10.31653/smf343.2021.81-87

Malahov O.V., Кolegaev M.O., Kiris O.B., Maslov I.Z.
National university “Odessa maritime academy”

FORCED OSCILLATIONS OF FLEXIBLE PIPELINES ON SEA SURFACE WAVING

Problem formulation

In offshore maintenance of oil platforms, a great number of technological processes on offshore fleet vessels (Diving Support Vessel, Construction Ship, Support and Supply Vessel) directly relate to the operation of flexible pipelines. Flexible pipelines are frequently used - from working fluids and fuel feeding to towing various surface and submersible craft. In some cases, in heavy seas, the flow velocities through the flexible pipeline can be very high. Ultimately, this will always lead to dangerous forced oscillations of the flexible pipeline that is used.

Analysis of recent researches and publications

A selection of the length of the pipeline that goes to the underwater part during the operation of the vessel is one of the determinants. There may be the cases when incorrectly chosen and set towing modes will lead to accidents due to large oscillations of the pipe [1, 2]. Prevention of uncontrolled oscillations is possible only in case when the relation of their frequency spectrum and the power or kinematic loads exerted by the incident flow is known.

Flexible pipelines due to their design in the form of "pipe - outer casing of insulation" do not require the use of special turns and compensators of axial movements during their operation. Their only limitation is the dependence of the working pressure on the temperature of the pumped liquid and the value of the maximum diameter as about 160 mm.

When an unrestricted flow of ambient liquid flows around the fixed pipeline (with curvature), at a certain velocity and above, the location and shedding of discrete vortices or vortex sheet will take place. In this case, the vibration will invariably occur, and it will inevitably result in the mode of undamped self-similar oscillations. Detachable flows should be considered as basic in the analysis of the interaction of the flow with the flexible pipeline.

The main problem in the use of flexible pipes is to determine their equilibrium spatial shape in the flow. The shape of a cylindrical pipe centerline in most cases is a spatial curve which at high velocities of the incident flow differs considerably from the equilibrium shape in a stable continuous flow [1]. The shape of the flexible pipeline is also of particular importance. Picture 1, taken from [1], shows four specific cross-sections, most commonly used in practice: elliptical, round, square and triangular. The diagrams below show that hydrodynamic torque doesn't arise only in case of a cylindrical cross-section. In all other cases, with an arbitrary orientation of one of the main cross section inertia axes of the flexible pipeline in relation to the direction of the incident flow velocity vector, hydrodynamic torques arise.

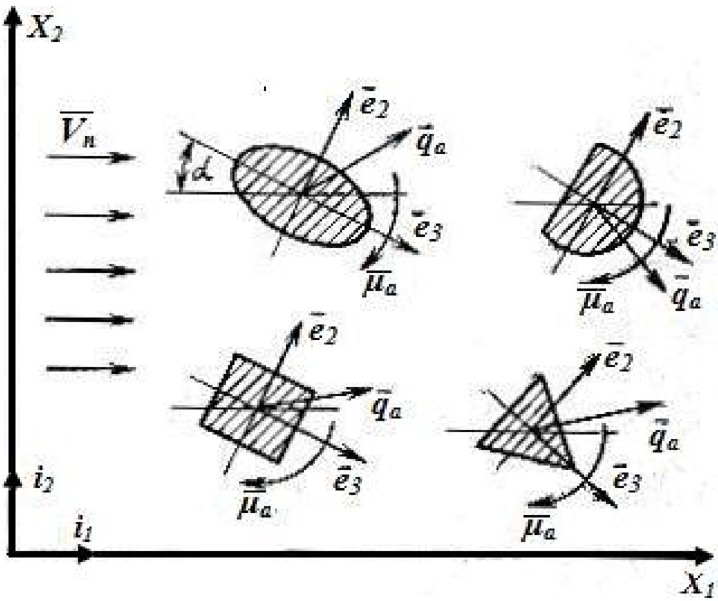

Figure 1. Influence of the shape of the flexible pipe on the nature of the interaction with the flow [1].

