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

The problem of identification of optimal locations of intermediate pumping stations in multi-stage hydrotransport systems operating without flow break in their placements along main pipelines is considered; It is explained that when identifying locations of intermediate pumping stations, it is necessary to consider the influence of hydrodynamic processes, i.e., in the methodology of calculation and design of 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 ground of comparison thereof. Validity of this methodology is proved by the wide range of experimental studies conducted on major industrial hydrotransport systems.

Keywords: **Industrial minerals; Computational fluid dynamics; Process optimization; On-line analysis; Mining.**

Introduction

Multi-stage hydrotransport systems are widely used for transportation of different types of solid free-flowing materials through the energy of flow of the liquid carrier medium – water, as usual, in many branches of industry, particularly mining, civil engineering, energy. The necessity to use the multi-stage hydrotransport system is predetermined by the fact that centrifugal pumps (ground pumps, dredge pumps, coal pumps, sand pumps) used mainly for supply of hydraulic fluids, operate at a low pressure, due to their constructional solutions.

In practice, under the real industrial conditions, the multi-stage hydrotransport systems with break of hydraulic fluids flow in locations of intermediate pump stations (IPS) as well as the multi-stage hydrotransport systems without break of hydraulic liquids flow, i.e. by the scheme “Pump-in-pump” (serial connection of several pumps to the main pipeline) [2, 3, 4], operate.

In exceptional cases, where the length of supply of hydraulic fluids is quite substantial, the method of pairing two pumps on one pump station is applied (they are connected serially, according to the “Pump-in-pump” scheme) only in case a due permission of the pump manufacturing plant is obtained.

The wide-range experimental studies conducted by us on multi-stage hydrotransport systems of large industrial facilities in various branches of industry in different regions of the former USSR, demonstrated that owing to numerous undisputable advantages, the multi-stage hydrotransport system operating without break of hydraulic fluids flow on IPS, placed at certain distances from each other along the main pipeline, is the most prospective.

However, we should note that all advantages of the discussed scheme can be fully realized only in case of ensuring the normal working regimes (both the transitional regimes and the non-steady processes are implied here), during the whole period of operation. Proceeding from the above aspect, these systems are complicated for operation to some extent, which is their relative shortcoming. To eradicate this relative shortcoming it is necessary to ensure a maximally possible smoothness of the transitional regimes upon launching both the Head Pump Station (HPS) and all the IPS, as well as in cas-

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es of occurrence of non-steady processes for other reasons – direct and/or indirect hydraulic shocks and accordingly, sharp pressure fluctuations. For this purpose, it is necessary to make corrections in the methodology of calculation and design of multi-stage hydrotransport systems operating without flow break on IPS. Otherwise, even in cases of planned launching and stoppage envisaged by operation technologies, considerable pressure fluctuations and consequently, undesirable events may occur, negatively affecting reliability and durability of the whole system and causing a material decrease of its technical-economic and ecological characteristics.

There is a method of transportation of multiphase hydroaerial fluids through the main pressure multi-stage hydrotransport systems that determines both the optimal sequences of launching and stoppage of connected centrifugal ground pumps and optimal intervals between these operations [6]. However, this method does not foresee the following: a) Methodology of identification of optimal location of IPS along the main pipeline; b) Its implementation is advisable only if sequences of launching and stoppage of HPS and IPS are determined beforehand, according to the established technology. In any other possible accidental processes (sudden interruption in supply of power energy to the serially connected pumps, or sudden supply of electricity thereafter for a short period of time, i.e. until attenuation of wave process) it is ineffective, since it cannot avoid occurrence of sudden pressure fluctuations.

As mentioned above, the currently applied methodology of calculation and design of multi-stage hydrotransport systems with serially connected centrifugal pumps, is based upon theoretical and empirical findings and graphical-analytical methods of identification of the required pressure for transportation of 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 non-steady processes [3, 2, 5].

Theoretical analysis

Below is considered the methodology offered by us, which comprehensively takes into account all parameters of both steady and non-steady working regimes.

