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Optimal Water Management of the Cascade of Pumping Stations

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ABSTRACT: The article developed methods for calculating and introducing improved water supply modes in systems of machine water lifting for irrigation (on the example of the cascade of Amu-Zang pumping stations). In order to make a decision on managing the operating modes of the objects of machine water lifting systems, it is necessary to clarify and implement the existing methods for calculating the water supply modes in them.

KEYWORDS: mathematical model, unsteady flow of water, main canals, optimal control problems, fundamental solution, differential equations, hydraulic structures.

I.INTRODUCTION

The optimal water management of a cascade of pumping stations involves effectively managing the movement of water through the system to ensure efficient and sustainable use of this resource. This can involve a number of factors, including water quality, availability, and demand, as well as environmental considerations.

To begin with, it is important to understand the ecological situation in the area where the pumping stations are located. This can involve assessing the health of the local ecosystem, including the presence of wetlands, waterways, and other natural features. It may also involve understanding the needs of the local flora and fauna, as well as any potential threats to these populations [26-28].

Once the ecological situation has been assessed, it is important to consider how water can be efficiently managed within the pumping station cascade. This may involve assessing the capacity of each station, as well as the amount of water that is being pumped through the system. It may also involve considering the source of the water, including whether it is being drawn from a local river or other waterway, or from an underground aquifer. In order to optimize water management, it may be necessary to implement a range of strategies, including:

-Water conservation measures, such as reducing the amount of water used in industrial or agricultural processes.

-Upgrading or modernizing existing pumping stations to improve efficiency and reduce energy consumption.

-Implementing water reuse strategies, such as treating wastewater and using it for irrigation or other purposes.

-Monitoring water quality and quantity, and adjusting pumping rates accordingly to ensure that water is being used in the most efficient and sustainable manner possible.

-Implementing ecosystem restoration projects, such as wetland creation or riparian restoration, to improve the health of local ecosystems and promote biodiversity.

Overall, optimal water management of a cascade of pumping stations requires a comprehensive understanding of both the ecological situation in the area and the needs of the local community. By implementing a range of strategies to conserve and manage water resources, it is possible to ensure the sustainable use of this vital resource while minimizing the impact on the environment.

At present, during the operation of pumped water lifting systems, significant unproductive losses of water and energy resources are observed, due to the imperfection of water supply modes, deviations between the required and actual modes, inconsistency in the functioning of the pumped water system facilities.

In catalogs and reference books, the universal characteristic of the pump is given as a family of curves at different speeds of rotation of the pump shaft [1,2,3]

$$Q^i = Q^i(H, n^i) \quad \eta^i = \eta^i(H, n^i) \qquad i=1,\dots,N \tag{1}$$

where n^i is the pump rotation speed corresponding to i th curve; N is the number of curves.

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The performance characteristics of the pumping unit are presented as a family of curves depending on the height of water rise at different angles of turn of the pump impeller blades [4,5,6]

$$\Omega_э^i = \Omega_{H,Q,n} \cup \Omega_{H,\eta,n} \tag{2}$$

Where,

$$\Omega_{H,Q,n} = \left\{ \begin{matrix} Q_j^i & i = 1,..., N, & (j = 1,..., K) \\ H_i & i = 1,..., N, & \\ n_i & j = 1,..., K, & \end{matrix} \right\} \text{- consumption characteristic of the pumping unit}$$

$$\Omega_{H,\eta,n} = \left\{ \begin{matrix} \eta_j^i & i = 1,..., N, & (j = 1,..., K) \\ H_i & i = 1,..., N, & \\ n_j & j = 1,..., K, & \end{matrix} \right\} \text{- energy characteristic of the pumping unit;}$$

n_j is the pump rotation speed corresponding to *the* j -th curve;
$\eta_j{}^i$ - efficiency *of the* i -th pumping unit for *the* j -th curve.

