ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

UDC 621.644.8

O.G. Butenko, PhD, Assoc.Prof.
Odessa National Polytechnic University, 1 Shevchenko Ave., 65044 Odessa, Ukraine; e-mail: alex_butenko@ukr.net

THE COEFFICIENT OF EFFICIENCY OF HYDRAULIC CIRCUITS

О.Г. Бутенко. **Коефіцієнт ефективності гідравлічної мережі.** Переміщення рідин промисловими і побутовими гідравлічними мережами щороку потребує кілька десятків мільярдів кіловат електроенергії на годину. На сьогодні не використовують жодного універсального показника, який би узагальнено характеризував ефективність перетворення електричної енергії у гідравлічну і ефективність використання цієї гідравлічної енергії. Це суттєво ускладнює оптимізацію параметрів гідравлічної мережі за енергетичним критерієм при її проектному або перевірочному розрахунку. ***Мета:*** Метою роботи є оцінка втрат в нагнітальному обладнанні гідравлічної мережі, а також в трубопровідній її частині шляхом введення загального показника ефективності транспортування рідини. ***Матеріали і методи:*** Показано, що для отримання характеристики енергетичної ефективності гідравлічної мережі не достатньо використання лише коефіцієнту корисної дії насосної установки, або розрахунку ефективності окремих елементів гідравлічної мережі. Для досягнення поставленої мети запропоновано ввести коефіцієнт енергетичної досконалості мережі, який є відношенням потужності потоку на виході із гідравлічної мережі до потужності потоку на валу насоса. ***Результати:*** Запропонований коефіцієнт враховує втрати напору в насосі та у трубопроводі і дає об'єктивну оцінку енергетичної ефективності мережі; крім того, він дозволяє порівнювати енергетичну досконалість гідравлічних мереж з різними параметрами і різними насосними установками. Запропонований коефіцієнт доцільно використовувати при проектуванні гідравлічних мереж та при проведенні перевірочних розрахунків.
Ключові слова: гідравлічна мережа, корисна потужність, потужність на валу, опір мережі, коефіцієнт енергетичної досконалості мережі.

O.G. Butenko. **The coefficient of efficiency of hydraulic circuits.** Moving liquids by industrial and domestic hydraulic circuits annually requires tens of billions of kilowatts of electricity per hour. Today there is not any universal indicator that would characterize generalized conversion efficiency of electrical energy into hydraulic and efficiency of using of hydraulic energy. This greatly complicates the optimization of the hydraulic circuit parameters on energy criterion in its design or testing calculation. ***Aim:*** The aim of the research is to assess the losses in the discharge equipment of hydraulic circuits, as well as in pipeline through the introduction of common indicator of the effectiveness of transporting liquid. ***Materials and Methods:*** We show that specifications for energy efficiency of hydraulic circuit it is not enough the pumping efficiency of the installation, or calculate the efficiency of individual elements of the hydraulic circuits. To achieve the goal asked to enter the energetic coefficient of energy perfected circuit, which is the ratio of output flow power from the hydraulic circuit to the flow power on the pump shaft. ***Results:*** The proposed coefficient takes into account the loss of pressure in the pump and in the pipeline and provides an objective assessment of the energy efficiency of the circuit; in addition, it allows you to compare the energy perfection of hydraulic systems with different parameters and different pumps. The proposed coefficient should be used in the design of hydraulic circuits and during the checking calculation.
Keywords: hydraulic circuit, useful power, shaft power, resistance of the circuit, coefficient of the energy perfected circuit.

Introduction. Water is a natural resource that essential for vital functions of living organisms, including humans, and for the vast majority of processes and industries. Therefore, a major engineering problem of mankind is the timely and uninterrupted supply of water of consumers in the required amounts. In today's world millions of kilometers of water pipes are constructed, charge of a liquid in which usually provide with electric pumps. Due to this on moving of liquids by industrial and domestic hydraulic circuits annually spend tens of billions of kilowatts of electricity per hour. Despite such significant amounts of electricity, in the design of hydraulic circuits use no universal indicator that would characterize generalized the efficiency of conversion of electrical energy into and hydraulic energy and its efficiency. This greatly complicates the optimization of the parameters of hydraulic circuit on power criterion in its design or checking calculation [1, 2].

The aim of this research is to assess the losses in the discharge equipment of hydraulic circuits, as well as in pipeline through the introduction of common indicator of the effectiveness of transporting liquid.

