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FREQUENCY CONTROL OF THE OPERATING MODE OF ELECTRICAL PROCESSES OF PUMPING DEVICES



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Abstract. *This article analyzes the improvement of the operating mode of pumping equipment with electric drives based on frequency control methods. Frequency control systems are of great importance in increasing the efficiency of pumps, reducing energy consumption, and ensuring their stability. Based on theoretical data and practical research, the article provides comprehensive information on various methods of controlling pumps with electric drives and their impact on operating parameters. The studied methods serve to save energy in production processes, maximize results during operation, and ensure uninterrupted operation of pumps. The practical application and efficiency of control systems, as well as future prospects, are considered as one of the main areas of the topic.*
Keywords: *pumping device, electric drive, operating mode, energy saving, economic efficiency, pump, short circuit rotor asynchron motor, control reley, frequency converter, automation tools.*

ЧАСТОТНОЕ УПРАВЛЕНИЕ РЕЖИМОМ РАБОТЫ ЭЛЕКТРИЧЕСКИХ ПРОЦЕССОВ НАСОСНЫХ УСТРОЙСТВ

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Аннотация. *В данной статье анализируется совершенствование режима работы насосного оборудования с электроприводами на основе методов частотного регулирования. Системы частотного регулирования имеют большое значение в повышении КПД насосов, снижении энергопотребления и обеспечении их устойчивости. В статье на основе теоретических данных и практических исследований представлена исчерпывающая информация о различных методах управления насосами с электроприводами и их влиянии на рабочие параметры. Изучаемые методы служат для экономии энергии в производственных процессах, максимизации результатов при эксплуатации и обеспечения бесперебойной работы насосов. Практическое применение и эффективность систем регулирования, а также дальнейшие перспективы расс -*

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матриваются как одно из основных направлений темы.
Ключевые слова: *насосное устройство, электропривод, режим работы, энергосбережение, экономическая эффективность, насос, асинхронный двигатель с короткозамкнутым ротором, реле управления, преобразователь частоты, средства автоматизации.*

NASOS QURILMALARINING ELEKTR JARAYONLARI ISH REJIMINI CHASTOTALI BOSHQARISH

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Annotatsiya. *Ushbu maqolada chastotaviy boshqarish usullari asosida elektr yuritmali nasos uskunalarining ish rejimini takomillashtirish tahlil qilingan. Nasoslarning samaradorligini oshirish, energiya sarfini kamaytirish va ularning barqarorligini ta'minlashda chastotaviy rostlash tizimlari katta ahamiyatga ega. Maqolada nazariy ma'lumotlar va amaliy tadqiqotlar asosida elektr yuritmali nasoslarni boshqarishning turli usullari va ularning ish parametrlariga ta'siri haqida to'liq ma'lumot berilgan. O'rganilgan usullar ishlab chiqarish jarayonlarida energiyani tejash, ekspluatatsiya jarayonida maksimal natijalarga erishish va nasoslarning uzluksiz ishlashini ta'minlashga xizmat qiladi. Boshqarish tizimlarining amaliyotda qo'llanilishi va samaradorligi hamda istiqbollari mavzuning asosiy yo'nalishlaridan biri sifatida ko'rib chiqilgan.*
Kalit so'zlar: *nasos qurilmasi, elektr yuritma, ish rejimi, energiya tejash, iqtisodiy samaradorlik, nasos, qisqa tutashuv rotorli asinxron dvigatel, boshqarish relesi, chastota o'zgartirgich, avtomatlashtirish vositalari.*

Introduction. The electric drive of the water extraction device operates under the influence of static torques that change during the start-up process of the centrifugal pump and change very little during normal operation. Therefore, when choosing a type of electric motor, in addition to its technical specifications, it is necessary to take into account the correct selection of the optimal option of starting devices, control devices, and the conditions of the place where the pump devices will be installed. Currently, in water extraction devices, mainly short-circuited rotor, in rare cases phase rotor asynchronous and in some cases synchron electric conductors are used.

Short-circuited rotor asynchronous electric starters are widely used in mining enterprises due to their simple structure, low cost, reliable operation, easy start-up process, and low electricity consumption.

They are started by directly connecting the stator windings to the mains using relay contactor and magnetic starter devices.

