{\partial\vec{n}} = \vec{r}\times\vec{n} \ \text{ на } \Sigma \ ;\ \frac{\partial\vec{\Omega}}{\partial\vec{n}} = \vec{r}\times\vec{n} \ \text{ на } S;$$

$$\frac{\partial\xi}{\partial t} + \vec{\nabla}\xi\cdot\left[\vec{\nabla}\varphi_0 + \vec{\nabla}(\vec{\omega}\cdot\vec{\Omega}) - \dot{\vec{\varepsilon}} - \vec{\omega}\times\vec{r}\right] = \frac{\partial\varphi_0}{\partial z} + \vec{\omega}\cdot\frac{\partial\vec{\Omega}}{\partial z} - \dot{\varepsilon}_z - (\vec{\omega}\times\vec{r})\big|_z\ ,\xi = z. \quad (1)$$

Equations of motion and dynamic boundary conditions are obtained on the basis of Hamilton–Ostrogradsky variational principle (2) with the Lagrange function of (3).

$$\delta\int_{t_1}^{t_2} L\ dt = 0, \quad (2)$$

$$L = \frac{1}{2}\rho\int_{\tau}\left[\vec{\nabla}\varphi + \vec{\nabla}(\vec{\omega}\cdot\vec{\Omega})\right]^2 d\tau + \frac{1}{2}I^{ij}_{res}\omega_i\omega_j +$$

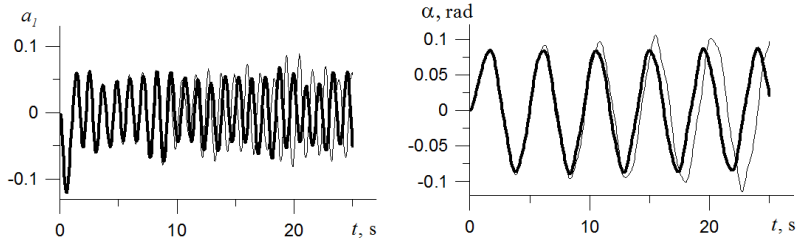
$$+\rho g\left(\cos\alpha_1\sin\alpha_2\cos\alpha_3 - \sin\alpha_1\sin\alpha_3\right)\int_{S_0} r\cos\theta(\xi + H)dS -$$

$$-\rho g\left(\sin\alpha_1\cos\alpha_3 + \cos\alpha_1\sin\alpha_2\sin\alpha_3\right)\int_{S_0} r\sin\theta(\xi + H)dS -$$

$$-\frac{1}{2}\rho g\cos\alpha_1\cos\alpha_2\int_{S_0}\xi^2 dS - \left(M_r h_r + M_l h_l\right)\left(1 - \cos\alpha_1\cos\alpha_2\right) + \vec{M}\cdot\vec{\chi}. \quad (3)$$

Solution of the problem is built based on the approach [1, 2]. Expansions of the unknown variables are constructed to satisfy boundary conditions on the rigid surface identically and condition on the free surface of liquid up to the third order of smallness. Resolving system of equations is obtained analytically for arbitrary number of liquid normal modes *N*. Numerical data is obtained for *N=12*.

Graphs on fig. 1 illustrate peculiarities of liquid motion on the free surface and angular motion of reservoir for the cases of outflowing (thin curves) and steady filling depth of liquid (thick curves). Amplitude of angular motion of reservoir is growing in time responding to the change of liquid filling depth which is in accordance with angular momentum conservation law.



a) *b)*

Fig. 1. Amplitude of the first antisymmetric normal mode of liquid (a), amplitude of the angular motion of reservoir (b).

Analysis of the results of numerical experiments shows that uniform outflowing of liquid does not lead to significant differences in the dynamics of the system reservoir-liquid with a free surface under external impulse excitation compared with the case of constant volume of liquid. In both cases considerable oscillations on the free surface develop and manifestation of nonlinear effects is observed.

1. *Narimanov G. S., Dokuchaev L. V., Lukovsky I. A.* Nonlinear dynamics of a spacecraft with liquid. – Moscow: Mashinostroenie, 1977.
2. *Limarchenko O., Matarazzo G., Yasinsky V.* Rotational motion of structures with tanks partially filled by liquid. Nat. Techn. Univ. of Ukraine "KRI", Intern. Math. Center Nat. Acad. of Sciences of Ukraine. – K. : FADA LTD, 2003. – 286 p.

ВПЛИВ РІВНОМІРНОГО ВИТІКАННЯ НА КУТОВИЙ РУХ РЕЗЕРВУАРУ З РІДИНОЮ ПРИ ІМПУЛЬСНОМУ ЗБУДЖЕННІ

Досліджено задачу про рух циліндричного резервуару з рідиною, що має вільну поверхню, під дією зовнішнього імпульсного навантаження за наявності рівномірного витікання. Показано, що побудована математична модель механічної системи адекватно відображує основні механічні ефекти і не суперечить законам збереження. Встановлено, що наявність рівномірного витікання рідини не призводить до суттєвих відмінностей в характері руху системи під дією зовнішнього імпульсного навантаження, порівняно з випадком сталого об'єму.