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ANALYSIS OF ENERGY CONSUMPTION OF PUMPING STATIONS

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Introduction.
In Uzbekistan, scientific research is being conducted to improve technological schemes and methods for the joint parallel operation of centrifugal pumps, taking into account variations in the required water flow rate and pressure stability in pipelines, regulation of the rotational speed of pump impellers, and changes in water level in the forebay, as well as to optimize their energy performance. In this area, particular priority is given to studies aimed at increasing the efficiency and reliability of controlling asynchronous motor systems with frequency converters by regulating the rotational speed of pump impellers to deliver the required water flow in irrigation pumping stations. At the same time, the development and improvement of automated control systems designed to achieve energy-saving operating modes and to modernize existing water supply technological systems with automated electric drives that meet contemporary requirements are also considered urgent tasks. The most effective method for energy-efficient control of pump units is the application of frequency-controlled electric drives.

MainPart.
In irrigation systems used for watering agricultural crop areas, more than 2,000 water-lifting pumping stations of various capacities supply water during the irrigation season. In addition, pumping stations for main water-lifting canals operate throughout the year. These pumping stations are equipped with more than 5,000 pump units, of which about 1,000 are of the Д5000–32 type. To drive the Д5000–32 pump unit, А4–630–4У3 type squirrel-cage asynchronous motors are used as electric drives. These motors have a rated power of 630 kW, rated voltage $U_н$=6000 В, rotational speed $n_н$=740 $\frac{айл}{мин}$, efficiency, η=94,5 %, power factor cosφ=0.83, and stator current Is =77.5 A.

The active power generated on the shaft of the pump unit at its rated values is calculated as follows:

$$P_{насос}=\frac{\gamma * Q_н * H_н}{102 * \eta_{нас}}=\frac{1000*1,4*32}{102*0,8}=549 \text{ кВт} \quad (1)$$

Here, $H_н$, $Q_н$ are the rated head and water flow rate of the pump unit, γ-gammaγ is the liquid density, and $\eta_{нас}$ – is the pump efficiency, which decreases as a result of wear of the pump impeller and due to an increase in the clearance between the impeller and the casing.

The active power consumed from the electrical grid by the asynchronous motor driving the pump is equal to:

$$P_{АД}=\frac{P_{насос}}{\eta_{АД}}=\frac{549}{0,945}=581 \text{ кВт} \quad (2)$$

The reactive power consumed from the electrical grid by the asynchronous motor driving the pump is equal to:

$$Q_{АД}=P_{АД}*tg\varphi=581*0{,}67=389 \text{ кВАр} \quad (3)$$

Here, $tg\varphi=\frac{\sqrt{1-cos\,\varphi_{Н}^{2}}}{cos\varphi}=\frac{\sqrt{1-0{,}83^2}}{0{,}83}=0{,}67$;

The apparent power consumed from the electrical grid by the asynchronous motor driving the pump is equal to:

$$S=\sqrt{P_{АД}^{2}+Q_{АД}^{2}}=\sqrt{581^2+389^2}=699 \text{ кВА} \quad (4)$$

In irrigation pumping stations, the water delivery schedule is approved and implemented according to seasonal monthly, daily, and hourly norms. To meet the requirements of these schedules, the water flow rate of pump units is regulated using throttle valves. Regulation of the water flow rate is carried out within the operating zone specified in the technical characteristics of the pump. Based on Figure 1, we determine the values of water flow rate and water head at point A corresponding to point N on the technical characteristic curve of the Д5000–32 type pump:

