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Selection of Hydro Power Plant (Micro HPP) Drives for Natural Water Flows

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Abstract: Currently, there is a growing demand worldwide for the use of hydro units with simple designs, compact sizes, high efficiency, and minimal environmental impact in electricity production. As with all types of machines, mechanical transmissions play a crucial role in ensuring high efficiency in the design of hydro units. This article presents several calculation schemes for selecting drives for hydromachines designed for natural water flows and recommends a rational drive design.

Keywords: hydro unit, mechanical transmission, efficiency, calculation scheme, energy, design, power, hydro turbine.

Introduction: In recent years, the use of various renewable energy sources has significantly increased worldwide. Among these, the development of hydro unit designs intended to harness energy from natural water flows, which are relatively inexpensive, have simple structures, high efficiency (efficiency coefficient), and do not harm the environment, has become a focal point for researchers globally [1, 2].

Considering that the energy source in the studied object is derived from water, the humidity level in the environment is significantly higher than usual. In such conditions, mechanical transmissions operating on adhesion mechanisms are more effective than those relying on friction-based mechanisms in the drive system of the hydromachine.

Based on the aforementioned sources, a series of calculation schemes for the hydromachine have been developed (Figure 1).

Research Method: The objective of this research is defined as developing a scientifically grounded design for drives with compact dimensions, low weight, and high efficiency to ensure the superior performance of hydromachines. The primary characteristics of machines include four main parameters, among which the efficiency coefficient is one of the most critical. Therefore, the efficiency of mechanical systems is expressed through power as follows:

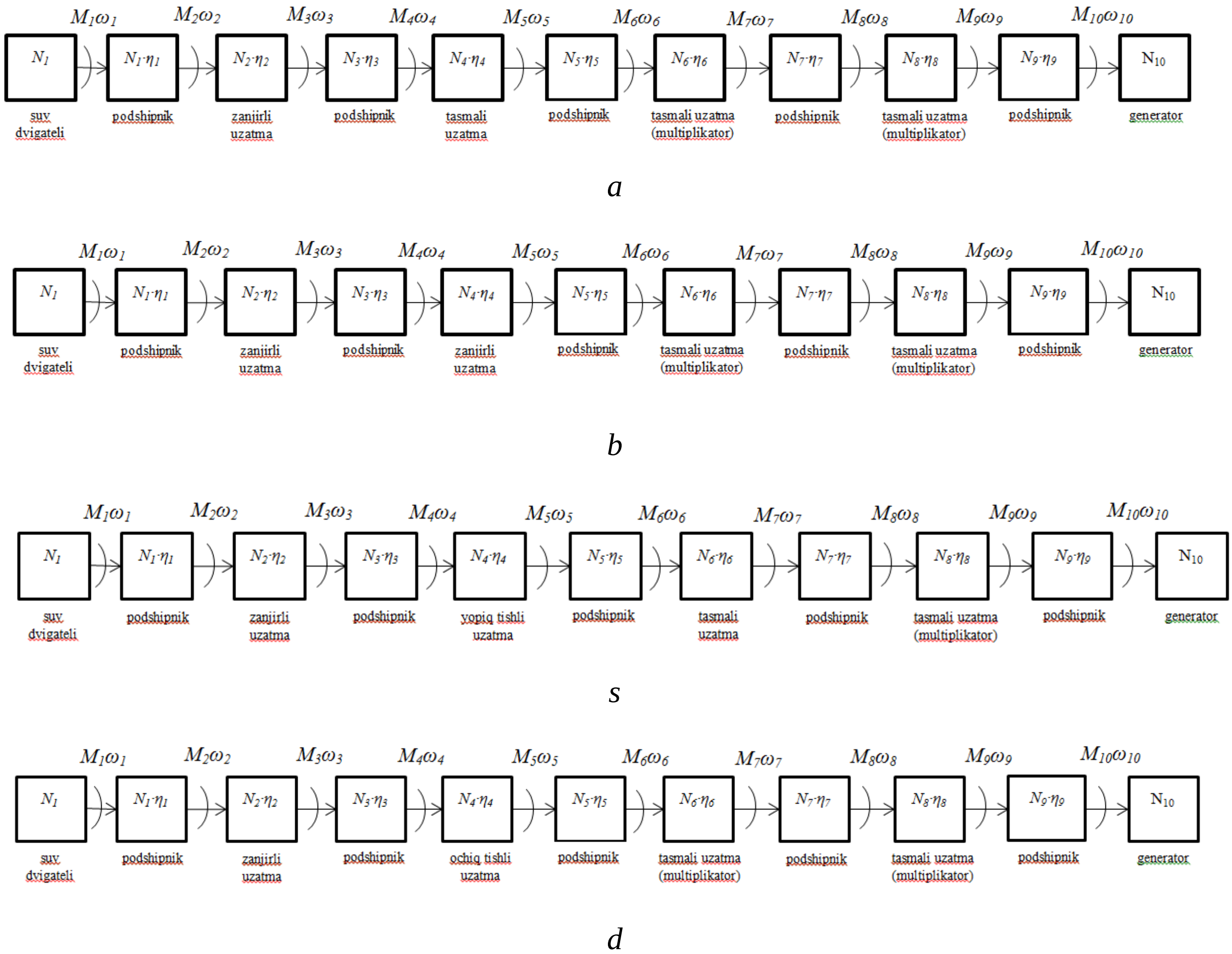
$$\eta = \frac{N_{f.k.}}{N_x}, \qquad (1)$$

