

Effect of parallel connection of pumping units on operating costs of pumping station

Nazir Ikramov^{1,*}, *Eduard Kan*¹, *Mirasil Mirzoev*², and *Takhir Majidov*¹

¹Department of Usage of water energy and pumping stations, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 100000 Kari Niyazi street, 39 Tashkent, Uzbekistan

²Hydromelioration faculty, Tajik agrarian University named after Sh.Shohtemur, 734003 Rudaky avenue 146. Dushanbe, Tajikistan.

Abstract. In Uzbekistan, as well as in many other countries of the world, pumping units operate in parallel into a common pressure pipeline at some pumping stations of the irrigation system. This was done mainly to save on the capital costs of the pipeline. Analysis and hydraulic calculation of the existing large irrigation pumping stations with pumping units operating in parallel showed that at some of them the conditions of parallel operation of pumping units were impaired. As a result, a negative hydraulic process arises, in the form of self-induced vibrations of the water flow in the pipeline, which leads to various damage and deformation of the pressure pipeline and pipeline supports. The calculations showed that with different modes of pumping units operating together, the power consumption at the Amu-Bukhara-1 and Namangan pumping stations, accounting for one unit increases by 0.72 ... 6.53%, and at the Amu-Bukhara-2 and Amu-Zang-2 pumping stations, this index, on the contrary, decreases by 0.32 ... 1.67%. Therefore, a properly selected operating mode of parallel-connected pumping units will lead to a decrease in operating costs, i.e. decrease in the prime cost of raised water.

1. Introduction

Currently, a large number of pumping stations operate in the irrigation systems of Uzbekistan and other countries of the world. 1668 pumping stations operate under the Ministry of Water Management of the Republic of Uzbekistan, which include more than 5000 pumping units. The total supply of these pumping stations is about 7000 m³/s, and about 2.3 million hectares are irrigated with them, which is more than 53% of all irrigated lands. Each year, about 8 billion kW·h of electricity is consumed for the operation of these pumping stations, which is about 15% of the total electricity generated in the republic per year. The age of all pumping stations is over 30 years [1]. At some pumping stations, pumping units operate in parallel and are connected to a common pressure pipeline through connecting pipelines (in order to save on the capital expenditures, at some pumping stations the pumping units are arranged in a chequered manner) and return pipeline twins

* Corresponding author: ikramov-1978@mail.ru

[2, 3, 4, 5]. The pressure pipelines of these pumping stations wear out due to the duration of operation on the one hand [5, 7, 10], and on the other hand due to the inability to provide equal pump heads at their connecting nodes, i.e. on return pipeline twins [5, 10].

When designing pumping stations, the following hydraulic conditions were not initially provided [1, 2, 5, 6, 7, 8, 9] such as:

- equality of the length of the connecting pipelines, since the pumping units are chequered and in order to achieve their equality, various hydraulic resistances are installed. Moreover, no sections with a uniform motion of flow L_{30d} are left between them, which led to an increase in the values of the local resistance coefficients, thereby increasing the equivalent length of the connecting sections;

- local hydraulic resistance - return pipeline twin, depending on the number of simultaneously operating pumping units, operates as different resistances (rotation by a certain angle, abrupt enlargement, return pipeline twin, etc.), and its value is assumed to be constant (these hydraulic properties of the return twin appear at pumping stations, where pumping units are arranged in a chequered manner, as well as on those where pumping units are located in one row).

As a result, the conditions of parallel operation of pumping units gets impaired, a negative hydraulic process occurs, in the form of self-induced vibration of water flow in the pipeline [1, 5, 10]. This leads to various damages and deformations of the pressure pipeline and its supports. So, for example, there was a breakdown of the flanges of the K-2-2 pumping station of the Tashkent region and the breakdown of fixed supports (with a rupture of the welded joint of the pipeline) of the Babatag pumping station of the Surkhandarya region. The mentioned negative hydraulic process by origin and decay time differs from the fluid line shock. Also differs from the instability of pumping units due to inconsistency of the characteristics of the pump and pipeline [1, 5, 10-20].

