Efficiency of using hydro-turbine pumping stations for machine irrigation

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Abstract. The use of hydro-turbine pumps increases the efficiency of pumping stations for machine irrigation by utilizing the free water energy of agricultural irrigation sources. The energy savings on irrigation pumping stations achieved through the use of hydro-turbine pumping stations (HTPS) (traditionally obtained through electrical networks) creates ecological conditions for the implementation of turbine pumps, while also improving the economic efficiency of pumping stations.

1 Introduction

Agricultural technology has always been closely related to land reclamation. One of the main tasks of land reclamation is to create conditions for improving the soil and increasing its fertility. Land reclamation, in turn, relies on hydraulic engineering and hydraulic construction. Obviously, without developed hydraulic construction, the planned development of the entire agricultural complex of any country is impossible, even for financially capable agro-holdings.

In the middle of the last century, hydraulic construction and land reclamation were intensively developing in Central Asia. A clear plan for land reclamation and irrigation of the virgin lands of this region was determined, and subsequently, plans were formed for the construction of hydraulic structures that would provide for the constant improvement of the condition of the lands and bring them up to the required quality for agriculture.

Thus, in a relatively short period of time, a whole series of unique hydraulic structures were built for the purposes of land reclamation and irrigation in the Central Asian republics. This gave a powerful impetus to the development of hydraulic engineering, which ensured the rise of the entire agricultural complex of the Central Asian region.

Any hydraulic engineering objects are supposed to be in operation for a long time. During the operation, mechanisms are improved, options for operating individual nodes and structures are optimized, and options for saving operational costs are sought. The extensive experience of Central Asian hydraulic construction and the operation of its objects provide material for analysing the long operational period of various hydraulic engineering objects. Studying the difficulties of construction and operation of these structures creates the basis for the construction of more advanced hydraulic structures that are more economically and environmentally friendly.

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The construction of hydro-turbine pump stations instead of just pump stations will allow reducing the costs of agricultural producers when operating irrigation pump stations, increasing their efficiency coefficient due to the reduction of consumed electrical energy (currently obtained from outside), and therefore, increasing the environmental friendliness of the object.

2 Materials and methods

The design of land improvement irrigation pumping stations is carried out taking into account the convenience of work during construction, high reliability during operation with the best coverage of the water consumption schedule at a high coefficient of equipment efficiency, and the lowest energy consumption.

The optimal option for the construction and equipment of the pumping station is chosen based on techno-economic calculations. The choice of the energy source for mechanical water lifting is also of great importance. It is known that a regular pump can work quite efficiently as a turbine by reversing the flow. Under certain conditions, it may be appropriate to construct hydro-turbo pump installations (HTPIs) that use the gift of water energy from irrigation sources [1,2].

Machine irrigation of land with water lifting using electric pumping stations has a significant disadvantage - high annual operating costs. A significant part of these costs is the cost of electricity consumed by pumping stations. In addition, pumping stations are difficult to fully automate the control of their work, especially those equipped with horizontal centrifugal pumps. Therefore, a significant staff of maintenance personnel is required. On electric pumping stations, the possibility of quality regulation of water supply by changing the number of pump revolutions is practically excluded - this is the most rational way to ensure minimum energy consumption for water lifting.

One way to reduce operating costs for machine irrigation and improve the conditions for reliable automation of pumping stations is to build hydro-turbine pumping station.

Figure 1 shows the scheme of HTPS operation: the pump lifts the required amount of water to the required height, and the turbine, working due to the hydraulic energy of the flow, serves as the drive for the pump, i.e. the engine in the unit [1, 3].

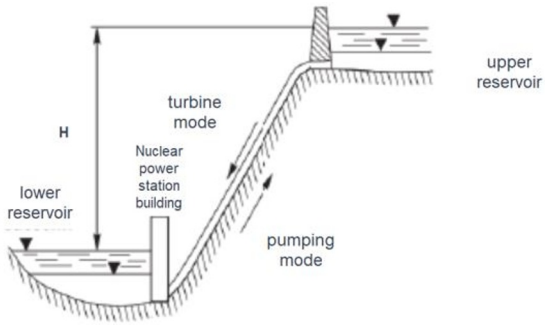

Fig. 1. Schematic diagram of the operation of a hydro-turbine pumping station, [1].

The construction of HTPS is driven by stricter requirements for maintaining ecological balance, energy conservation, environmental protection, as well as the difficulties in energy supply for consumers isolated or remote from the main power grids.

3 Results

A necessary condition for the construction of a hydro-turbine pumping station is the possibility of creating a concentrated water head in the water source, i.e., the concentration of a significant portion of the water energy of the irrigation source in the gate near the machine-irrigated lands to provide the operation of the hydraulic turbine. In other words, if the source of irrigation is a river, then there must be a dam or other possibility of creating a diversion, and in turn, on the main canals, there must be drops with a significant height of water fall or other structures facilitating the creation of a concentrated head. With the listed conditions, HTPS provide a significant economic benefit compared to conventional electric pump stations and allow for improved automation and operation of machine irrigation systems.