The operating modes of pumping units of industrial enterprises are mainly determined by the technological process of the enterprise. There are water consumption and pumping regimes similar to those of municipal water supply and sewage pumping stations. Pumping units of industrial enterprises can also operate with a pronounced night and day mode of water consumption. The operating modes of heat pumping plants and recycling water supply systems depend significantly on the outside air temperature and, consequently, on the time of year, climate and supply. The supply of pumping units operating directly into the network without intermediate tanks should be equal to the water consumption at any given time (in the absence of leaks and unproductive costs). In reality, in any water supply system there are leakages and unproductive costs, which reach 15-20% of the total supply. Consequently, the pumping unit's delivery should be slightly higher than the water consumption. As the water consumption increases, the flow rate has to be increased and the head losses in

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the pipes increase accordingly. To compensate for this, the pressure developed by the pump unit must be increased. When water consumption is reduced, the supply and pressure must be reduced. For a long time water consumption and supply were adjusted by changing the number of operating pump units or the degree of opening of gate valves (gates) on the pressure lines of pumps and pumping units. At present, pump impeller speed is more often regulated by means of REP [1-4].

Materials and Methods. The operating mode of a pumping unit supplying water to a consumer through an accumulating tank (reservoir, water tower, etc.) is characterized by the fact that at certain periods of time the pumping unit's supply differs from the water consumption. If the supply is greater than the water consumption, the water level in the tank rises, if it is less, the level falls. In the case of an equal supply and water consumption, the level in the tank stabilizes at the same level. In this case, unless there are variable speed drives, the water consumption and supply of the pumping unit is controlled by switching the unit on when the water level drops to the lower set point and switching it off when the upper set point is reached. The cycle is then repeated. If the pump unit consists of several units, its operating mode differs in that several upper and lower levels are set, at which the number of operating units changes. As the water consumption increases, the frequency of switching on the units increases and the duration of the pauses decreases, because the volume of liquid in the tank is activated faster with increasing water consumption. At the same time, the liquid level reaches the bottom position more quickly and, as a result, additional pumps are switched on more often. The mode of operation of pumping units when pumping liquid from receiving tanks, such as sewage pumping station, is similar to the previous case, with the difference that the units are switched on when the tanks are filled to the upper levels, and are switched off when emptied to the lower levels. The number of switching on and off operations per day of pumping units in a sewage pumping station with tanks reaches 40÷50, and in some cases 100. Such number of switching on and off is unacceptable for units of large capacity, therefore in installations with units with capacity higher than 150÷250 kW

Pump drive. Pumps are mainly driven by asynchronous squirrel cage and synchronous AC motors. Sometimes induction motors with phase rotor are used. Electric motors with power up to 400 kW are usually made for voltage 380÷660 V, and above this power - for 6÷10 kV.

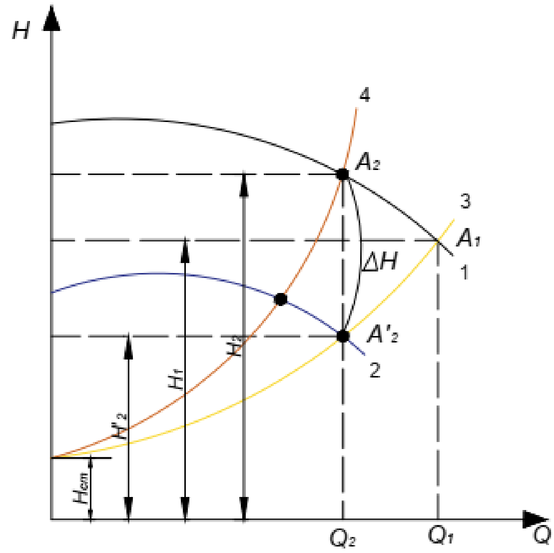

Fig.1. Regulation of centrifugal pump operation mode:

1 - pump characteristic at nominal speed; 2 - the same at reduced speed; 3 - pipeline characteristic at full opening of the gate; 4 - the same at reducing the degree of gate opening; H1, H2 - heads corresponding to feeds Q1, Q2; Hst - static component of head.

Operation modes of the pumping unit depend on changes in water consumption or wastewater inflow. The nature of change of water consumption and sewage inflow is determined by many, independent of each other, reasons: climatic and weather conditions, operation mode of enterprises and organizations of the city, the number of cultural and entertainment events, the content of their programs. For a well-founded decision on expediency of use of regulated electric drive (RED) in a pumping unit it is necessary to know how its operation mode changes for the whole calculation period, for example, a calendar year. Daily schedules do not give such an idea, because they differ significantly from each other, depending on the time of the year, day of the week, etc. It is practically impossible to describe them with mathematical equations. Therefore, to analyze the operation modes of pumping units [3], it is reasonable to use water or effluent supply distribution curves, which are called ordered water supply diagrams, by analogy with ordered

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diagrams of electrical loads [7].