As it is known regarding the steady working regime of hydrotransport system, the number of pumps necessary for supply of hydroaerial fluids at the given distance is determined considering the Q-H characteristics of pumps, geodesic height of supply and pressure losses along the main pipeline, i.e.:

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

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

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

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

$$\Delta h_2 = \Sigma \xi \frac{\mathrm{v}^2}{2g}, \qquad (3)$$

ξ – 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 IPS-s located along the main pipeline. The whole length of the pipeline:

$$L=\frac{2gDK_r\,(\Delta H-\Sigma\xi\,\frac{v^2}{2g}-H_g)}{\lambda v^2}, \qquad (4)$$

K_r – is the coefficient of pressure reserve envisaging certain backwater on suction connections of IPS, necessary for avoidance of flow break of hydroaerial fluid in these parts (sections) in cases of even insignificant violation of working regimes. Thus, to ensure stability of operation of the hydrotransport system in the steady regime, it is necessary to observe the following condition:

$$L\le\frac{2gDK_r\,(\Delta H-\Sigma\xi\,\frac{\text{v}^2}{2g}-H_g)}{\lambda \text{v}^2}, \qquad (5)$$

As indicated above, in transitional regimes (launching and stoppage of centrifugal pumps connected serially in the main pipeline) and in non-steady processes (direct and indirect hydraulic shocks and other fluctuation processes), considerable changes of pressures occur, which negatively affect the operation of the hydrotransport system, as a whole. The maximal values of increased pressure (the amplitude) and frequency of fluctuations depend upon the reasons and conditions of occurrence and the speed of development of non-steady processes. Such reasons and conditions may differ depending on specific conditions (general structure of the system, transportation scheme, the main pipeline profile, types and quantity of pipeline fittings, hydrodynamic parameters of hydraulic fluids transportation, etc.) [1, 5].

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

$$T=\frac{2L}{a}\quad or\quad L=\frac{a\cdot T}{2}, \qquad (6)$$

where a – is velocity of spread of the impulse (fluctuation process) in the main pipeline – velocity of spread of the wave and, depends on the following: geometrical parameters of the pipeline; hydrodynamic parameters of hydroaerial fluid flow; physical-mechanical properties (parameters) of hydroaerial fluid, solid particles, air, and materials used for the pipeline engineering; concentrations of hydroaerial fluid components [3, 7], m/sec; T – is maximal duration of the impulse phase (fluctuation process), sec; L – is the whole length of the main pipeline in which the wave process takes place (see Figure 1), m.

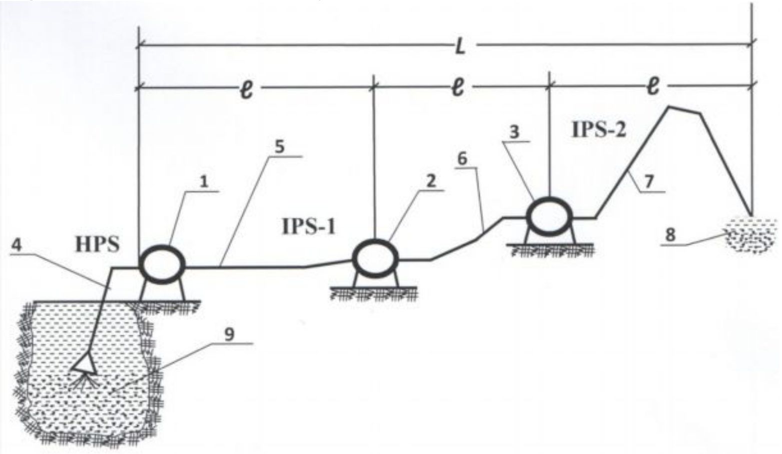

Figure 1 - The Scheme of the multi-stage hydrotransport system with the centrifugal pumps connected to each other according to “Pump-in-pump” Scheme: HPS – Head (suctioning) Pump Station; IPS – Intermediate Pump Stations: 1 – the Head Pump Station (HPS); 2 – The First Intermediate Pump Station (IPS-1); 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

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

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

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

Based on the optimal 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 by the “Pump-in-pump” scheme, should be determined according to Function (4), namely:

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

where ΔH_1 – is a total (full) loss of the hydraulic head necessary for overcoming hydraulic resistance in the rectilinear part ℓ_1 of the pipeline between the HPS and IPS-1 (see Fig. 1), m; $(\Sigma\xi\frac{v^2}{2g})_1$ – is a total loss of the hydraulic head in the same section, necessary for overcoming the local resistances, m; Hr_1 – is a geometrical height of supply of hydroaerial fluid into the same section, i.e. the difference between the geodesic marks of locations of the HPS and IPS-1, m.