2. Materials and methods

We studied the hydraulic properties of the return pipeline twins installed on the pressure pipelines of the large pumping stations of Babatag and Amu-Zang-2 of the Surkhandarya region, Amu-Bukhara-1 and Amu-Bukhara-2 of the Bukhara region, as well as the Namangan pumping station of Namangan region. It is determined that the value of the hydraulic resistance of the return pipeline twin [1, 5, 10] depends on the following indices:

- the number of simultaneously operating pumping units in a common pressure pipeline;
- proportionality or disproportionality of junction of flows;
- measure of the angle of junction of flows;
- cross-sectional area ratios of the (common) flows to be merged and merged.

The pressure losses on the return pipeline twin are determined by the following formulas [2, 6]: for direct flow passage:

$$h_{n,n} = \frac{1}{2g} \left(g_0^2 + g_n^2 - 2 \frac{\omega_n}{\omega_0} g_n^2 - 2 \frac{\omega_6}{\omega_0} g_6^2 \cos \alpha \right) \quad (1)$$

for lateral flow passage:

$$h_{6,n} = \frac{1}{2g} \left(g_0^2 + g_6^2 - 2 \frac{\omega_n}{\omega_0} g_n^2 - 2 \frac{\omega_6}{\omega_0} g_6^2 \cos \alpha \right) \quad (2)$$

here: g_n – water velocity in the direct flow, m/s;
 g_6 – water velocity in the lateral flow, m/s;
 g_0 – water velocity in a merged (common) flow, m/s;
 ω_n – cross-section area of the direct flow, m^2 ;
 ω_6 – cross-section area of the lateral flow, m^2 ;
 ω_0 – cross-section area of the merged (common) flow, m^2 ;

g – free-fall acceleration, m/s^2 ;
 $\cos \alpha$ – junction angle of flows.

3. Results and Discussion

Calculations of the local resistance coefficient values of the return pipeline twin at these pumping stations showed that, depending on the junction angle of flows, it varies from 0.26 to 24.34. At relations of cross sections of the merged and total flows $\omega_n/\omega_0=0.1 \div 1.0$ it makes $24 \div 0.5$ and changes when the junction angle changes from 2 to 190%, and at non-proportional junction it changes by $2 \div 65\%$ [1, 5, 10].

An example of the results of calculating the pressure losses and the local resistance coefficient on the return pipeline twins installed on the pressure pipeline of the Babatag pumping station (Fig. 1, 2) is given in Table 1.