where: $N_{f.k.}$– is the power of useful work (i.e., the power expended for useful work), W; $N_{x.}$– is the power supplied to the system (i.e., the total power input to the system), W.

Research results and discussion. In the developed calculation schemes, the mechanical systems consist of working parts connected in series. According to [3; pp. 452-453], if a machine is composed of \(n\) mechanisms connected in series, the efficiency of such a machine equals the product of the efficiencies of all the mechanisms within it. If the efficiencies of the mechanisms in the machine are denoted as $\eta_1, \eta_2, \eta_3, \ldots, \eta_n$, the overall efficiency of the machine can be mathematically expressed as follows:

$$\eta_{ум} = \eta_1 \cdot \eta_2 \cdot \eta_3 \ldots \eta_n = \frac{N_n}{N_x}, \qquad (2)$$

where: N_n– power in n mechanisms, W.



1-rasm. Calculation scheme

In calculating the efficiencies of the developed calculation schemes, the efficiencies of all working components within the systems can be selected from Table 1 [4; pp. 4-5].

Table 1. The useful work coefficient of the elements of the system

№	Drive Element	Efficiency (η)
1	A pair of bearings	0,990...0,995
2	Belt Drives	0,96...0,97
3	Open gear drive	0,95...0,96
4	Enclosed gear drive	0,97...0,98
5	Open chain drive	0,90...0,95
6	Enclosed chain drive	0,95...0,98

In order to choose the rational one from the calculation schemes presented in Figure 1, we calculate their useful work coefficients based on the above information. In order to make the calculations uniform, we take the power of the driving force Nx as 5 kW.

In the calculation scheme of the hydraulic unit presented in Fig. 1 a, the working parts are connected in series, and a belt transmission is selected as the transmission mechanism. According to the scheme, we express its general useful work coefficient as follows [5]

$$\eta_{ум1} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot \eta_6 \cdot \eta_7 \cdot \eta_8 \cdot \eta_9,$$

where η_1, η_3, η_5, η_7, η_9– useful performance coefficient of bearings; η_2 – the useful work coefficient of the chain drive; η_4, η_6, η_8– useful work coefficient of belt drives.

Using the values of useful work coefficients given in Table 1, we calculate the useful work coefficient of the calculation scheme in Fig. 1 a. useful work at the smallest values of the coefficients

$$\eta_{ум1} = 0{,}99 \cdot 0{,}9 \cdot 0{,}99 \cdot 0{,}96 \cdot 0{,}99 \cdot 0{,}96 \cdot 0{,}99 \cdot 0{,}96 \cdot 0{,}99 = 0{,}757$$

at the largest values of useful work coefficients

$$\eta_{ум1} = 0{,}995 \cdot 0{,}95 \cdot 0{,}995 \cdot 0{,}98 \cdot 0{,}995 \cdot 0{,}98 \cdot 0{,}995 \cdot 0{,}98 \cdot 0{,}995 = 0{,}872$$

Taking into account equations (1) and (2), we express the power on the generator shaft as follows

$$N_7 = N_1 \eta_{ум1},$$

where N_1– power on the water wheel shaft, kW.

$$N_{10} = 5 \cdot (0{,}757 \div 0{,}872) = (3{,}785 \div 4{,}360) \text{ kW.}$$

In the calculation scheme of the hydraulic unit presented in Fig. 1 b, the working parts are connected in series, and a closed gear transmission is selected as the transmission mechanism. According to the scheme, we express its general useful work coefficient as follows

$$\eta_{ум2} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot \eta_6 \cdot \eta_7 \cdot \eta_8 \cdot \eta_9,$$

where η_1, η_3, η_5, η_7, η_9– useful performance coefficient of bearings; η_2, η_4– useful work coefficient of the chain drive; η_6, η_8– the efficiency coefficient of belt conveyors (multiplier).