In a common form, the torque hydrodynamic vector can be represented as follows:

$$\vec{M} = \vec{M}_{вр}\vec{e}_1 = \frac{1}{2}C_m \rho d v_n^2 \vec{e}_1 \quad (1)$$

where $\vec{M}_{вр}$ – torque; e_1 – vector that determines the direction of the tangent to the axis line of the flexible pipe; C_m – fluid dynamical factor determined by the flow angle of attack; ρ – density of the flow; d – diameter of the flexible pipe; V_n – normal component of the incident flow velocity vector.

When considering the physical principles of flexible pipelines operation, that are exposed to ambient liquids external influence, there should be taken into account the possibility of transition with a certain combination of system critical parameters to unstable oscillations. Usually a hydraulic system, the main element of which is a flexible pipeline, is characterized by the presence of several degrees of freedom. The linear equations of oscillatory motion describing such a system include factors that change periodically [1].

Research Objective Statement

The main problem in the task of the interaction between moving flow and flexible cylindrical pipeline, which performs oscillating movements, is the lack of necessary data concerning the distribution of hydro- or aerodynamic forces on the streamlined surface. This distribution should be known depending on the shape parameter of the streamlined surface and the angle of attack of the incident flow.

Investigation results

The incident flow velocity is one of the main factors that affect the frequency of vortices shedding from the surface of a cylindrical pipe. This effect is shown in picture 2 taken from [3]. It shows that for all three researched pipelines, the dependence of the frequency of vortex shedding on the flow velocity can be approximated by a linear law. The graph also demonstrates that the decrease in pipe diameter is a positive factor for its oscillations frequency reduction - the same frequencies of vortex shedding are observed in this case at much higher velocities.

One of the main problems that arise during a flexible pipeline under water operation is the dynamic load it experiences from the incident flow. Such a load is directly dependent on the flow velocity.

As it was shown by the results of calculations of the force interaction between continuous flow and flexible pipeline, three determining parameters can be distinguished: the velocity of the incident flow; the outer diameter of the flexible pipeline; the total length of the flexible pipeline.

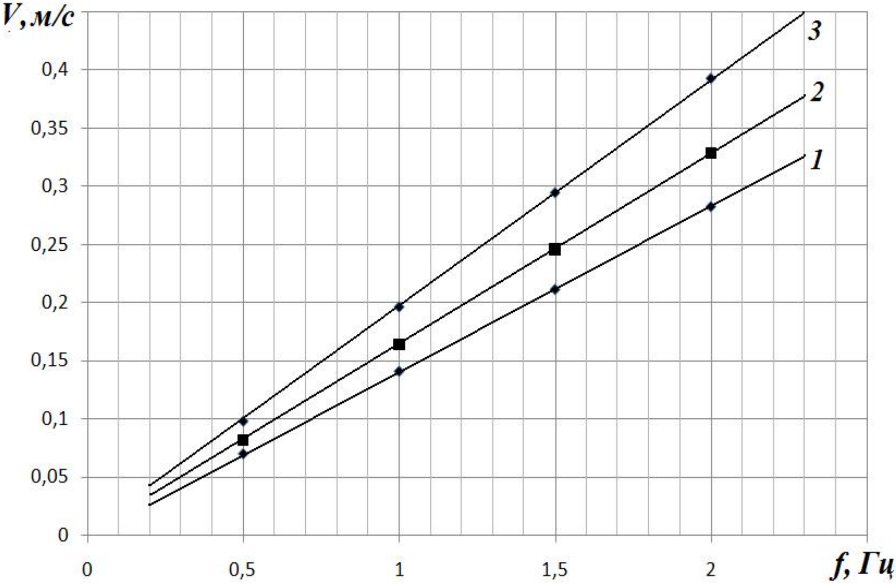

Fig. 2. Influence of flow velocity onto the frequency of vortex separation from the cylindrical pipeline [3].