The permissible area D of the operation of the pumping unit in the coordinates QH is determined by the following external boundaries [7,8,9]

$$\left. \begin{matrix} D_{1\max}^i = \Omega_T^{i\max} & \cap & \Omega_{H,Q,n}^i, \\ D_{1\min}^i = \Omega_T^{I\min} & \cap & \Omega_{H,Q,n}^i, \\ D_{2\max}^i = \Omega_{H,Q,n\max}^i, & & \\ D_{2\min}^i = \Omega_{H,Q,n\min}^i, & & \end{matrix} \right\} \tag{3}$$

Where, Ω_{Tmax}, Ω_{Tmin} are the characteristics of the pipeline at the maximum and minimum geometric lifting height; n_{max}, n_{min} - maximum and minimum speed of rotation of the pump.

If the given values of Q and H are located inside the area D, then it is considered that the required water flow can be provided by this unit, otherwise this mode cannot be implemented by this unit. When several units are operating, the boundaries of the allowable area are determined by summing up the flow rates within the boundaries of the areas at a constant lifting height.

The pressure loss in the pipeline is determined by the Darcy-Weisbach formula [10-12]

$$H_l = \frac{\lambda L v^2}{2 g D_г}, \tag{3}$$

where L is the length of the pipeline (m), Dg is the hydraulic diameter of the pipe (m), v is the flow velocity (m/s), λ *is the coefficient of hydraulic friction,* $_{determined}$ theoretically or experimentally.

II. SIGNIFICANCE OF THE SYSTEM

The article developed methods for calculating and introducing improved water supply modes in systems of machine water lifting for irrigation (on the example of the cascade of Amu-Zang pumping stations). The study of methodology is explained in section III, section IV covers the experimental results of the study, and section V discusses the future study and conclusion.

III. METHODOLOGY

In practice, the following formula is used for a round pipeline [13,14]

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$$H_l = \frac{0{,}083\lambda L Q^2}{D^5}, \tag{4}$$

Where D - pipe diameter (m), Q - water flow (m ^{3}/ s).

Sometimes it is convenient to apply the Manning formula [15,16,17]

$$H_l = \frac{10{,}3(nQ)^2}{D^{5{,}33}}, \tag{5}$$

Where n is the pipe roughness coefficient.

An example of calculating pressure losses in a pipeline using the Darcy-Weisbach method

Q (m3/s)	*H_l (m)*
10.00	0.23
20.00	0.92
30.00	2.06
40.00	3.66
50.00	5.73
60.00	8.24
70.00	11.22
80.00	14.66

Hydraulic friction coefficient $\lambda=0.0015$, pipeline length $L = 2217\ m$

An example of calculating pressure losses in a pipeline using the Manning method

Q (m3/s)	*H_l (m)*
10.00	0.24
20.00	0.98
30.00	2.20
40.00	3.91
50.00	6.11
60.00	8.81
70.00	11.99
80.00	15.65

Roughness coefficient $m=0.015$, pipeline length $L = 2217\ m.$

Thus, the characteristic of pressure losses in the pipeline of the pumping station is presented in the form of functional curves depending on the flow and the height of the lift [18]:

$$\Omega_T^i = \begin{Bmatrix} Q_j^i & \\ H_l^j + H + h_l & J = \overline{1,K} \end{Bmatrix}, \tag{6}$$

where, $Q^j{}_i$ - the argument of the pressure characteristic of the pipeline, the flow of the pumping station; K is the number of points in the pressure characteristic; H - geometric height of the pumping station; h_l \u003d - pressure loss of pumps in connecting pressure pipelines; $H^j{}_l$ = - pressure loss in the pressure pipeline

