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ON DETERMINING THE LOCATIONS OF INTERMEDIATE PUMP STATIONS IN MULTI-STAGE HYDROTRANSPORT SYSTEMS OPERATING WITHOUT FLOW BREAK

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Key words: hydrotransport, main pipeline, solid material, pump milti-stage, optimal location, hydrodynamic processe stationary regime, non-stationary regimes

Abstract:
The multi-stage hydrotransport systems are widely used for transportation of different types of solid free-flowing materials through the energy of the liquid environment – water, as usual. This manner of transportation is applied in many branches of industry, particularly in the mining, civil engineering, power. A problem of determining the optimal locations of intermediate pump stations on main pipelines in the multi-stage hydrotransport systems operating without flow break is considered. It is explained that when determining the locations of the intermediate pump stations an influence of hydrodynamic processes is necessary to envisage, i.e., in the methodology of calculation and design of the analogical systems, the parameters of non-steady (non-stationary) regimes should be kept in mind in line with the basic parameters of currently applied steady (stationary) regimes, while the final calculated parameter should be received on the grounds of comparison thereof. A validity of this methodology is proved by the wide range of experimental studies conducted on major industrial hydrotransport systems.

1. Introduction

The multi-stage hydrotransport systems are widely used for transportation of different types of solid free-flowing materials through the energy of the liquid environment – water, as usual. This manner of transportation is applied in many branches of industry, particularly in the mining, civil engineering, power. A necessity of use of the multi-stage hydrotransport system is predetermined by the fact that the centrifugal pumps (ground pumps, dredge pumps, coal pumps sand pumps) used mainly for supply of the hydraulic fluids, are operating with a low pressure, due to their constructional properties

In practice, in the realistic industrial conditions, the multi-stage hydrotransport systems with braking the hydraulic fluids flow in locations of the intermediate pump stations (IPS) as well as the multi-stage hydrotransport systems without breaking the hydraulic liquids flow, i.e. by the scheme "Pump-in-pump" (serial placement of several pumps in the main pipeline [1-3]), are put into operation.

In exceptional cases, where a distance of supply of the hydraulic fluids is quite long, a method of pairing of two pumps in one pump stations is applied (in such cases the pumps are arranged in series, according to the "Pump-in-pump" scheme). However, this be done if a due permission of a manufacturer of the pump is obtained, only.

The wide-range experimental studies conducted by us on multi-stage hydrotransport systems of the large industrial facilities in different regions of the former USSR, demonstrated that owing to numerous undoubted advantages, the multi-stage hydrotransport system operating without break of the hydraulic fluids' flow on IPSs placed on certain distances from each other on the whole length of the main pipeline, is the most perspective.

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However, we should note that all the advantages of the discussed scheme can be realized fully in case of ensuring the normal working regimes, only (both the transitional regimes and the non-steady processes are meant here), during the whole period of operations. Proceeding from the above aspect, these systems may be considered complicated for technical maintenance that is their relative shortcoming. To remove the latter it seems necessary to ensure a maximally possible smoothness of the transitional regimes upon launching both the Head Pump Station (HPS) and all the IPSs, as well as in cases of occurrence by any reason of the non-steady processes – direct and/or indirect hydraulic shocks causing the sudden fluctuations of the pressure. For this purpose, it is necessary to make corrections in the methodology of calculation and design of the multi-stage hydrotransport systems operating without flow break on IPSs. Otherwise, even in cases of planned launching and stopping envisaged by operational technologies, the considerable fluctuations of the pressure and consequently, the undesired events may occur, with having a negative effect on reliability and durability of the whole system and causing a material decrease of its technical-economic and ecological characteristics.

There exists a method of transportation of the many-phase hydroaerial fluids through the pressure pipelines of the multi-stage hydrotransport systems that determines both the optimal sequences of switching-off and switching-on the serially connected centrifugal ground pumps and the optimal intervals between these operations [5]. However, it does not foresee the following: a) Methodology of determination of the optimal locations of IPSs on the whole length of the main pipeline; b) Its implementation is advisable in cases only, if the sequences of switching-off and switching-on the HPS and IPSs are determined beforehand, according to the established technology. In any other possible incidental cases (a sudden interruption in supply of the power energy to the serially connected pumps, or a sudden supply of electricity thereafter in a short time-period, i.e. until attenuation of waves) it is ineffective, since it cannot avoid an occurrence of the sudden fluctuations of the pressure.