In the conditions of machine irrigation, the construction of HTPS is possible according to several schemes [2, 3, 4].

Figure 2 shows how, with the help of a water intake structure from the river to the main canal with a slope less than the slope of the river, the required water flow is taken for self-flowing and machine irrigation.

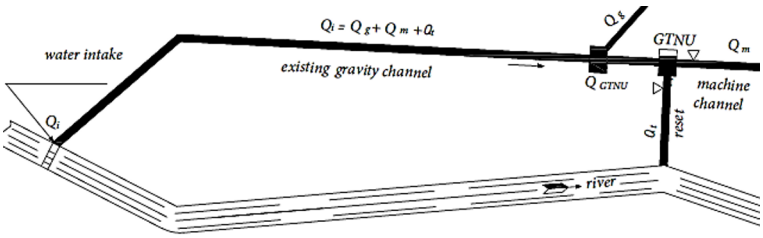

Fig. 2. Scheme of HTPS on the main canal.

In this case, the total water intake from the river will be:

$$Q_i = Q_g + Q_{HTPS} = Q_g + Q_m + Q_t \qquad (1)$$

where Q_i - water intake from the river; Q_g - water flow for gravity irrigation; Q_{HTPS}- water flow passing through the HTPS; Q_m - water flow for machine irrigation; Q_t - water flow for turbine operation.

The water flow Q_i passes through the main canal to the water divider, where Q_g goes further along the main canal and is used for gravity irrigation, while Q_{HTPS} is directed to the HTPS. The water discharged from the turbine Q_t is returned back to the river through a special discharge channel, while the flow Q_m is lifted by a pump to the machine irrigation canal [2, 3, 5, 6].

In figure 3, it is shown how, using a water intake structure from the river into the main canal with drops, the required water flow for gravity and machine irrigation is taken.

$$Q_i = Q_g + Q_m = (Q_{gs} + Q_t) + Q_m \qquad (2)$$

where Q_{gs} - water flow in the main canal section between the water divider and the inclusion of the HTPS discharge.

$$Q_{gs} = Q_g - Q_t \qquad (3)$$

$$Q_{HTPS} = Q_t + Q_m \qquad (4)$$

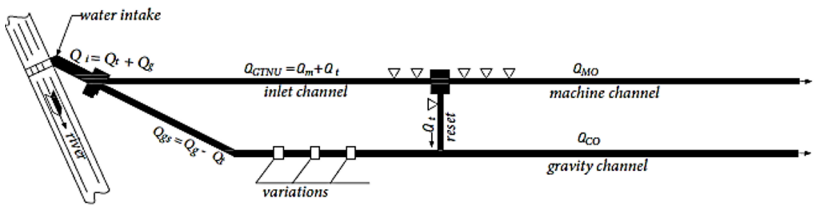

Fig.3. Scheme of a HTPS using the drops on the main canal.

The flow rate Q_{HTPS} is transported through a supply (derivation) canal to the HTPS, which is located near the land for machine irrigation. The water flow rate Q_m is pumped up into the machine canal. The spent water Q_t is discharged back into the main canal.

In figure 4 it is shown how with the help of a water intake structure, a flow rate of water is taken from the river into the main canal, which has a drop, in the amount necessary for self-flow and machine irrigation, i.e.:

$$Q_i = Q_g - Q_t \quad (5)$$

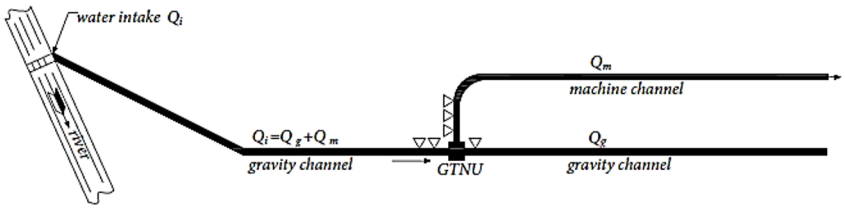

Fig.4. Scheme of a HTPS on a designed channel with a drop.

Figure 5 shows the construction of a HTPS for irrigation of elevated lands, as planned for the irrigation of the right bank of the Great Namangan Canal (GNC) in Uzbekistan.