Flow rate, gauge height and efficiency operating pumping unit, i.e., the state of each operating pumping unit, is characterized by a triple: (z_{nb}, z_{nb}, n_{pi}) where: n_{pi} is the rotation speed of the operating pump. Consequently, the flow rate and efficiency of the i-th pumping unit is determined from the expressions [19]

$$\Omega_p^i(Q_p^i, H_p^i) = (\Omega_t^i \cap \Omega_{H,Q,,n}),\ \ n_i = n_i^p, \qquad \Omega_{H,Q,n} \subset \Omega_э^i, \tag{5}$$

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This expression is the intersection of the curve of pressure loss in the pipeline and the flow characteristics of units operating at given $n^{p}{}_{i}$ - the speed of rotation of the pump. Point $\Omega_{p}{}^{i}(H_{p}{}^{i}, Q_{p}{}^{i})$ is the operating point of *the i* -th pumping unit.

The efficiency is determined by the characteristics of the pump efficiency [20].

$$\eta_p^i = \Omega_{H,Q,,n} \cap \Omega_p^i(Q_p^i, H_p^i)$$

The total flow and power consumption for a pumping station line as a whole is defined as the algebraic sum of the flow rates and capacities of the operating unit of the first line [21-23]

$$Q_{HC} = \sum_{i \in N^p} Q_i, \qquad N_{HC} = \sum_{i \in N^p} N_i, \tag{6}$$

where: $N_i = \gamma H_i Q_i / 102\ \eta_i$ - power *of the i* -th pumping unit;

γ- volumetric weight of the pumped liquid.

Thus, the water flow and power consumption of the pumping station are determined by algorithmic dependencies [24,25]

$$\begin{aligned} Q_{нс}(t) &= F_q(t,\ N^p(t),\ \ z_{вб}(t),\ \ z_{нб}(t)) \\ N_{нс}(t) &= F_n(t,\ N^p(t),\ \ z_{вб}(t),\ \ z_{нб}(t)) \end{aligned}, \tag{7}$$

where $N_p(t)$ *is* the set of operating pumping units, $Z_{wb}(t)$ is the water level of the upstream pool, $Z_{nb}(t)$ is the water level of the downstream pool.