1 – *D = 1,42 m*; 2 – *D = 1,22 m;* 3 – *D = 1,02 m.*

In the calculations, for the convenience of the comparative analysis of the results related to flexible pipelines with different geometry, there was used a dimensionless flow velocity U. This velocity was formulated as a ratio between the flow velocity at infinity to the flow velocity at the frontal point (zero velocity) on the surface of the pipeline.

In the calculations, the value of the distributed load per unit of length of the flexible pipeline was obtained. The results are shown in picture 3, where the abscissa shows the values of the working lengths of the submerged flexible pipe. The values of the load F, *N*, which the flexible pipeline experiences per unit of length of its linear meter, are plotted on the ordinate axis. The three calculated curves shown in the graph below correspond to three different values of dimensionless velocities of the simulated flow - U=0.31, U=0.47 and U=0.63.

The nature of the load changing onto the flexible pipe has shown that starting from the values of the dimensionless flow rate exceeding 0.63 (i.e. more than 63% of the flow velocity at infinity) the working length of the flexible pipe should be limited to a maximum value of 45 meters. Exceeding this value in the future can bring a sharp increase in the amplitude of self-oscillations of the flexible pipeline and a jump in load more than twice. Thus, as an example in fig. 3, it can be seen that the dynamic load exerted by the flow of the flexible pipe varies from 86.4 *N* per linear meter of cable to 170 N/m, i.e. almost twice.

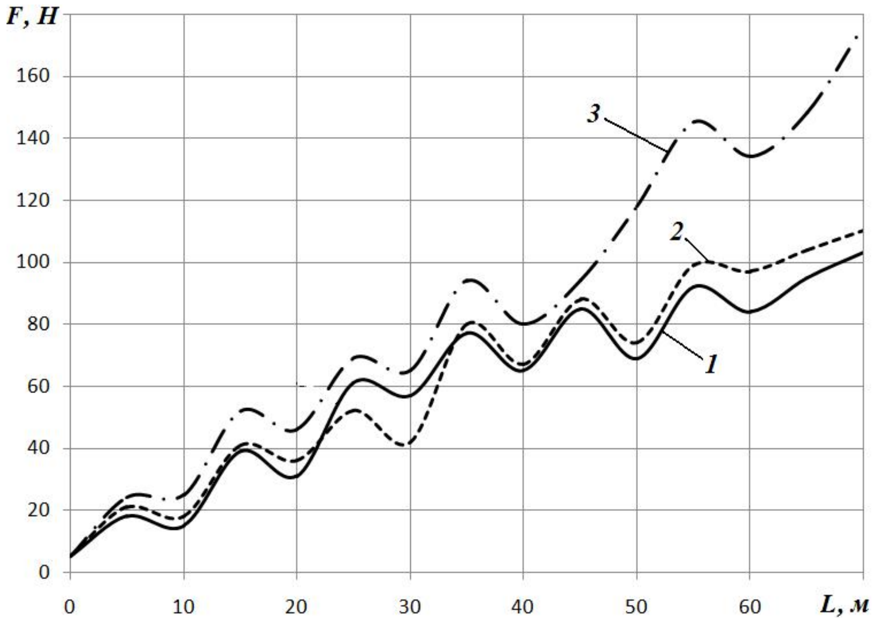

Fig. 3 Load distribution over flexible pipe.

Dimensionless flow velocity: 1 – U=0.31; 2 – U=0.47; 3 – U=0.63.

Flow picture of fluid motion over of a cylindrical flexible pipe near a flat screen, which may correspond to the seabed, the working surface of the underwater platform for divers, etc. differs from a similar interaction with a completely unrestricted flow. In such hydrodynamical process, a flexible and moving pipeline will no longer be the only source of flow perturbation. In this case, the process of vortex formation will be determined by a double system in the form: "hard screen - streamlined pipeline".

