Variable geometry impeller centrifugal pump

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Abstract. The article compares the energy efficiency of the pump installation in a changing flow rate for options without flow control and with regulation by reducing the shaft speed and trimming the impeller. A comparison of these methods. A description is given of the operation of the pumping unit with a self-trimming impeller and an algorithm for controlling it.

Pumping stations and pumping units installed in them are designed to supply water to piping networks for various purposes and, as a result, are the most critical elements. When designing water supply systems, engineers are faced with the technical task of linking the joint work of pumping stations, a network of piping lines and structures on them. The goal of the created system is to provide consumers with water with a minimum guaranteed pressure and the required flow rate.

The water flow in the pipeline network is variable and varies during the day depending on the need for water, which is represented by various modes of operation of the network. These modes are dictated by the uneven hour and nature of water consumption by various network subscribers. To reduce the irregularity of water flow at the supply section from the pumping station to the network, pressure-regulating structures are installed - water towers, accumulating tanks. Therefore, for systems with variable flow rate to ensure the supply of all network subscribers, it is necessary to provide a pressure control system at the dictating point.

The distribution of water flow by the hours of the day is set by the unevenness coefficient determined by [1] and depends on the number of consumers. In a particular case, the non-uniformity is determined by the probability of action of devices that are consumers of the system in question, and depends on their number in the hydraulic system.

The coordination of the joint work of the pumping station and the water supply network is mathematically described by the system of equations:

\[
\begin{align*}
H_{\text{pump}} &= f(Q) \\
H_{\text{pipe}} &= H_g + SQ^2
\end{align*}
\]  (1)

Where \(H_{\text{pump}}\) – head developed by a pump or group of pumps;
\(H_{\text{pipe}}\) – pressure losses in the pipeline network;
\(Q\) – water flow in sections of the pipeline network;
\(S\) – resistance of individual sections of the pipeline network to the dictating point.

In the mode of minimum hourly consumption, unregulated operation of the pumping station leads to an increase in excess pressure in the water supply system, since the operating point on the joint pump-
feed network schedule changes its position relative to the calculated one. This operating mode is characterized by excessive pressure, i.e. increase in free pressure relative to the minimum guaranteed (Fig. 1).

Figure 1. Characteristic operation of the pump-water supply system
1 - position of the operating point with uncontrolled pump operation
2 - position of the operating point with adjustable pump operation

Figure 1 shows that the unregulated operation of a centrifugal pump or a group of them in variable flow systems leads to an increase in guaranteed pressure for consumers, which negatively affects the energy efficiency of this state of the system, since the amount of electrical energy consumed per unit of pumped liquid can be reduced. To do this, use methods of regulating the operation of pumping units.

Under the regulation of the operation of pumping units in the technical literature [2, 3] we mean a change in the characteristics of the external elements of the water supply system that are directly related to their work in order to maintain the required pressure and at the same time reduce the power consumption. These include the throttling method for artificially changing the resistance of the pipeline network and reducing the flow of incoming water, the method of changing the speed of the pump drive shaft and the method of trimming the impeller.

The change in the frequency of rotation of the impeller is achieved through the use of a frequency converter in the wiring diagram of an asynchronous motor, which changes the frequency of the alternating current supplying the motor windings.

Since the characteristic of the pumping equipment is the passport data obtained as a result of a bench test, this complicates the research task by the fact that the Q-H, Q-N, Q-η dependency curves cannot be described as mathematical dependencies. Therefore, the selection of pumping equipment and recalculation of characteristics is carried out by the graphoanalytical method.

The parameters curves of the characteristics of a centrifugal pump with frequency regulation of the drive is described by the equation:

\[
\frac{n_1}{n_2} = \frac{Q_1}{Q_2} = (\frac{H_1}{H_2})^{0.5} = (\frac{N_1}{N_2})^{0.33}
\]
The parameters curves of the characteristics of the centrifugal pump when trimming the impeller is described by the equation:

\[ \frac{H_2}{H_1} = \frac{Q_2}{Q_1} = \frac{N_2}{N_1} \left(\frac{D_2}{D_1}\right)^2 \]  

(3)

Where \( n_1; n_2 \) – drive shaft rated and reduced speed,
\( Q_1; Q_2 \) – nominal and reduced pump flow,
\( H_1; H_2 \) – pump head rated and reduced,
\( N_1; N_2 \) – power consumption of the pump rated and reduced,
\( D_1; D_2 \) – outer diameter impeller nominal and trimmed respectively.

The difference between the frequency regulation and trimming of the impeller from throttling is that the pump characteristics are adjusted to such a state of the pump-water supply system when the pressure levels of the dictating consumer are reduced to the minimum guaranteed (Fig. 1).