Analogical methods are applied for identification of distances ℓ_2, ℓ_3, etc. (if necessary). In such cases the whole hydrotransport system will be protected against wave processes, in any event of occurrence thereof. This can be explained by the fact that in case of occurrence of non-steady process for any reason, the impulse (wave) of disturbance spreads through the whole length of the main pipeline (to 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 from where hydroaerial fluid leaks into atmosphere, as well as at the intake valve of the suction pipe 4, that is put into the intake sump 9, i.e. in the section of supply of hydraulic fluid to the hydrotransport system (through the suction pipe of the HPS) or in the intake sump, if the head pump works with the backwater. As the conditions (4) and (5) will be observed, intensive attenuation of fluctuation process will take place. As a result, the pressure will not increase considerably.

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ДО ПИТАННЯ ВИЗНАЧЕННЯ МІСЦЕРОЗТАШУВАННЯ ПРОМІЖНИХ НАСОСНИХ СТАНЦІЙ У БАГАТОСТУПЕНЕВИХ ГІДРОТРАНСПОРТНИХ СИСТЕМАХ, ЯКІ ПРАЦЮЮТЬ БЕЗ РОЗРИВУ СУЦІЛЬНОСТІ ПОТОКУ

Розглядається питання визначення оптимального місцерозташування проміжних насосних станцій у багатоступеневих гідротранспортних системах, що працюють без розриву суцільності потоку в місцях їх розташування у трубопровідній магістралі; обґрунтовується, що при визначенні місцерозташування проміжних насосних станцій необхідно враховувати вплив гідродинамічних процесів, тобто в методології розрахунку та проектування аналогічних систем, які використовуються на даний час при розрахунках основних параметрів усталеного (стаціонарного) режиму, слід враховувати і параметри неусталених режимів і на основі їх порівняння визначити кінцеве значення шуканого параметру; правомірність цієї методології встановлена широкомасштабними експериментальними дослідженнями, які проведені на великих промислових гідротранспорних системах.

***Ключові слова*: промислові мінерали; обчислювальна гідродинаміка; оптимізація процесу; аналіз он-лайн; гірнича промисловість.**

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К ВОПРОСУ ОПРЕДЕЛЕНИЯ МЕСТОРАСПОЛОЖЕНИЯ ПРОМЕЖУТОЧНЫХ НАСОСНЫХ СТАНЦИЙ В МНОГОСТУПЕНЧАТЫХ ГИДРОТРАНСПОРТНЫХ СИСТЕМАХ, РАБОТАЮЩИХ БЕЗ РАЗРЫВА СПЛОШНОСТИ ПОТОКА

Рассматривается вопрос определения оптимального месторасположения промежуточных насосных станций в многоступенчатых гидротранспортных системах, работающих без разрыва сплошности потока в местах их размещения по трубопроводной магистрали; обосновывается, что при определении месторасположения промежуточных насосных станций необходимо учесть влияние гидродинамических процессов, то есть в методологии расчета и проектирования аналогичных систем, принимаемых в настоящее время при расчетах основных параметров установившегося (стационарного) режима, следует учесть и параметры неустановившихся режимов и на основе их сравнения определить окончательное значение искомого параметра; правомерность этой методологии установлена широкомасштабными экспериментальными исследованиями, проведенными на крупных промышленных гидротранспортных системах.

***Ключевые слова:* промышленные минералы; вычислительная гидродинамика; оптимизация процесса; анализ он-лайн, горная промышленность.**