For the flexible pipeline, in the course of the flow gap movement there will be a qualitative change in the factors of frontal and lifting force. During this flow movement by analogy with Magnus effect there will appear additional forces that cause attraction or repulsion of the streamlined body to or from the shielding surface. In such a case, the higher the flow rate in the area between the body and the screen is, the greater such forces may be.

Picture 4 shows the estimated change in the value of the lifting force factor C_y depending on the dimensionless geometric parameter – a measure of the distance of the flexible pipe from the rigid flat screen $\frac{D}{H}$.

From the graph, it is gathered that when the amount of space between the pipeline and the screen decreases, the amplitude of oscillations starts to decrease. As the results of numerous studies showed, in this case, a shift in the frequency (periodicity) of oscillations of the pipeline to a greater interval takes place.

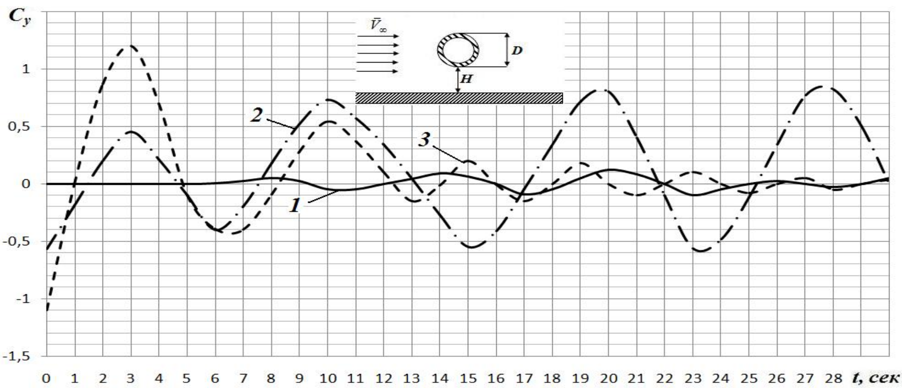

Figure 4. Time changing for lifting force factor C_y of the cylindrical pipeline at arbitrary distances from the rigid surface

$$1 - \frac{D}{H} = 0 \,;\, 2 - \frac{D}{H} = 0{,}25 \,; \qquad 3 - \frac{D}{H} = 1$$

Conclusions

1. The nature of the load changing onto the flexible pipe has shown that starting from the values of the dimensionless flow rate exceeding 0.63 (i.e. more than 63% of the flow velocity at infinity) the working length of the flexible pipe should be limited to a maximum value of 45 meters. Exceeding this value in the future can bring a sharp increase in the am-

plitude of self-oscillations of the flexible pipeline and a jump in load more than twice.

2. Flow picture of fluid motion over of a cylindrical flexible pipe near a flat screen, which may correspond to the seabed, the working surface of the underwater platform for divers, etc. differs from a similar interaction with a completely unrestricted flow.
3. When the volume of the area between the pipeline and the surface that is the screen decreases, the amplitude of oscillations starts to decrease. As it was stated during numerous studies in this case, there also took place a shift in the frequency (periodicity) of oscillations of the pipeline to a greater interval.

REFERENCES

1. Svetlitskiy V. A. Mehanika tuboprovodov i shlangov. – M.: Mashinostroenie, 1982. – 280 p.
2. Nien-Tszr Tsai. Analysis of Nonlinear Transient Motion of Cables Using Bond Graph Method. *J. Eng. Ind*. May 1972, 94(2): 500-506. https://doi.org/10.1115/1.3428182
3. Ermanuk E. V., Gavrilov N.V. Dinamicheskie kharakteristiki tsilindricheskih tel, kolebluschihsya v lineyno stratifitsirivannoy jidkosti. Vuchislitelnie Technologiy. 2001. Vol. 6. Part. 2. pp. 283–289.