High energy efficiency and economic savings are achieved when introducing frequency converters in the operating mode of centrifugal pump equipment. Organization of automatic mode using pressure sensors installed in pusher and drive pipes of centrifugal pump devices and smooth control of the operation mode of asynchronous electric drives are considered as the economic achievements achieved in the use of a frequency converter device.

For this purpose, the operating time of centrifugal pump devices with a short-circuited rotor asynchronous motor with a power of 250 kW and a nominal voltage of 380 V is 7000 hours or 292 days. The use of frequency converters in production enterprises shows the following factors of energy saving [1,2]: electricity saving 20%; current repair will decrease, service and management will increase; the service life of the electric motor increases; prevents negative effects on electrical networks and reduces the value of starting current at nominal load of electric motors; lightly starts the electric motor and allows to continuously change the rotation frequency depending on the gas volume of the boiler room. When using a frequency converter, the most obvious economic benefit of using frequency converters can be achieved through energy savings. But other saving factors should not be overlooked: smooth opening reduces the load on the shaft mechanism. This is a direct way to reduce wear and tear and extend the life of the equipment; smooth starting and stopping of the pump avoids water hammer in the system; the lower the speed of the electric pump drive, the longer the service life of the system. Noise and vibration are reduced; start-up current at start-up does not exceed 4-8 times, which allows to reduce the installed (maximum) power and simplify the overload and short-circuit protection system; inclusion of the pump in the automatic control circuit allows to maintain the set parameters such as pressure, flow rate. Without operator intervention or remotely; precise pressure maintenance in the system allows to reduce the maximum pressure in the pipeline, which reduces the probability of its rupture.

The formulas are valid for turbulent motion of the liquid in the pump, because only in this case the head loss is proportional to the square of its velocity [6]. Tests of large centrifugal pumps (300D90A) at the operating object and experiments in the laboratory with small pumps (ECV) have shown that at low speed the unambiguous ηrat_{var} relationship between head and pump delivery is broken [1].

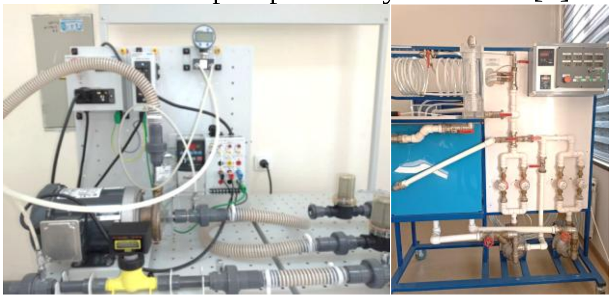

Fig.2. Laboratory installation of electric drive control with frequency converter of a centrifugal pump.

As an example, consider a real pumping station with 4 pumps. At one time the station was designed with the prospect of growth, but still operates in the mode with one pump running. In order to equalize the motor-hours worked by the units, once a month switching to the next pump takes place.

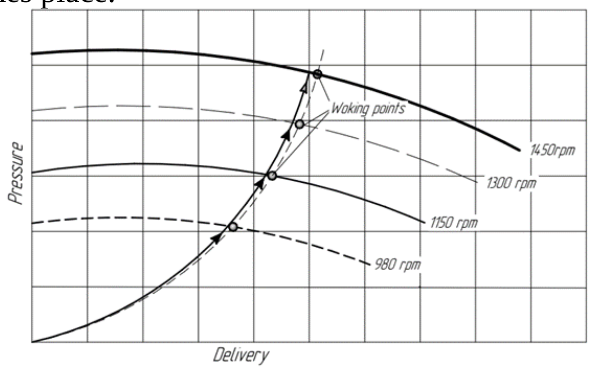

Fig.3. Family of characteristic curves for the 300D70 pump.

Pressure regulation at the outlet of the station is provided by a damper, i.e. throttling.

- Pump mark 300D90A;
- Pump capacity Qopt=1250, m^3/hour;
- Head North=54, m (water column);
- Electric motor brand AIR355 C4U3; Mechanical power P=250, kW;
- Speed n=1490, 1/min; Supply voltage U=380, V; Motor current I=437, A;
- Pressure at the outlet of the pump station pvvy=2,3 kGs/cm^2;
- Pressure at the pump inlet pvh=0,3 kGs/cm^2;
- Water consumption per month

Vmesh=330000 m^3;

- Type of regulation - throttling. Figure 3 shows the characteristic curves and the position of the optimum operating point at different rotor speeds for a closely related 300D70 pump [2].

