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MAIN PRINCIPLES OF DETERMINING THE WORKING SECTION AND LENGTH OF SHIP'S FLEXIBLE PIPELINES

Problem statement

When determining the working section of any ship's flexible pipeline and its basic geometric dimensions it is necessary to proceed from the theoretical and experimental results for its hydro or aeroelastic vibrations. By choosing the optimal cross–section of the pipeline, it is possible to control the emerging dynamic processes in the operational mode [1]. In terms of ship conditions, a mere increase of a flexible pipeline diameter can lead to the change of self–oscillation mode from the galloping to the damped one.

Analysis of recent research and publications

To select the diameter of the working section of a cylindrical flexible pipeline, a calculation algorithm was developed.

At the first stage, when calculating the cross–sectional diameter of the pipeline, it is necessary to proceed from the condition that during its operation it will not experience bending or torsion loads. In this case, by analogy with the pipeline, which has rigid walls, the flexible pipeline must meet the operational needs of all pressure–flowrate characteristics of the particular marine hydraulic system under consideration.

For the subsequent calculations, it is necessary to set the range of changes in the initial characteristics of the flow to be transported through the pipeline. In this case, the following initial data should be stated:

– range of temperature variations for determination of the properties of the working fluid T, ^0C;

– density of the working fluid ρ, kg/m^3 and the boundaries of its variation;

– kinematic viscosity of the working fluid, ν, m^2/sec and its variation range;

– length of the pipeline, l, m;

– material of the pipeline;

– equivalent roughness of the flexible pipeline inner surface, Δ, mm;

– maximum volumetric flowrate of the working fluid, Q, cub.m/sec;

– working pressure at the beginning of the pipeline, P_1, *Pa*;

– working pressure at the end of the pipeline, P_2, *Pa*;

– the height of the initial cross-section of the pipeline, z_1, *m*;

– the height of the finite cross-section of the pipeline, z_2, *m*;

– all flow friction factors and related local loss rate, ζ.

When specifying the numerical value of the flow viscosity to be transported through the pipeline, it is necessary to select the numerical values that correspond to the minimum values within the set temperature range. In relation to the density of the flow transported, this rule shall be applied in the opposite manner – the subsequent calculation shall make use of the maximum numerical density value.

It is necessary to determine the hydromechanical mode of the working fluid flow inside the pipeline.

In case when the pipeline is operated in a laminar mode of the working fluid flow, its diameter can be calculated as

$$d = \sqrt[4]{\frac{128\nu\left(l+\left(\sum\varsigma\frac{V^2}{2g}\right)\right)Q}{\pi g\left(\frac{p_1}{\rho g}-\left(\left(z_2-z_1\right)+\frac{p_2}{\rho g}\right)\right)}} \qquad (1)$$

If the operation of the pipeline is carried out in a turbulent mode of fluid flow, the convergence method is used, as per which it is necessary:

– to set a series of standard values for internal diameters within the next range: *D, mm*: *4, 6, 8, 9.5, 12.14, 16, 18, 22, 24, 25, 27, 30, 32, 35, 38, 40, 42, 48, 51, 54, 58, 63, 70, 76, 90*.

The selection of the diameter from this range should be done given that the tolerances within the range from *4* to *40 mm* are *0.5 mm*, and within the range from *42* to *90 mm* they are equal to *1 mm* [2, 3, 4].

– for the flowrate value *Q* which is set in the raw data, a number of values of the required head H_n are calculated according to the equation

$$H_n = (z_2 - z_1) + \frac{p_2}{\rho g} + \left(\sum \zeta + 0.11 \left(\frac{\Delta}{d} + \frac{68}{Re} \right)^{0.25} \frac{l}{d} \right) \frac{16Q^2}{2g\pi^2 d^4}$$
(2)

where Re – Reynolds number;
– to plot H_n against d;

– based on the set value of the available head $H_p = \frac{p_1}{\rho g}$ (meter of water column, mH2O), the pipeline diameter d could be calculated using the plotted relationship.

After determining the value of the calculated diameter using the reference literature [2, 3, 4, ...], a standard greater diameter should be selected.

The size of the pipeline diameter should be adjusted taking into account the actual conditions of its operation on board ships.

As it can be seen in figure 1, during their operation on board flexible pipelines can change their cross–section shape under bending load. In figure 1, the initial diameter D_1 of the cylindrical pipe is reduced to the diameter D_2 of the elliptical pipe.

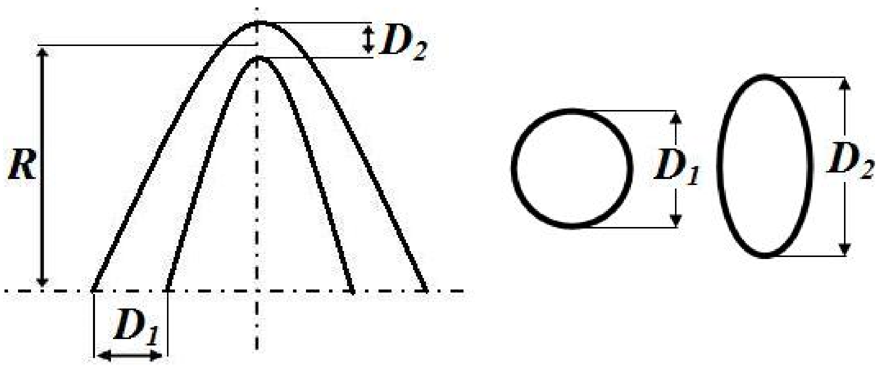

Fig. 1. Geometry of flexible pipeline while bending.