Using the values of useful work coefficients given in Table 1, we calculate the useful work coefficient of the calculation scheme in Fig. 1 b. at the smallest values of useful work coefficients

$$\eta_{ум2} = 0{,}99 \cdot 0{,}9 \cdot 0{,}99 \cdot 0{,}9 \cdot 0{,}99 \cdot 0{,}96 \cdot 0{,}99 \cdot 0{,}96 \cdot 0{,}99 = 0{,}709.$$

at the largest values of useful work coefficients

$$\eta_{ум2} = 0{,}995 \cdot 0{,}95 \cdot 0{,}995 \cdot 0{,}95 \cdot 0{,}995 \cdot 0{,}98 \cdot 0{,}995 \cdot 0{,}98 \cdot 0{,}995 = 0{,}845.$$

Taking into account equations (1) and (2), we express the power on the generator shaft as follows

$$N_{10} = N_1 \eta_{ум2} = 5 \cdot (0{,}709 \div 0{,}845) = (3{,}545 \div 4{,}225) \text{ kW.}$$

In the calculation scheme of the hydraulic unit presented in Figure 1c, the working parts are connected in series, and a closed chain transmission is selected as the transmission mechanism. According to the scheme, we express its general useful work coefficient as follows

$$\eta_{10} = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot \eta_6 \cdot \eta_7 \cdot \eta_8 \cdot \eta_9,$$

where $\eta 1$, $\eta 3$, $\eta 5$, $\eta 7$, $\eta 9$− useful performance coefficient of bearings; η_2− chain drive useful work coefficient; η_4− closed gear useful work coefficient, η_6, η_8− the efficiency coefficient of belt conveyors (multiplier).

Using the values of useful work coefficients given in Table 1, we calculate the useful work coefficient of the calculation scheme in Fig. 1 c. Useful work is at the smallest values of the coefficients

$$\eta_{ум3} = 0,99 \cdot 0,9 \cdot 0,99 \cdot 0,97 \cdot 0,99 \cdot 0,96 \cdot 0,99 \cdot 0,96 \cdot 0,99 = 0,765.$$

at the largest values of useful work coefficients

$$\eta_{ум3} = 0,995 \cdot 0,95 \cdot 0,995 \cdot 0,98 \cdot 0,995 \cdot 0,98 \cdot 0,995 \cdot 0,98 \cdot 0,995 = 0,872.$$

Taking into account equations (1) and (2), we express the power on the generator shaft as follows

$$N_{10} = N_1 \eta_{ум3} = 5 \cdot (0,765 \div 0,872) = (3,825 \div 4,36)\ \text{kW}.$$

In the calculation scheme of the hydrounit shown in Fig. 1 d, the working parts are connected in series, and an open chain transmission is selected as the transmission mechanism. According to the scheme, we express its general useful work coefficient as follows

$$\eta_4 = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdot \eta_4 \cdot \eta_5 \cdot \eta_6 \cdot \eta_7 \cdot \eta_8 \cdot \eta_9,$$

where $\eta 1$, $\eta 3$, $\eta 5$, $\eta 7$, $\eta 9$− useful performance coefficient of bearings; η_2− chain drive useful work coefficient; η_4− useful duty ratio of an open gear, η_6, η_8− the efficiency coefficient of belt conveyors (multiplier).

Using the values of useful work coefficients given in Table 1, we calculate the useful work coefficient of the calculation scheme in Fig. 1 d. Useful work is at the smallest values of the coefficients

$$\eta_{ум4} = 0,99 \cdot 0,9 \cdot 0,99 \cdot 0,95 \cdot 0,99 \cdot 0,96 \cdot 0,99 \cdot 0,96 \cdot 0,99 = 0,749.$$

at the largest values of useful work coefficients

$$\eta_{ум4} = 0,995 \cdot 0,95 \cdot 0,995 \cdot 0,96 \cdot 0,995 \cdot 0,98 \cdot 0,995 \cdot 0,98 \cdot 0,995 = 0,845.$$

Taking into account equations (1) and (2), we express the power on the generator shaft as follows

$$N_{10} = N_1 \eta_{ум4} = 5 \cdot (0,749 \div 0,845) = (3,745 \div 4,225)\ \text{kW}.$$

Summary. The above calculations indicate that in selecting drives for hydromachines designed for natural water flows, the calculation schemes in Figures 1b are not recommended due to their low efficiency. Although the schemes in Figures 1a and 1c demonstrate higher efficiency, they are not advisable because of their complex structural design and high mass. Based on the analysis, the calculation scheme in Figure 1d is recommended. This scheme is characterized by its simplicity, high efficiency, compact dimensions, and relatively lower forces exerted on the supports. This suggests that future research will focus on hydromachines equipped with open gear transmissions.

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