This difference provides greater energy efficiency of these control methods than throttling. For example, Table 1 shows the calculated values of the specific energy consumption for each option for regulating the operation of the Grundfos NB 40-200 / 206 pumping unit with the joint operation of a steel conduit with a nominal diameter of 175 mm and a length of 1 km based on data published by the manufacturer.

**Table 1.** Comparison of specific energy consumption per unit of pumped liquid for different regulation methods

| Q, \( \text{m}^3/\text{h} \) | H, m | N, kW | Efficiency, % | \( N/Q \), kW/\( \text{m}^3/\text{h} \) |
|----------------|--------|--------|----------------|----------------|
| without regulation or throttling |
| 55 | 46 | 10,7 | 68,2 | 0,19 |
| 50 | 47 | 10,5 | 67,5 | 0,21 |
| 45 | 50 | 10,2 | 67 | 0,23 |
| 40 | 52,5 | 9,48 | 65,3 | 0,24 |
| 35 | 53 | 8,85 | 62,5 | 0,25 |
| 30 | 55 | 8,2 | 58,7 | 0,27 |
| 25 | 56 | 7,6 | 54 | 0,30 |
| 20 | 56,5 | 6,9 | 48 | 0,35 |
| 15 | 56,9 | 6,2 | 40 | 0,41 |
| frequency regulation |
| 55 | 46 | 11,25 | 61 | 0,20 |
| 50 | 45,15 | 10 | 61 | 0,20 |
| 45 | 44,3 | 8,95 | 61 | 0,20 |
| 40 | 43,6 | 8 | 59,3 | 0,20 |
| 35 | 43 | 7,14 | 57,3 | 0,20 |
| 30 | 42,4 | 6,36 | 54,5 | 0,21 |
| 25 | 41,98 | 5,67 | 50,5 | 0,23 |
| 20 | 41,56 | 5,05 | 45,2 | 0,25 |
| 15 | 41,22 | 4,48 | 38,1 | 0,30 |
| impeller trimming |
| 55 | 46 | 10,7 | 68,2 | 0,19 |
| 50 | 45,15 | 9,67 | 67,5 | 0,19 |
| 45 | 44,3 | 8,60 | 67 | 0,19 |
Analyzing dependencies (2) and (3), we can conclude that the cutting of the impeller has an advantage over frequency regulation due to the possibility of reducing the supply by half more without reducing the minimum guaranteed head while maintaining a higher efficiency value. According to the materials of the catalog of the manufacturer of pumping equipment [4], the addition of a frequency converter to the motor circuit of the motor windings reduces the efficiency of the pumping unit from 3 to 10%.

The disadvantage of trimming the impeller is the irreversibility of the changes, and if it is necessary to increase the pump capacity, it will be necessary to stop the operation of the pump unit and replace the impeller.

Therefore, to increase the energy efficiency of regulating the operation of the pumping unit, it is necessary to formulate and solve the technical problem of ensuring the possibility of changing the outer diameter of the impeller during its operation.

The problem can be solved as follows, to change the design of the impeller blades and to make them consisting of two parts, movable and stationary, to move the moving part of the blade from the edge to the center of rotation (Fig. 2).

![Figure 2. Sketch of self-trimming impeller](image)

a) front view b) back view
Figure 3. The proposed pump operation scheme

The centrifugal pump (Fig. 3) works as follows: when excessive pressure occurs between the suction zone 1 and discharge 2, which corresponds to a non-productive mode, the pressure sensor 7, using the control unit 6 and the electromagnetic valve 5, changes the pressure ratio of the pumped liquid in the hydraulic lines 4 supplying the pumped liquid into cavities 8 separated by mechanical seals 9 between the pump casing and the impeller. When the pressure changes in the cavities of the impeller casing, an angular displacement of the actuating element occurs, leading to the displacement of the pins of the moving blades to a position corresponding to the required outer diameter. The outer diameter of the impeller is thus variable. Upon reaching the required pressure in the network supplied by the pump, which corresponds to optimal operation, the control unit through the valve distributes the pressure in the hydraulic actuators by a signal from the pressure sensor, fixing the position of the blades corresponding to the required impeller diameter.

If the proposed changes in the design of the flowing part of the impeller will not lead to a deterioration in efficiency within 10%, then in systems with variable flow, the pump according to the described design without a frequency drive will be more energy efficient than a similar one with a frequency drive. The use of pumping units with the described design can allow abandoning the operation of regulatory structures in the water supply system, as well as reducing water losses in pipelines caused by excessive hydrostatic pressure, which in turn will reduce operating costs and reduce the accident rate of water supply networks and unproductive losses of water during its transportation.

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