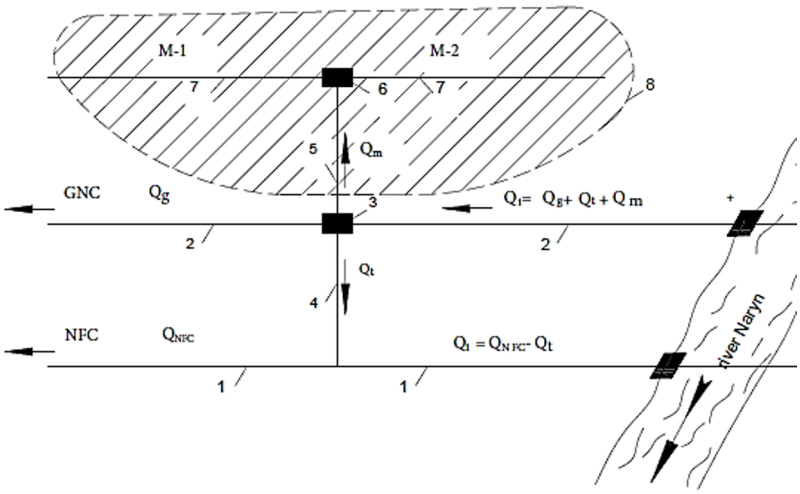

Fig.5. Scheme for the construction of the HTPS on the Great Namangan Canal

In figure 5: 1 - Northern Fergana Canal (NFC), 2 - Great Namangan Canal (GNC), 3 - HTPS building, 4 - HTPS discharge channel, 5 - HTPS pressure pipelines, 6 - water release

structures, 7 - machine canals, 8 - boundary of the right-bank machine-irrigated lands of GNC.

The concentrated head for the operation of the hydraulic turbines of the HTPS is created due to the difference in water levels in two channels running parallel to each other at different elevations. The geodetic difference in water levels, i.e. the potential head for turbines, should be about 50 m, which will allow obtaining a significant power of hydraulic turbines when passing a relatively small amount of water Q_t . The head water intake will consist of water flow rates for free-flow irrigation Q_g, machine irrigation Q_m, and additional water flow for the operation of turbines Q_t .

4 Discussion

It is easy to see that hydro-turbine pumping stations have a higher efficiency compared to an electric pump station under the same conditions of water energy usage. As it is known, the powers on the pump shaft N_p and the turbine N_t are expressed respectively by the equations:

$$N_p = \frac{\gamma\ H_p\ Q_p}{102\ \eta_p} \qquad (6)$$

$$N_t = \frac{\gamma\ H_t\ Q_t\ \eta_t}{102} \qquad (7)$$

where N_p and N_t are the powers on the pump and turbine shafts, respectively, in kWt; Q_P is the flow rate of one pump, m^3/sec; Hp is the total head lift of water by pumps, m; η_p is the pump efficiency; Q_t is the water flow rate through the turbine, m^3/sec; H_t is the head of water acting on the turbine, m; and η_t is the turbine efficiency.

Considering that on a hydro-turbine pump station, the turbine and pump should have equal powers, the main equation for calculating the station efficiency can be written as:

$$\frac{H_p\ Q_p}{\eta_p} = H_t\ Q_t\ \eta_t \qquad (8)$$

and from it, the efficiency of the hydro-turbine pump station can be obtained:

$$\eta_{HTPS} = \eta_t\ \eta_p = \frac{H_p\ Q_p}{H_t\ Q_t} \qquad (9)$$

Pump stations and hydro-turbine pumping stations are two different types of structures, each with its own operating principle and design features, so the efficiency of these installations significantly differs. A pump station is mostly used to lift water from a low elevation to a higher one, and its efficiency ranges from 50-80% [2, 3, 8]. A hydro-turbine pumping stations is used to convert water energy into electrical energy, and its efficiency can reach values from 80% to 90% [2, 3, 8]. In each case, the efficiency value depends on the design features and operating conditions of a specific structure.

Thus, the efficiency of a hydro-turbine pumping stations is usually higher, by 20-30%, compared to a pump station. The choice between a pump station and a HTPS depends on specific conditions and requirements for the energy installation [4, 5, 6]. It should be noted that in winter (in the non-vegetation period), a hydro-turbine pump station can be used only for generating electricity. To do this, turbine-generator units should be installed on the station or the possibility of quickly switching the turbine from the pump to the generator should be provided.

5 Conclusion

The described variations of hydro-turbine pumping stations have several advantages, such as:

1. The use of HTPS allows for a reduction in electricity consumption, which in turn reduces the load on power plants and results in a decrease in emissions of harmful substances into the atmosphere.
2. The application of hydro-turbine pumping stations makes it possible to build water lifting stations in remote and hard-to-reach areas where there is no possibility of connecting to the electric power grid.
3. Unlike other methods of water lifting, HTPS are compact and do not require large expenses for repair and replacement of equipment, which leads to significant cost savings during long-term operation.
4. HTPS can be used in combination with other energy sources, such as solar and wind energy, which allows for the creation of a more sustainable and environmentally friendly irrigation system.
5. In general, hydro-turbine pumping stations significantly reduce annual operating expenses for water lifting.

Given favorable technical and natural conditions, the use of hydro-turbine pumping stations for water lifting is very expedient, has environmental importance, and significant savings in operating costs for irrigation systems.

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