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Determination of the coefficient of economic efficiency of frequency regulator

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Abstract: The work is devoted to the finding of the formula for calculating economic efficiency of the frequency control method. This method is considered on the example of vertical tank drainage. Also in this work the principle of operation of the frequency controller and its application are described. The figuring out of the formula is based on the expression for calculating efficiency and this system capacity, depending on pump volume flow rate.

Introduction

Centrifugal pumps attract great interest from researchers [1–8]. At the same time, modern methods of calculating such pumps are of considerable interest [9–12]. However, questions of economic efficiency often stay without explanation.

Nowadays, the automation of pumping stations is increasingly using schemes based on frequency regulators. Such automated circuits with a frequency converter provide:

–Protection of drive motors from short circuits, phase breakage, overheating, overloads, voltage drops.

–Smooth change in performance when pressure decreases or increases. The frequency Converter can also operate in the supply control mode for several parameters of the water supply or heating system.

–Fault alarm.

–It's also a great way to save energy. This is important for large liquid pumping systems.

The essence of the frequency control method is that by changing the frequency of the pump that pumps the liquid at the right time, it is possible to save energy spent on the system. This method is used in various environments where the main thing is pumping liquids. For example, such as oil pipelines, water pipelines, etc. it is also worth noting that frequency converters are used for automation of simple Autonomous water supply systems, as well as powerful stations with a large number of pumps.

In this article, an attempt was made to use the methods of mathematical analysis to derive a General formula for determining the coefficient of economic efficiency of frequency control.

This formula is remarkable because it can in practice help companies determine individually whether it is profitable for them to save on electricity by spending money on a frequency regulator, or conversely.

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Method

The method of mathematical analysis is based on expression for calculating efficiency and this system capacity, depending on pump volume flow rate. In our model $y(0)=0, y(T)=h.$ We show a scheme of the drainage tank in figure Figure 1.

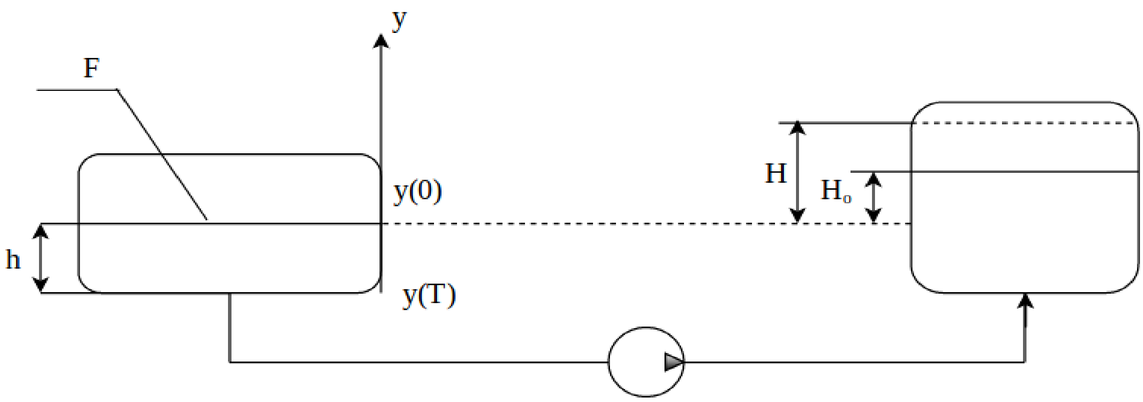

Figure 1. High-quality scheme of the drainage tank

The height of the pump, depending on flow rate:

$$H_{pump}(Q)=A+B\cdot Q+C\cdot Q^2$$

where A, B, C — pump constants.

So the height is equal to:

$$H=H_o+y+\alpha\cdot Q^2$$

where $\alpha=0,0827\dfrac{x\cdot l}{d^5}$ — the constant.

If we equate the above heights and express flow rate Q, we get:

$$Q(y)=\frac{-B\pm\sqrt{B^2-4(\alpha-C)(H_o+y-A)}}{2(\alpha-C)}$$

Analysis of the obtained formula for flow rate Q to the sign before the square root:

$$\alpha>0,\ C<0$$

It means that:

$$\alpha-C>0$$

$$H_{static}^{friction}=H_o+y$$

$$H_{pump}^{o}=A$$

$$H_{static}^{friction}<H_{pump}^{o}$$

Also:

$$H_o+y-A<0$$

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Then:

$$\sqrt{B^2-4(\alpha-C)(H_o+y-A)}=\sqrt{B^2+4\left|(\alpha-C)(H_o+y-A)\right|}>|B|$$

$$Q(y)=\frac{-B+\sqrt{B^2-4(\alpha-C)(H_o+y-A)}}{2(\alpha-C)}$$

Now we find the maximum efficiency of the system with a frequency regulator.