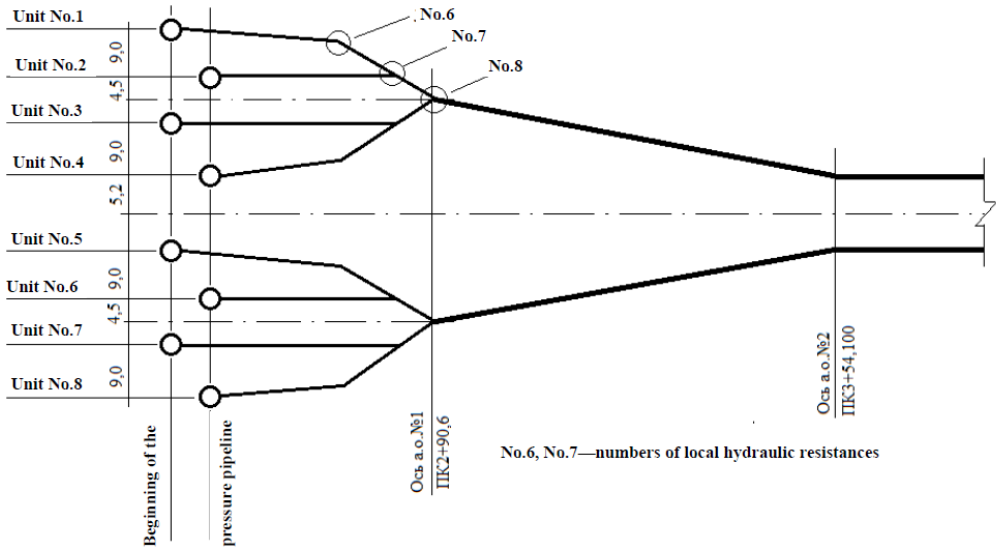


Fig. 1. Scheme of a plan of the initial section of the pressure pipeline of the Babatag pump station.



Fig. 2. Pressure pipeline of the Babatag pumping station.

Table 1. Calculation of pressure losses and local resistance coefficient on the return pipeline twins installed on the pressure pipeline of the large Babatag pumping station

No. of simultaneously operating Pumping units (PU)	7 th local resistance-return pipeline twin			8 th local resistance-return pipeline twin		
	Operating conditions	pressure losses, m	resistance coefficient	operating conditions	pressure losses, m	resistance coefficient
PU No.1	operates as a direct section of the pipeline	0	0	simultaneously operates as a sharp rotation of pipe by 40 ⁰ and abrupt enlargement	0.286	9.985
PU No.2	operates as a sharp rotation of pipe by 30°	0.071	0.155	simultaneously operates as a sharp rotation of pipe by 40° and abrupt enlargement	0.286	9.985
PU No.1 and No.2	return pipeline twin	0.121	1.75	simultaneously operates as a sharp rotation of pipe by 40° and abrupt enlargement	0.938	9.985
PU No.1, No.2 and No.3	return pipeline twin	0.121	1.75	return pipeline twin with disproportionate flow junction	0.908 (h _{6,n} = -0.286 m)	4.29
PU No.1, No.2, No.3 and No.4	return pipeline twin	0.121	1.75	return pipeline twin	0.774	2.058

Analysis of table 1 shows that the value of the pressure and the resistance coefficient of the return pipeline twin varies depending on the number of simultaneously operating units. In addition, it turned out that when 3 pumps operate, a vacuum appears at the connecting node. We believe that just this is one of the reasons for the formation of a self-vibrating water motion in a pressure pipeline.

It should also be noted here that the beginning of the self-vibrating water motion in the pressure pipeline appears from the moment the pump unit is connected to an already operating network and will continue until the pressure of the pump units is equalized. We consider that this phenomenon was the cause of the breakdown of the flange connection of the K-2-2 pump station and the breakdown of the support of the Babatag pump station [1].

In addition, the calculations showed that the difference in the sum of losses of the return pipeline twin with the simultaneous operation of the pumping units No.1 and No.2 of the Babatag pumping station was 5.5 cm. All these and previous proofs mean that the pumps operate with a predetermined mode of self-vibrating flow in the pressure pipeline.

By forming up the characteristics of a group of pumps connected to a common pressure pipeline, as well as forming up based on hydraulic calculations of the characteristics of pipelines, we determined the operating modes of the above-mentioned pumping stations. The results of the calculations are given in Table 2.

Table 2. Mode of operation of large pumping stations with pumping units operating in parallel into a common pressure pipeline

Name of pumping stations	With operation of 1 pumping unit			With operation of 2 pumping units					With operation of 3 pumping units		
	Supply Q, m ³ /s	Pressure H, m	Power, kW	Supply Q, m ³ /s	Pressure H, m	Power, kW	Power accounting for 1 PU.	Power difference from single operation of PU in %	Supply Q, m ³ /s	Pressure H, m	Power, kW
Amu-Bukhara- 1	9.0	45	5155	17.0	48	10385	5192,5	+0.72	24.6	51	15968
Amu-Bukhara-2	17.5	49	10914	34.0	50	21636	10818	-0.88	49.5	51	32445
Babatag	4.9	71.5	4459	9.7	72	8889	4444,5	-0.32	14	75	13364
Amu-Zang- 2	17.4	49	10851	33.0	51.5	21630	10815	-0.32	-	-	-
Namangan	7.0	78	6946	13.8	80	14051	7025.5	+1.10	20.2	81	20824

Continuation of the Table 1.