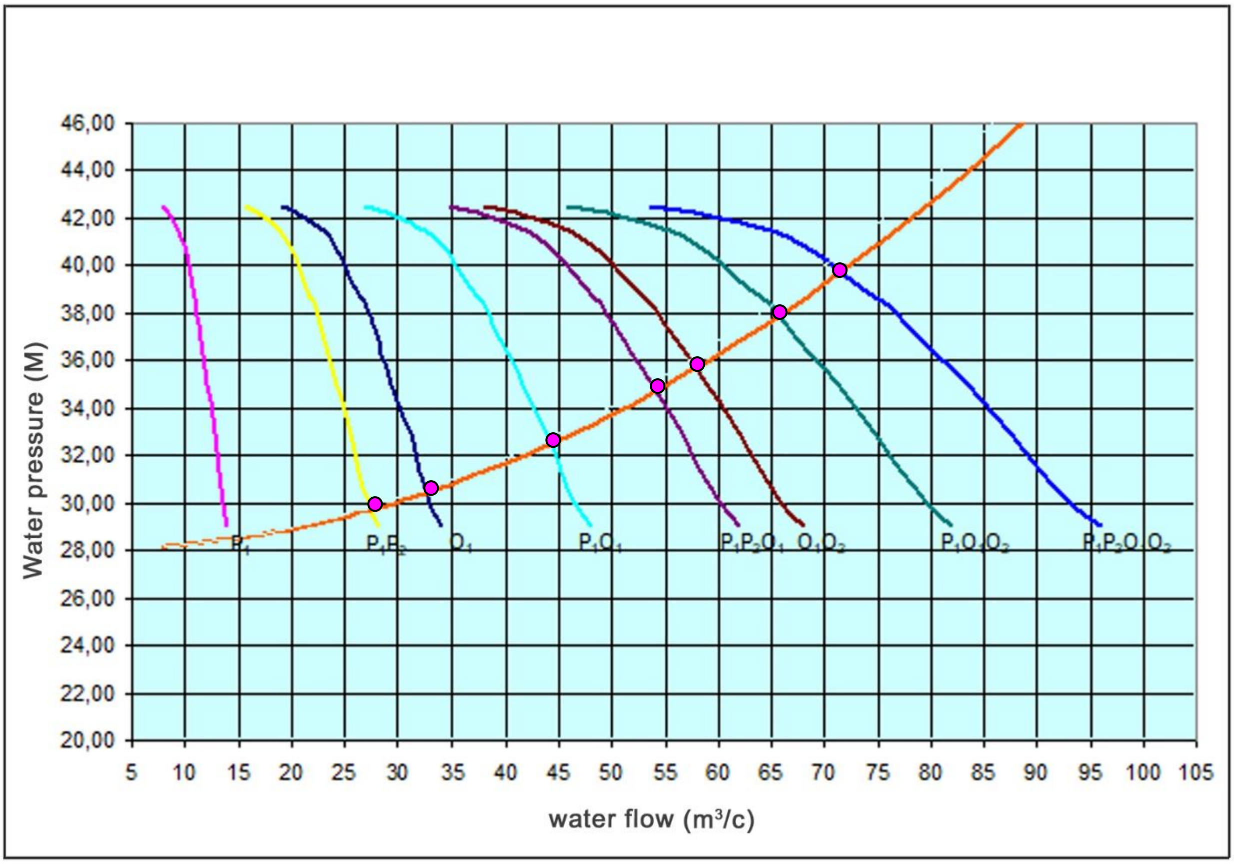

fig. 12. Operating characteristic of the Amu-Zang pumping station (line-1) of parallel operation of units

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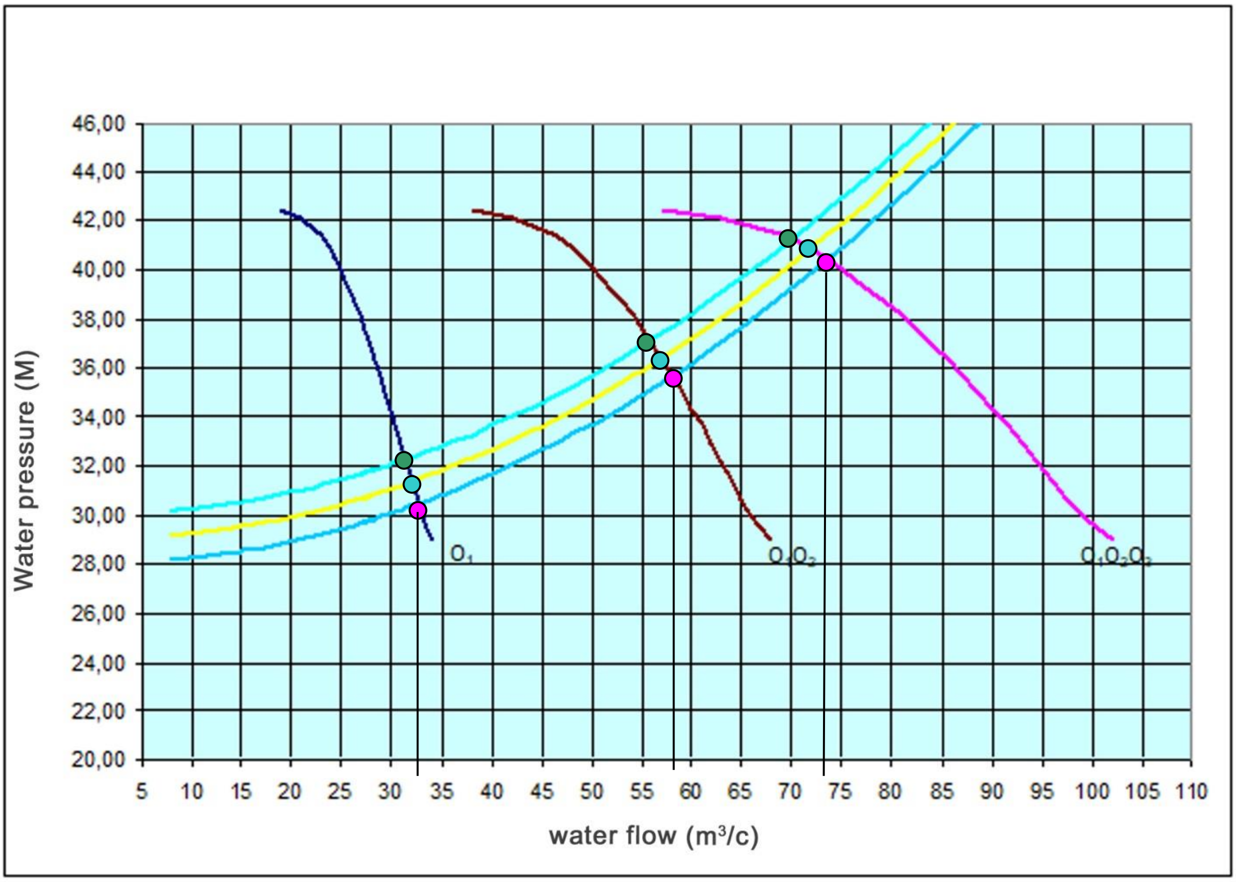