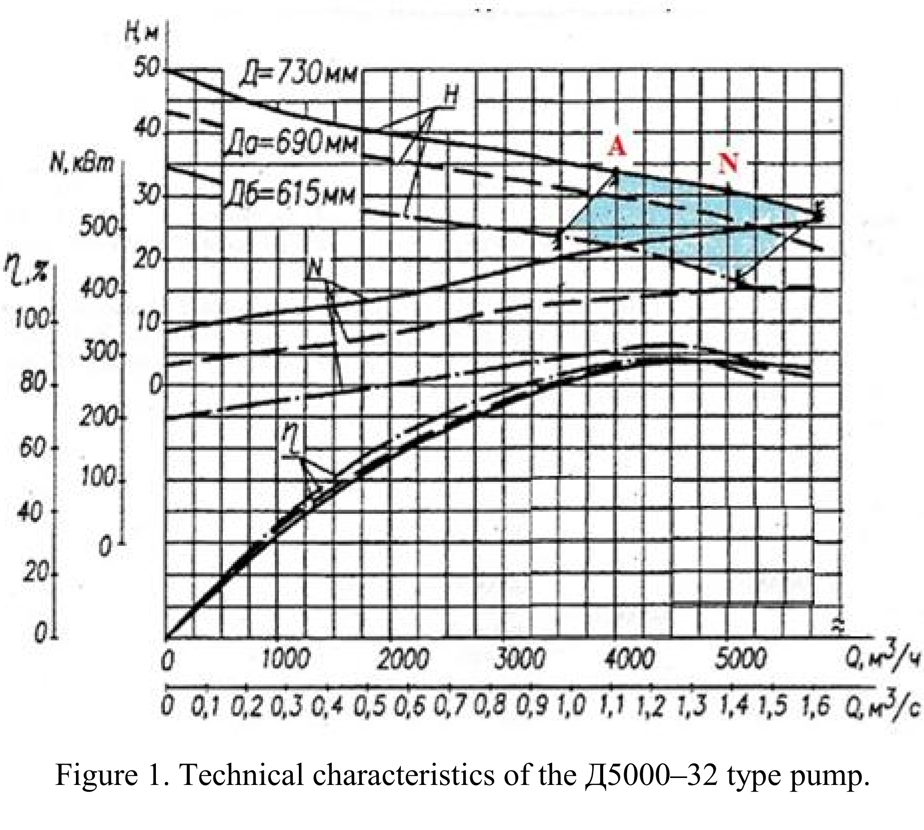

Figure 1. Technical characteristics of the Д5000–32 type pump.

The specially marked section of the pump technical characteristic corresponds to the highest values of the pump efficiency and is called the “operating region.” Within the “operating region,” the pump water flow rate can be varied from 1.1 m³/s to 1.4 m³/s. By closing the gate valve, the steepness of the pipeline characteristic increases, and the operating point of the pump shifts from point N to point A. In this case, the water delivery decreases to 4000 m³, the head generated by the pump increases to 34 m of water column, and the pressure in the pipeline downstream of the gate valve decreases to 32 m. The decrease in pressure downstream of the gate valve occurs due to pressure losses in the gate valve. When the gate valve is opened, the steepness of the pipeline characteristic decreases. As a result, the water flow rate increases, the head generated by the pump decreases, and the pressure in the pipeline downstream of the gate valve increases. This method, known as “throttling,” is considered economically inefficient, since additional energy is required to overcome the additional hydraulic resistance in the gate valve. Taking into account the values of water flow rate Q_A=1,06 $м^3$/c, water head H_A= 34 *м,* pump efficiency $\eta_н = \eta_а$ = 80%, and water density γ=1000 kg/m3 we calculate the active, reactive, and apparent powers drawn from the grid by the asynchronous motor for point A on the pump technical characteristic:

$$P_A=\frac{\gamma * Q_A * H_A}{102 * \eta_{нас} * \eta_{АД}}=\frac{1000*1,06*34}{102*0,8*0,945}=467 \text{ кВт}$$

$$Q_A=P_A * tg\varphi=467*0,67=313 \text{ кВАр}$$

(5)

$$S=\sqrt{P_A^2+Q_A^2}=\sqrt{467^2+313^2}=562 \text{ кВА}$$

An energy-efficient method of regulation is to vary the rotational speed of the impeller in centrifugal pumps. When the rotational speed of the pump impeller changes, the characteristics of water head and flow rate at the pump outlet also change. A decrease in the impeller’s rotational speed lowers both the water flow rate and head proportionally. Conversely, increasing the rotational speed of a centrifugal pump impeller raises the generated head and the pressure in the pipeline, which results in faster water flow and an increase in the flow rate. Using a frequency converter with a squirrel-cage asynchronous motor system allows for smooth adjustment of the pump impeller speed over a wide range. Using the technical characteristic graph of the Д5000–32 type pump (Figure 1), we calculate the characteristic values formed based on the water flow rate and head corresponding to the changed rotational speed:

For the nominal speed, we use the ratio n=730 rpm

$$\frac{Q_A}{Q}=\frac{n_A}{n}, \tag{6}$$

It is known that $n_{\text{А}}=\frac{Q_{\text{А}}*n}{Q}=\frac{1.1*730}{1.4}=584$ ай/мин.

We determine the head generated by the pump at point A.

$$\frac{H_{\text{А}}}{H}=\frac{n_{\text{А}}^2}{n^2} \qquad (7)$$

We determine the water flow rate and head at a control frequency of the frequency converter f=40 Hz.

$Q_{40\text{Гц}}$= 3800 *м³/час* =1,06 *м³*/с; $H_{40\text{Гц}}$= 28 *м*;

We determine the active power consumption of the asynchronous motor from the frequency converter.

$$P_{40\text{Гц}}=\frac{\gamma*Q_{40\text{Гц}}*H_{40\text{Гц}}}{102*\eta_{\text{нас}}*\eta_{\text{АД}}}=\frac{1000*1{,}06*28}{102*0{,}8*0.945}=385 \text{ кВт} \qquad (8)$$

The active energy consumption from the electrical grid by the asynchronous motor system with a frequency converter is equal to:

$$P_{\text{ЧЎ}}=\frac{P_{40\text{Гц}}}{\eta_{\text{ЧЎ}}}=\frac{385}{0{,}98}=393 \text{ кВт} \qquad (9)$$

Modern frequency converters, due to the use of wide pulse-width modulation, have a power factor of no less than 0.96; therefore, the reactive power consumption from the electrical grid is equal to [4,14]:

$$Q_{40\text{Гц}}=P_{40\text{Гц}}*tg\varphi=393*0{,}29=114 \text{ кВАр} \qquad (10)$$

Here, $tg\varphi=\frac{\sqrt{1-\cos\varphi_{\text{Н}}^2}}{\cos\varphi}=\frac{\sqrt{1-0{,}96^2}}{0{,}96}=0{,}29$;

The apparent power consumption from the electrical grid by the asynchronous motor system with a frequency converter is equal to:

$$S=\sqrt{P_{40\text{Гц}}^2+Q_{40\text{Гц}}^2}=\sqrt{393^2+114^2}=409 \text{ кВА} \qquad (11)$$

Conclusion.
Above, we determined the electrical energy consumption of the Д5000–32 type pump unit when

controlling the water flow rate and head using a throttle valve and by varying the rotational speed of the pump impeller. Now, we compare them in terms of:

Active power:

$$\Delta P_A = P_A - P_{чў} = 467 - 393 = 74 \text{ кВт} \quad (12)$$

Reactive power:

$$\Delta Q_P = Q_А - Q_{чў} = 313 - 114 = 199 \text{ кВАр} \quad (13)$$

The irrigation season for agricultural fields lasts T=3600T = 3600T=3600 hours per year, during which the reduction in active energy consumption is equal to:

$$\Delta Э_{А1} = \Delta P_А * T = 74 * 3600 = 266400 \text{ кВт*соат},$$

The reduction in reactive energy consumption is equal to:

$$\Delta Э_{P1} = \Delta Q_P * T = 199 * 3600 = 716400 \text{ кВАр*соат}.$$

When a frequency converter asynchronous motor system is used, the active and reactive electrical energy consumed from the grid is not wasted. Useful work is performed with minimal energy losses. In this case, the requirements of power supply networks regarding the amount of reactive energy are fully met.

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