Materials and Methods. Algorithm of design of hydraulic circuits consists of several basic steps:

– according to a technical tasks we selected diameter of water pipeline from the standard series;

DOI 10.15276/opu.1.51.2017.09

– determined the power needed to pump a given charge of a liquid by the selected pipe diameter;

– we selected pressuring unit which can provide a certain power with maximum efficiency of the pump. However, taking into account the efficiency of conversion of mechanical energy on a shaft in the hydraulic energy of fluid at the pump, but do not consider the efficiency of hydraulic energy of the fluid moving in the pipeline to consumers.

The efficiency of the pump is equal to the ration of the net power (N_n), which the liquid received in the pump, to the shaft power (N_s):

$$\eta = \frac{N_n}{N_s}.$$

Net power can be calculated by the formula:

$$N_n = \rho g Q_p H_p,$$

where ρ – fluid density, kg/m^3;

Q_p – supply, m^3/s;

H_p – pump head, m.

The pump head directly in the pipe network spent to overcome the static height H_{st} and for losses $\Delta h = SQ_p^2$ (S – hydraulic resistance of network, s^2/m^5). That is, for a simple pipeline the pump head can be calculated by the formula given in the [3]:

$$H_p = H_{st} + SQ_p^2.$$

Thus, increasing the resistance of network and energy losses in its pipeline leads to increasing of efficiency and capacity of the pump, and in certain modes to increase its efficiency. Since this growth of power consumed to overcome losses in the circuit, we can not call it helpful.

This contradiction is one example of what is to characterize the overall energy efficiency of hydraulic circuit is not enough to use only the indicators of pumping unit. Moreover, in the absence of the pump, this figure in principle not be used in pipelines that operate "from the tank", i.e. flow occurs under the action of hydrostatic pressure.

In [4] for the general characteristics of the energy efficiency of hydraulic circuits authors introduced the concept of efficiency of individual elements of hydraulic circuit and proposed the formula:

$$\frac{1}{\eta_s^2} = \frac{1}{\eta_p^2} + \sum_{n=1}^{k}\left(\frac{1}{\eta_n^2} - 1\right)\frac{w_j^2}{w_i^2}, \tag{1}$$

where η_s, η_p, η_n – hydraulic efficiency of the whole system, pump and n-element of the system, respectively;

w_i, w_j – sectional area of individual sections .

Eq. (1) allows to estimate the energy efficiency of hydraulic system, but for real circuit where number of elements can be up-valued numbers are not very convenient. Moreover, effectiveness of closed valve is zero that leads to the necessity to divide by zero.

As an alternative, for overall energy efficiency of hydraulic circuit proposed to use the coefficient of the energy perfected of circuit ε, which is the ratio of power of output flow from hydraulic circuit N_{out} to the power which is the power on the pump shaft N_s. Since output power flow N_{out} equal to the difference of net power N_n and power losses in the pipeline $\Delta N_{los} = \rho g S Q_p^3$, and shaft power can be determined by the formula

$$N_s = \frac{\rho g Q_p H_p}{\eta_p},$$

then coefficient of the energy perfected of circuit could be calculated as

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

$$\varepsilon = \eta_p \left(1 - \frac{SQ_p^2}{H_p}\right), \qquad (2)$$

where the first multiplier takes into account the energy efficiency of the pump, and the second – the effectiveness of the pipeline circuit.

If we consider the pipeline, consisting of sections connected consistently, in which the total resistance is the sum of the resistances of these sections, the formula will be the follows:

$$\varepsilon = \eta_p \left(1 - \frac{Q_p^2 \sum_{i=1}^{n} S_i}{H_p}\right).$$

Results and Discussion. Let us analyze the dependence of the example of a hydraulic circuit with variable resistance, static height H_{st} of which is 3 m. The hydraulic system in question uses a pump of mark K 20/30 (132), the use of which is common in water supply systems [4].

Fig. 1 shows the corresponding head-flow characteristics of pump and circuit.

The maximum feed of pump and therefore charge of liquid Q in the circuit accounted for about 9 l/s corresponds to the minimum resistance of circuit value. With the gradual increase in resistance of operating point (intersection point of pressure pump and network characteristics) will be displaced to the left. On the charge scale in interval of 9 to 5.8 l/s (Fig. 1), the increase of resistance leads to increase of the efficiency of the pump.

At the same time, the effectiveness of moving of fluid in the pipeline circuit, which is characterized by the expression (2) decreases. Reduced overall energy perfected of circuit ε. After the transition of operating point through the point of graph efficiency maximum (5.8 l/s, η_p = 0.66), as shown in Fig. 2, increase in resistance results in reducing of efficiency of pipeline and pump, thus to further reducing of the overall perfected of circuit.

Thus, the growth of energy losses in the pipeline the pump efficiency can be increased, but the overall efficiency of a hydraulic circuit, as seen from the graph in Fig. 2 decreases.