Fig. 12. Operating characteristic of the Amu-Zang pumping station (line-2) of parallel operation of units

To assess the modes of water supply in the cascade of the Amu-Zang pumping station, it is necessary to be able to accurately determine the flow and operating modes of pumping units at all pumping stations.

IV. EXPERIMENTAL RESULTS

The calculation should take into account the scheme for connecting pumping units to a common pressure pipeline, water horizons in the downstream and upstream pools, the operation of the pressure pipeline through the threshold with a closed outlet shield, hydraulic losses in individual pipelines and at the point of confluence of flows into a common pipeline.

Along with the hydraulic characteristics of the regime, energy parameters should be determined: the power consumed for water lifting, the efficiency of individual elements and the entire water lifting installation as a whole, and the specific power consumption for water lifting.

When calculating the operating modes of a group of centrifugal pump units with adjustable flow, the influence of the flow control device must be taken into account, i.e. adjustable guide vanes.

To determine the possibility of calculating the operating modes of centrifugal pumping units operating in parallel on a common pressure pipeline on a computer, a set-theoretic algorithm has been developed and implemented as a software module.

The initial data for the calculation are the universal individual characteristics of the pumping units, the data for the calculation are the universal individual characteristics of the pumping units, reduced to the point of connection of individual pipelines into a common pressure pipeline and the discharge characteristic of the pressure pipeline. Functional dependencies of the universal characteristics of pumping units are set in multiple tabular form. Determining the values of the function by the values of the arguments is carried out by the method of interpolation of one-dimensional and two-dimensional functions, between the nearest elements to the desired one.

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The calculation of the operating point - the point of intersection of the total characteristic of a group of operating pumping units with the pressure characteristic of the pipeline, is carried out by dividing the sub-areas. The calculation is terminated after reaching the required accuracy of the coincidence of the flow rates for these characteristics. The software module calculates the delivery and the total swing height (gauge head) according to a given variant of operating pumping units. The results of the calculation for the first pressure pipeline of the Amu-Zangs pumping station with four pumping units: two exchange units (P1, P2) and two main ones (O1, O2), operating with an open shield of the outlet structure, are shown in Table 1.-2.