The efficiency of a system with a frequency regulator frequency n_1 can be found from the equation:

$$\eta(Q)=A_1+B_1*Q+C_1*Q^2$$

A_1, B_1, C_1 —constants of pumps with frequency regulator.

We differentiate this equation. In this case the system flow rate Q is converted to the maximum system flow rate Q_{max}

$$\eta'=2*C_1*Q_{max}+B_1=0$$

We express it from this equation:

$$Q_{max}=\frac{-B_1}{2*C_1}$$

In this case, the formula for finding the maximum efficiency of the system with a frequency regulator is:

$$\eta_{max}=A_1+B_1*\left(\frac{-B_1}{2*C_1}\right)+C_1*\left(\frac{-B_1}{2*C_1}\right)^2$$

We obtain the final formula, using simple algebraic transformations :

$$\eta_{max}=A_1-\frac{B_1^2}{4*C_1}$$

The coefficient of economic efficiency of frequency control can be found by the formula:

$$K_{ef}=\frac{T*N*W_1}{T*N_1*W_1+W}$$

where T —the time resource of the pump, [T]=[hour];

W_1—the kW electricity per hour cost;

W — the frequency regulator cost;

N_1—the pump capacity with a frequency regulator;

N — the pump capacity without a frequency regulator;

We write down the formula for finding the power of the pump without a regulator:

$$N=\rho*g*H_H*Q$$

ρ—the density of the fluid in the system

g —acceleration of gravity;

Substitute the expression for H_H then the formula will take the form:

$$N=\rho*g*\left(A+B\cdot Q+C\cdot Q^2\right)*Q$$

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Now find the power of the pump using the frequency regulator. It can be calculated as the product of power without a regulator on the ratio of the maximum possible efficiency to the efficiency of the frequency regulator:

$$N_1 = N * \left(\frac{\eta_{max}}{\eta(Q)} \right)$$

Substitute already have found expressions for N, $\eta_{max} and \eta(Q)$:

$$N_1 = \rho * g * \left(A + B \cdot Q + C \cdot Q^2\right) * Q * \left(\frac{A_1 - \frac{B_1^2}{4 * C_1}}{A_1 + B_1 * Q + C_1 * Q^2} \right)$$

Substitute all the values for the capacities in the formula for calculating the efficiency coefficient K_{ef}:

$$K_{ef} = \frac{T * \rho * g * \left(A + B \cdot Q + C \cdot Q^2\right) * Q * W_1}{T * \rho * g * \left(A + B \cdot Q + C \cdot Q^2\right) * Q * \left(\frac{A_1 - \frac{B_1^2}{4 * C_1}}{A_1 + B_1 * Q + C_1 * Q^2} \right) * W_1 + W}$$

We can substitute the previously calculated pump volume flow rate Q into the formula for the final result.

The economic efficiency coefficient may be less than, equal to, or greater than one. We can conclude whether it is profitable to use a frequency controller for the pump for this operating system, depending on the coefficient value.

If $K_{ef} < 1,$ when the using of a frequency regulator is not profitable, because the cost of it and its operation will be more than the system without regulation.

Else if $K_{ef} > 1$, when the using of the frequency control method is advantageous for this operating system.

Else $K_{ef} = 1,$ when using the regulator doesn't matter.

Results

During the study working formula was obtained for determining the coefficient of economic efficiency of frequency regulator, which depends on many parameters, including the pump flow rate, the cost of kW, the cost of the regulator, the time resource of the pump, its constants, as well as the density of the liquid in the system. The ultimate formula is as follows:

$$K_{ef} = \frac{T * \rho * g * \left(A + B \cdot Q + C \cdot Q^2\right) * Q * W_1}{T * \rho * g * \left(A + B \cdot Q + C \cdot Q^2\right) * Q * \left(\frac{A_1 - \frac{B_1^2}{4 * C_1}}{A_1 + B_1 * Q + C_1 * Q^2} \right) * W_1 + W}$$

where A, B, C — constants of pumps without frequency regulator;

A_1, B_1, C_1 —constants of pumps with frequency regulator;

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α —the constant;
T — the time resource of the pump, [T]=[hour];
W_1 —the kW electricity per hour cost;
W — the frequency regulator cost;
ρ —the density of the fluid in the system
g —acceleration of gravity;

We can substitute the previously calculated pump feed value into the formula for the final result. We can draw a conclusion about the economic efficiency of using this method, depending on the value of the efficiency.

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