As we have already mentioned above, the currently applied methodology of calculation and design of the multi-stage hydrotransport systems with centrifugal pumps serially connected in the main pipeline, is based upon theoretical and empirical findings and graphical-analytical methods of determination of the necessary flows for transportation of the hydroaerial fluids to the given points, according to which a required number of the pumps is established without taking into account the effects of the transitional regimes and of the non-steady processes [1, 2, 7].

2. Theoretical analysis

The methodology offered by us is given bellow, which takes into account all the parameters of both stead and non-steady working regimes.

As it is known regarding the steady working regime of the hydrotransport system, the number of pumps necessary for supply of the hydroaerial fluids to the given distance is determined with keeping in mind the Q-H characteristics of the pumps, a geodesic height of the supply and the losses of the flow on the whole length of the main pipeline, i.e.

$$n_p = \frac{\Delta H}{H_p} = \frac{K_3\left(\Delta h_1 + \Delta h_2 + H_g\right)}{H_p}, \qquad (1)$$

where: n_p – is a number of the pumps necessary for transportation of the hydroaerial fluid to the given distance in the given conditions; H_g – is a geometrical height of supply (lift) of the hydroaerial fluid, m; H_p – is the hydraulic head developed (by working Q-H characteristics) by a single pump, m; ΔH – is a full loss of the hydraulic head on the whole length of the main pipeline, necessary for overcoming its hydraulic resistance, m; Δh_1 – is a loss of the hydraulic head in the rectilinear parts of the main pipeline, m;

$$\Delta h_1 = l\,\frac{L}{D}\cdot\frac{\mathrm{v}^2}{2g}, \qquad (2)$$

where D – is an inside diameter of the main pipeline of the main pipeline, m; L - is a whole (total) length of the rectilinear parts of the main pipeline ; λ – is the coefficient of the hydraulic resistance of the rectilinear parts of the main pipeline; v – is an average velocity of the flow of the hydroaerial fluid in the main pipeline, in case of steady motion, m/sec; g – is the acceleration of the force gravity, m/sec^2; Δh_2 - is a full (total) loss of the flow necessary for overcoming the local resistances inside the main pipeline, m;

$$\Delta h_2 = \Sigma x \frac{\mathrm{v}^2}{2g} \quad , \tag{3}$$

x - is the coefficient of all locative resistances in the main pipeline.

By integrated solutions of (1) – (3), we can determine both the total length (L) of the main pipeline and the optimal distances between the IPSs to be placed on the whole length thereof. The whole length of the pipeline:

$$L = \frac{2gDK_r\,(\Delta H - \Sigma x \frac{v^2}{2g} - H_g)}{l\mathrm{v}^2}\,, \tag{4}$$

K_r – is the coefficient of the flow's reserve envisaging a certain value of the backwater on the inlet connections of the IPSs, necessary for avoidance of the flow break of the hydroaerial fluid in these parts (sections) in cases of even insignificant violation of the working regimes. Thus, for insuring a stability of operations of the hydrotransport system in the steady regime, it is necessary to observe the following condition:

$$L \le \frac{2gDK_r\,(\Delta H - \Sigma x \frac{\mathrm{v}^2}{2g} - H_g)}{l\mathrm{v}^2}\,, \tag{5}$$

As indicated above, in the transitional regimes (launch and stop of the centrifugal pumps connected serially to each other in the main pipeline) and in the non-steady processes (direct and indirect hydraulic shocks and other processes of fluctuation), considerable changes of the pressures within the wide limits take place, with having a negative effect on the operation of the hydrotransport system, as a whole. The maximal values of the increased pressure (the amplitude) and the frequency of fluctuation depend upon the reasons and conditions of occurrence and of speed of development of the non-steady processes. Such reasons and conditions may of a very different nature and caused by concrete conditions (general structure of the system, a scheme of transportation, a profile of the main pipeline, types and quantity of the pipeline fittings, the hydrodynamic parameters of transportation of the hydraulic fluids, etc.) [6, 7].