Power accounting for 1 PU	Power difference from single operation of PU in %	With operation of 4 pumping units					With operation of 5 pumping units				
		Supply Q, m ³ /s	Pressure H, m	Power, kW	Power accounting for 1 PU.	Power difference from single operation of PU in %	Supply Q, m ³ /s	Pressure H, m	Power, kW	Power accounting for 1 PU.	Power difference from single operation of PU in %
5322.7	+3.25	31.2	54.0	21443	5360.75	+3.99	-	-	-	-	-
10815	-0.91	63.5	53.5	43238	10809.5	-0.97	76.5	55	53550	10710	- 1.9
4459.7	+0.15	17.9	77	17542	4385.5	-1.67	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
6941.3	-0.11	25	82	26091	6522.75	+6.53	-	-	-	-	-

Analysis of table 2 showed that at the Amu-Bukhara-1 and Namangan pumping stations with an increase in the number of pumping units operating in parallel, the power consumed per unit increases by 0.72 ... 6.53%. At the Amu-Bukhara-2 and Amu-Zang-2 pumping stations, this figure, on the contrary, decreases by 0.32 ... 1.67%.

At Amu-Bukhara-1 and Namangan pumping stations, connection of pumping units to a pressure pipeline is performed through a collector. With an increase in water consumption in it, the pressure losses also increase, which leads to an increase in power accounting for one pumping unit. At Amu-Bukhara-2, Amu-Zang-2 and Babatag pumping stations, such connections performed through individual connecting pipelines and connection nodes consisting of a T-joint. Therefore, at these pumping stations, apart from the Babatag pumping station, with an increase in the number of pumping units operating in parallel, the power consumption accounted for one unit decreases. At the Babatag pumping station with parallel operation of 3 units, the power accounted for one unit increases by 0.15%. This is explained by the impairment of symmetry of the poured out flows at the connection node (twin), where the lengths of the connecting pipelines are different, since the pumping units in the building of the pumping station are arranged in a chequered manner. As a result, the

inequality of pressure at the connection node leads to the self-vibrating motion of water in the pipeline and increases the power consumption.

Hence, the connection of pumping units with a pressure pipeline through connecting pipelines and connection nodes decreases the power consumption by 0.32 ... 1.67%. However, this leads to the emergence of self-vibrating water motion in the pipeline [1,5,10], the value of which in some cases reaches the pressure in the pipeline during a hydraulic hammer. This leads to a rupture of the pipeline and an increase in operating costs. Thus, the pressure pipeline of the Babatag pumping station was damaged twice, i.e. there was a rupture of the second pipeline, and initially (in 2008) between anchor and intermediate supports No.1, then (in 2010) between anchor supports No.2 and No.3. Pipeline rupture occurred precisely in the place where the pipeline thickness was the smallest due to wear-out (corrosion, abrasive damage).

4. Conclusions

Self-vibrating water motion in the pressure pipeline, in the presence of connecting nodes are inevitable, they can appear in the presence of any of the above mentioned factors, both individually and in integrated effect. As a result, it can lead to various damage and deformation of the pressure pipeline and its supports.

With different modes of pumping units operating together, the power consumption at the Amu-Bukhara-1 and Namangan pumping stations, accounting for one unit increases by 0.72 ... 6.53%, and at the Amu-Bukhara-2 and Amu-Zang-2 pumping stations, this index, on the contrary, decreases by 0.32 ... 1.67%. Therefore, a properly selected operating mode of parallel-connected pumping units will lead to a decrease in operating costs, i.e. decrease in the prime cost of raised water.

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