Table 1. Pressure loss on the pipeline Amu-Zang pumping station

R	**R**	**ABOUT**	**ABOUT**	**Geometric swing height (m)**								
1	2	1	2	25.44	25.89	26.33	26.78	27.22	27.67	28.11	26.56	29.00
				26.42	26.85	27.29	27.72	28.15	28.58	29.01	29.44	29.88
				26.42	26.85	27.29	27.72	28.15	28.58	29.01	29.44	29.88
				26.99	27.38	27.82	28.25	28.69	29.12	29.56	29.99	30.42
				28.26	28.64	29.02	29.39	29.77	30.16	30.57	30.99	31.40
				30.59	30.97	31.35	31.73	32.11	32.48	32.85	33.22	33.57
				30.59	30.97	31.35	31.73	32.11	32.48	32.85	33.22	33.57
				32.16	32.40	32.69	33.01	33.33	33.65	33.99	34.33	34.65
				28.26	28.64	29.01	29.39	29.77	30.16	30.57	30.99	31.40
				30.59	30.97	31.35	31.73	32.11	32.48	32.85	33.22	33.57
				30.59	30.97	31.35	31.73	32.11	32.48	32.85	33.22	33.57
				32.16	32.40	32.69	33.01	33.33	33.65	33.99	34.33	34.65
				34.76	35.12	35.47	35.85	36.17	36.51	36.85	37.19	37.53
				36.25	36.48	36.73	37.02	37.31	37.57	37.82	38.06	38.32
				36.25	36.48	36.73	37.02	37.31	37.57	37.82	38.06	38.32
				37.42	37.65	37.84	38.03	38.15	38.28	38.46	38.68	38.90

Table 2. Water consumption at the Amu-Zang pumping station

R	**R**	**ABOUT**	**ABOUT**	**Geometric swing height**								
1	2	3	4	25.44	25.89	26.33	26.78	27.22	27.67	28.11	26.56	29.00
				10.16	10.06	9.90	9.72	9.53	9.35	9.16	8.98	8.79
				10.16	10.06	9.90	9.72	9.53	9.35	9.16	8.98	8.79
				20.15	19.86	19.49	19.11	18.74	18.36	17.99	17.62	17.25
				24.91	24.72	24.52	24.32	24.13	23.92	23.72	23.51	23.30
				35.08	34.77	34.42	34.04	33.66	33.27	32.88	32.49	32.09
				35.08	34.77	34.42	34.04	33.66	33.27	32.88	32.49	32.09
				43.60	43.19	42.71	42.11	41.51	40.90	40.17	39.39	38.65
				24.91	24.72	24.52	24.32	24.13	23.92	23.72	23.51	23.30
				35.08	34.77	34.42	34.04	33.66	33.27	32.88	32.49	32.09
				35.08	34.77	34.42	34.04	33.66	33.27	32.88	32.49	32.09
				44.60	44.19	43.71	43.11	42.51	41.90	41.17	40.39	39.65
				49.26	48.88	48.51	48.14	47.77	47.40	47.03	46.66	46.29
				58.85	58.30	57.62	56.89	56.15	55.45	54.73	54.01	53.26
				58.85	58.30	57.62	56.89	56.15	55.45	54.73	54.01	53.26
				62.81	61.83	60.93	60.00	59.17	58.34	57.37	56.30	55.43

In these tables, operating pumping units are shown on the left side of the table, filled numbers mean that the unit is running, unpainted numbers mean that it is not working.

With a sufficiently accurate setting of the individual characteristics of the pumping units, these tables provide the dispatcher with reasonable information about the actual water supply of the pumping station, and also allow you to choose the most economical modes of operation of the units to implement the water supply plan.

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V. CONCLUSION AND FUTURE WORK

As can be seen from the tables, many operating units significantly affect the main performance indicators of pumping stations: the manometric pumping height increases with an increase in the number of pumping units turned on by 5 - , which is about 6 м25% of the geometric swing height and, accordingly, the cost of electricity for water lifting will increase. And the influence on the total water supply of the change unit is reduced from 10 m ^{3}/s to 3.5 m ^{3}/s.

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