With recirculation control, the pump operates in a near-optimal mode with maximum (optimum) capacity regardless of the water flow. The mechanical energy consumption is equal to the rated motor power, the electrical energy consumption will be the same, but taking into account the motor efficiency and cos(ϕ). The energy consumption can be calculated from the nameplate data.

$P_{\text{recirc}} = P_{opt} = U \times I \times \sqrt{3} = 380 \times 437 \times \sqrt{3} = 288kVA$;

With throttling control, the operating point of the pump is shifted to a higher pressure and lower flow, the energy consumption is reduced, but the efficiency of the pump drops sharply. The reduction in energy consumption can be estimated from the pump characteristic curve graphs or from an approximate formula:

$P_{dross} = \frac{P_{opt}}{2} \times (1 + \frac{Q}{Q_{opt}})$ and $Q = \frac{V_{month}}{730} = \frac{330000}{730} = 452 \, {m^3}/{h}$;

$P_{dross} = \frac{288}{2} \times (1 + \frac{452}{1250}) = 196kVA.$

Calculate the rotor speed of the pump based on the conditions of reduced capacity and head:

$n_Q = n \times \frac{Q}{Q_{opt}} = 1490 \times \frac{452}{1250} = 539rmp \rightleftarrows$

$n_H = n \times \sqrt{\frac{H}{H_{opt}}}$ and $H = (p_{\text{exit}} - p_{\text{inlet}}) \times g = 19{,}6m n_H = n \times \sqrt{\frac{H}{H_{opt}}}$ and $n_H = 1490 \times \sqrt{\frac{19{,}6}{54}} = 898rmp.$

The operating point that provides the required performance will be reached at pump speeds between n_H and n_Q. Let's assume the rotor speed to be large.

$P_{\text{regul}} = P_{opt} \times (\frac{n_H}{n})^3 = 288 \times (\frac{898}{1490})^3 = 63kVA.$

The motor speed is controlled by a frequency converter (FC). The efficiency of a frequency converter with a power of more than 100 kW is usually not worse than 95%. Taking this into account, the power consumption will be.

$$P_{\text{frequency converter}} = \frac{P_{\text{regulation}}}{\eta} = \frac{63}{0{,}95} = 66kW.$$

Results. Let's calculate the cost of electricity for the three regulation options. Let's assume the electricity price is 0.08$/ kWh. Let's assume the number of hours per month is 730 hours. Taking into account that for powerful electric motors cos(ϕ)>0.9, we assume active power equal to reactive power.

Table 1

Comparative analysis in different control methods of electric drives

Method of regulating the pumping station capacity	Power consumption, kW	Energy consumption per month, kWh	Electricity price per month ($)
Recirculation	288	210240	16819
Throttling	196	143080	11446
Frequency converter	66	48180	3854

The price of an electrical installation with a 250 kW IF varies from 7200$. (minimum configuration) to $22000. (configuration with redundancy and “smooth” switching of several pumps). Thus, the payback period of frequency converter implementation will be from 3 to 7 months. Taking into account the terms of commissioning and discounting, the payback period will increase, but will be no more than 6-9 months. Subsequently, you can expect to save 11562$ per year. Additional savings will be achieved by reducing wear and tear and improving the reliability of the pump station and pipeline system. The inclusion of a frequency converter will allow the pump station to be monitored and controlled from the dispatch center. This, in turn, will free up some personnel.

Conclusion. High energy efficiency and economic efficiency were achieved when introducing frequency converters in the operation mode of centrifugal pump equipment. The frequency converter device increased the electricity saving by 20%, reduced the current repair of the pump device, increased the service life of the electric drive of the pump, and increased the performance index.

A detailed mathematical model of the transient process of the microprocessor control during the operation of the “Frequency converter – asynchron motor” system, a simulation model, and a program that provides for measuring and controlling the pressures in the inlet and outlet pipes and building a description of the pump device during the establishment of the nominal operating mode of the pump devices were created.

When using the "frequency converter – asynchron motor" system, when centrifugal pump devices are started, the starting current of its electric motors is reduced by 2.5 times, and the service life without repair is extended from 6-7 months to 25 months. As a result, in this way, energy and resource savings were achieved in the operating mode of centrifugal pump devices. Taking into account the timing of the NSR and discounting, the payback period will increase, but will be no more than 5-9 months. Subsequently, savings of $11562 per year can be expected.

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