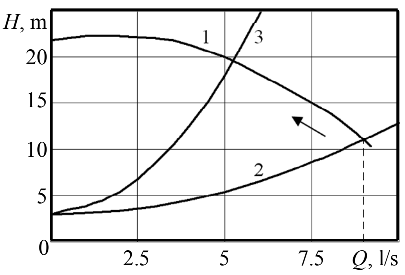

Fig. 1. Head-flow characteristics of pump (1) and the circuit: 2 – $S = 9.9 \cdot 10^4$ s^2/m^5, 3 – $S = 6 \cdot 10^5$ s^2/m^5

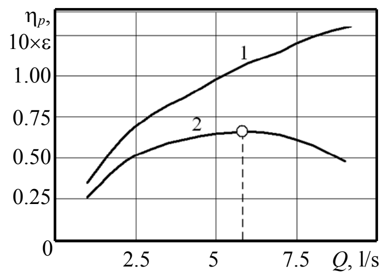

Fig. 2. Dependence ε (1) and the efficiency of the pump (2) from the charge of liquid in the hydraulic circuit

The graph in Fig. 2 shows that the increase in resistance of circuit in any case leads to reducing the charge of liquid in the system, increasing losses in it and reducing the coefficient of the energy perfected of circuit. The exception may be circuits which, depending on the brand of the pump, on the graph of dependence its coefficient of the energy perfected of circuit (Fig. 2, curve 1) and efficiency (Fig. 2, curve 2) from the charge flow in the hydraulic circuits can be seen the segments with sharp drop in of pump efficiency $\eta_p = f(Q)$. On these segments decrease in the expression (2) caused by the growth of resistance in hydraulic circuit S, can be entirely compensated by growth of the efficiency of the pump. In this (relatively rare) event a graph $\varepsilon = g(Q)$ will have maximum.

It is easy to see that the proposed ε value can vary in the range]0; 1[. Indeed, if the fluid is ideal (able to move lossless), then $\eta_p = 1$, $S = 0$. Substituting the data mentioned in (2) and obtain the value ε = 1.

Conclusions. The proposed for specifications of energy efficiency the coefficient of the energy perfected of circuit ε has clear physical content – the ratio of power flow at the outlet of the circuit to the power fed into the circuit. It takes into account losses in pumping unit and pipeline circuit and is universal because it allows you to compare the energy perfected of hydraulic circuit with different parameters and different pumps and hydraulic circuits working "from the tank". The proposed coefficient should be used in designing of new of hydraulic circuits and during the checking calculation.

Література

1. Energy efficiency optimization in water distribution systems / A. Bolognesi, C. Bragalli, C. Lenzi, S. Artina // Procedia Engineering. – 2014. – Vol. 70. – PP. 181-190. DOI:10.1016/j.proeng.2014.02.021
2. Арсирий, В.А. Снятие ограничений мощности котлов по тяге и дутью / В.А. Арсирий, В.С. Федотова, Е.А. Арсирий / Новости Теплоснабжения. – 2015. – № 5(177). – С. 30–35.
3. Бутенко, О.Г. Технічна гідромеханіка / О.Г. Бутенко. – Одеса: Наука і техніка, 2016. – 298 с.
4. Арсирий, В.А. Расчет эффективности гидравлической системы / В.А. Арсирий, Е.А. Олексова, Д.А. Голубова // Холодильна техніка і технологія. – 2002. – № 4(78). – С. 48–51.
5. Насосы АЭС / П.Н. Пак [и др.]; ред. П.Н. Пак. – М.: Энергоатомиздат, 1989. – 328 с.

References

1. Bolognesi, A., Bragalli, C., Lenzi, C., & Artina, S. (2014). Energy efficiency optimization in water distribution systems. *Procedia Engineering*, 70, 181–190. DOI:10.1016/j.proeng.2014.02.021
2. Arsiry, V.A., Fedotova, V.S., & Arsiry, E.A. (2015). Removing boiler power limitations of the thrust and blow. *Novosti Teplosnabzheniya*, 5, 30–35.
3. Butenko, O.G. (2016). *Technical Hydromechanics*. Odessa: Nauka i Tekhnika.
4. Arsiry, V.A., Oleksova, E.A., & Golubeva, D.A. (2002). The calculation of hydraulic system efficiency. *Refrigeration Engineering and Technology*, 4, 48–51.
5. Pak, P.N. (Ed.). (1989). *The Pumps of Nuclear Power Stations*. Moscow: Energoatomizdat.

Received February 1, 2017
Accepted March 22, 2017