Proceeding from the nature of wave-processes in the main pipeline, regardless the reasons of non-occurrence of the non-steady processes in this or that sections of the pipeline, the impulses are spread with *a* velocity to the both sides of the section of their occurrence. In such cases, a total phase of the fluctuations (changes of the pressure) should be determined by the following function

$$T = \frac{2L}{a} \quad or \quad L = \frac{a \cdot T}{2}, \tag{6}$$

where a – is a velocity of spread of the impulse (a process of fluctuation) in the main pipeline - a velocity of spread of the wave and, depends on the following: Geometrical parameters of the pipeline; Hydrodynamic parameters of the flow of the hydroaerial fluid; Physical-and-mechanical properties (parameters) of the hydroaerial fluid, solid substances, air, and the materials used for manufacturing the pipeline; Concentrations of components of the hydroaerial fluid [1, 4], m/sec; T – is a maximal duration of the phase of impulse (process of fluctuation), sec; L – is a whole length of the main pipeline in which the wave-process takes place (see Fig. 1), m.

According to Formula (6), as longer the main pipeline as longer the phases of the fluctuation processes. Therefore, when determining the distances between the serially connected pumps, it is necessary to observe the condition $L \le \frac{aT}{2}$, to ensure a stability of the whole hydrotransport system in cases of non-steady working regimes in any section of occurrence thereof. If this condition is observed, a maximally fast attenuation of the process will take place with a relevant decrease of the value of increased pressures. Besides, a possibility of occurrence of the resonance-like events (summarization of the waves) and of increases in values of the pressures, will be excluded.

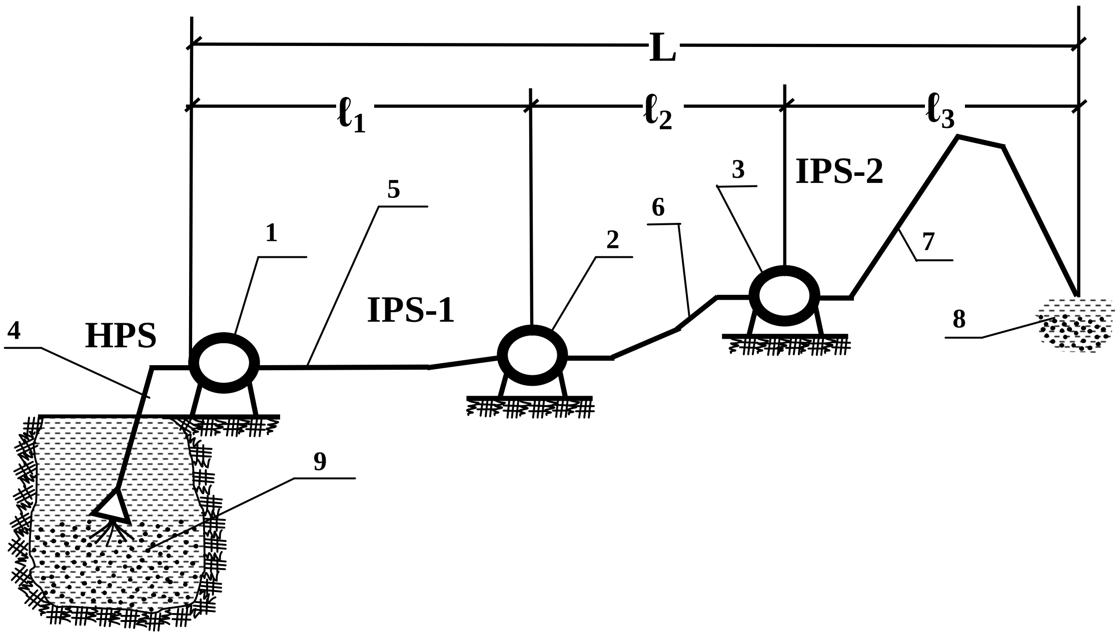

Fig. 1 *The Scheme of the multi-stage hydrotransport system with the centrifugal pumps connected to each other according to "Pump-in-pump" Scheme:*
HPS – Head (suctioning) Pump Station; IPS – Intermediate Pump Stations: 1 – the Head Pump Station (HPS); 2 – The First Intermediate Pump Station (IPS-1); 3 – The Second Intermediate Pump Station (IPS-2); 4 – Suctioning Pipe; 5 – Section of the main pipeline from HPS to IPS-1; 6 - Section of the main pipeline from IPS-1 to IPS-2; 7 - Section of the main pipeline from IPS-2 to the point of supply of the hydroaerial fluid; 8 – Point of supply of the hydroaerial fluid (area of storage of the solid particles of the free-flowing materials; 9 – Intake sump