In this case, the flexible pipeline bending radius R can exceed its initial diameter D_1 up to five times.

For these reasons, it is necessary to ensure the stability of the flexible pipeline, regardless of the change in diameter. In this case, when selecting the working diameter, and therefore the shape of the pipe cross–section, it is necessary to proceed from the condition of the continuity of the flow of the liquid transported:

$$\frac{Q_1}{Q_2} = 1 = \frac{V_1}{V_2}\frac{D_1^2}{D_2^2} \tag{3}$$

where V_1 и V_2 – flow velocity inside the pipeline with standard and modified cross–section, m/s.

From (3) it follows that the corrected value of the flexible pipeline diameter should be selected as

$$D_2 = D_1\sqrt{\frac{V_2}{V_1}} \tag{4}$$

In expression (4), the value of the speed V_2 should be taken as the maximum possible value in a specific vessel hydraulic system [5]. When selecting this value, it should also be considered that the limiting velocity value for the liquids inside pipelines is about 15 m/sec. At velocities above this value, cavitation within the moving flow will appear, which will instantly change all flow–pressure characteristics of the hydraulic system or simply lead to flow stopping [6, 7, 8].

After the flexible pipeline operating diameter was calculated, special attention should be paid to issues related with admissible lengths of the pipe for sea surface work. The emerging self–similar oscillations in flexible pipelines during working agents transfer from one ship to another can lead in heavy seas (which can be treated as a source of forced oscillations) to emergency operating modes. For this reason, float systems should always be applied when flexible pipelines are used for sea surface work. In addition to preventing sagging of long pipelines, such systems can act as forced oscillations absorbers and provide operating conditions with evenly distributed loads.

Investigation results

According to the results described above, the distance between the floats must be chosen so that the length of the working section used wouldn't be critical. The calculation of the critical length can be carried out using the developed mathematical models. An example of such calculations is shown in figure 2. Based on this plotting, it was concluded that if the values of the dimensionless flow velocity on the pipeline surface are more than 63% of the incoming flow velocity, the working length of the cable should not exceed 45 meters.

An example of the basic estimated lengths depending on flexible pipeline diameters is shown in Fig. 2 and table 1.

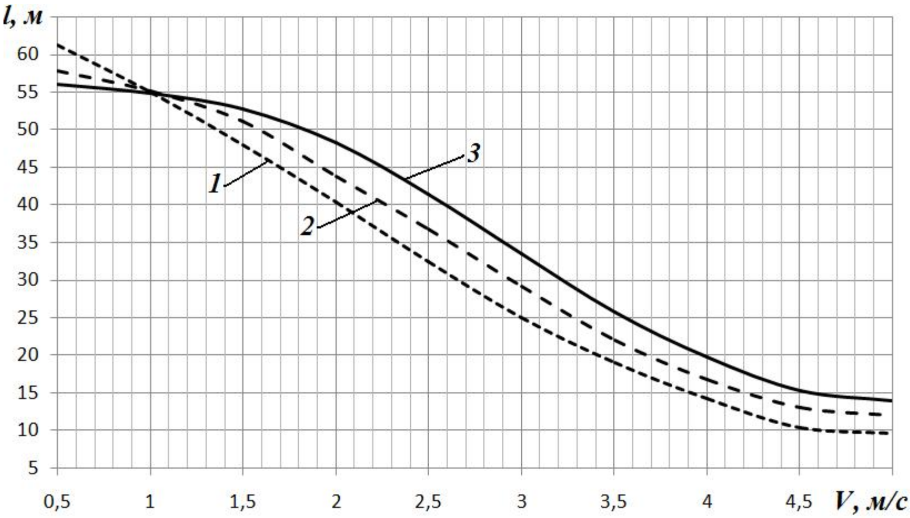

Fig. 2 Flow velocity effect on the working section length selection for

1 – pipeline diameter *D=50 mm*;

2 – pipeline diameter *D=100 mm*;

3 – pipeline diameter *D=200 mm*.

The stated data may be treated as preliminary operational values for pipeline lengths selection. More precise digital readings shall take account of static pressure and all external and internal dynamic loads affecting the pipeline surface.

Table 1. Estimated length of flexible pipelines working sections at various incident flow velocities

Flow velocity	Estimated length of the working area, *l, m* for different pipeline diameters		
	D = 50 *mm*	D = 100 *mm*	D = 200 *mm*
V = 0,5 m/sec	61,2	57,8	56
V = 1 m/sec	55	55,1	54,8
V = 1,5 m/sec	48	51	52,7
V = 2 m/sec	40,3	43,8	48,2
V = 2,5 m/sec	32,4	36,7	41,4
V = 3 m/sec	25	29,1	33,4
V = 3,5 m/sec	19	22	25,7
V = 4 m/sec	14,2	16,7	19,7
V = 4,5 m/sec	10,4	13	15,3
V = 5 m/sec	9,6	11,9	13,9

Conclusions

1. The occurrence of ship's flexible pipelines and cables vibrations during their operation with oscillation under water, near shielding surfaces, and on the sea surface in heavy seas is hard to predict using modern methods.

2. The nature of the distributed load change per flexible pipeline length unit demonstrates that, when dimensionless flow rate exceeds 63% in comparison with the flow rate at infinity, the flexible pipeline working length should be limited to a maximum value of 45 m. The length above this can cause a sharp increase in the amplitude of flexible pipeline self-oscillations and load jump more than twice.

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