However, the analysis of the Functions (1), (4) and (7) makes it clear that an increase of distances between the IPSs and of the whole length of the main pipeline is absolutely impermissible because of the following factor: Their optimal values must be determined with taking into consideration the both preconditions – parameters of both steady and non-steady regimes. In this case

$$L \le \frac{2gDK_r\,(\Delta H - \Sigma x\,\frac{\mathrm{v}^2}{2g} - H_g)}{l\mathrm{v}^2} \ge \frac{T\cdot a}{2}\,. \quad (7)$$

Based on the whole length of the main pipeline as determined by the Condition (7), the optimal distances between the HPS and the IPSs connected serially to each other in the main pipeline, should be determined according to by Function (4), by the "Pump-in-pump" scheme. Namely

$$\ell_1 \le \frac{2gDK_r\,(\Delta H - (\Sigma x\,\frac{\mathrm{v}^2}{2g})_1 - H_{r1})}{l\mathrm{v}^2}\,, \quad (8)$$

where ΔH_1 – is a total loss of the hydraulic head necessary for overcoming the hydraulic resistance in the rectilinear part ℓ_1 of the pipeline between the HPS and IPS-1 (see Fig. 1), m; $(\Sigma x\,\frac{\mathrm{v}^2}{2g})_1$ – is a total loss of the hydraulic head in the same section, necessary for overcoming the local resistances, m; H_{r1} – is a geometrical height of supply of the hydroaerial fluid into the same section, i.e. the difference between the geometric marks of locations of the HPS and IPS-1, m.

The analogical methods are applied in cases of determining the distances ℓ_2, ℓ_3, etc. (if necessary)> In such cases all the hydrotransport system will be protected against the wave-processes, in any event of occurrence thereof. This can be explained by the fact that if any non-stable process takes place by any reason, the impulse (wave) of disturbance spreads through the whole length of the main pipeline (to the both sides of the section of their occurrence, depending on the section in which the non-steady process has occurred), while the waves will be reflected on the end part 7 of the main pipeline, i.e. in the section where the hydroaerial fluid leaks into the atmosphere, as well as at the intake valve of the suctioning pipe 4, that is put into the hydrostatic sump 9, i.e. in the section of supply of the hydraulic fluid to the hydrotransport system (the suctioning pipe of the HPS) or in the intake sump, if the main pump works with the backwater. If the conditions (4) and (5) are observed, an intensive attenuation of the process of fluctuation will take place. As a result, the pressure will not be increased considerably.

References:

[1] Makharadze L. et al.: Reliability and Durability of Pressure Hydrortansport System. (1984) Moscow, Nedra, 119p. (in Russian).
[2] Dzidziguri A. et al.: Choice of the Optimal Scheme of the Multi-stage Hydrotransport System with Centrifugal Ground-pumps. (1985), Scientific Works of V.I. Lenin Georgian Polytechnic Institute. Series, Mining Electromechanics and Automation", Tbilisi, №.5 (287), p. 5-9 (in Russian).
[3] Makharadze L. et al.: Classification and Analysis of the Schemes of Pressure Hydrotransport Systems operating in the Mining Industry. (1987), Selected Works "Mining Electromechanics and Transport". Tbilisi, "Metsniereba", p.13-22 (in Russian).
[4] Makharadze L. et al.: Non-steady Presses in the Pressure Hydrotransport System and their Protection from Hydraulic Shocks.(1986) "Metsniereba", Tbilisi. 153 p. (in Russian).
[5] Makharadze L.et al.: (1980) Method of Transportation of Hydraulic Fluids through the Pipelines. Copyright Certificate, USSR, №.770963. Inventions News, Moscow №.38.
[6] Dmitriev G. et al.: (1991), Pressure Hydrotransport Systems (Manual). Moscow, Nedra, 304 p. (in Russian).
[7] Makharadze L. et al.: (2006), The Pipeline Hydrotransport System from Sharp Increases. Tbilisi, "Metsniereba", 350 p. (in Russian).

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