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Low-Power Hydraulic Motor for Mobile Micropower Stations and Pumps

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Abstract—The development of a low-power (1–10 kW) hydraulic motor for mobile micropower stations and pumps is considered; it is based on the energy of water moving under gravity in a river or other water body. A prototype motor is tested.

Keywords: hydraulic motor, water wheel, microhydropower systems, speed, power, energy, shaft, blade, chain drive, blade inclination

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Environmental and economic considerations call for new energy sources and research on energy efficiency. Possibilities include wind energy, solar energy, natural heat sources, and, in particular, the energy of water bodies (rivers and tides).

Uzbekistan experiences many sunny days and has many rivers, canals, and mountain streams. Since solar energy requires expensive equipment, the energy of flowing water is of more interest.

First, we review the literature on the design of low-power hydraulic generators (no more than 10 kW).

An article in *Water and Environment Journal* discusses microhydroelectric power stations that require special equipment [1]. The use of energy from flowing water in mountainous regions was discussed in [2], with calculation of the power of microhydroelectric power stations as a function of the flow of water. Numerous articles have been devoted to the design of microhydroelectric power stations [3]. Scientists from Malaysia and Egypt have developed a classification of hydroturbines for microhydropower stations and have recommended specific power stations for specific power ranges. A unit for producing energy from uniformly flowing water (a system inverse to a hydraulic pump) was described in [4]; the power of the falling water and the corresponding power generated were calculated.

Our literature review shows that the predominant approaches currently are dams and diversion systems, alone or in combination, with a hydraulic pressure head of 3–18 m; free-flow hydropower systems are also employed.

The simplest and cheapest approach is to use a hydraulic motor. Calculations show that a hydrogenerator of volume 1 m^3 with a water speed of 1 m/s may produce 1–2 kW; at 2 m/s, six times as much power may be generated.

The energy produced by a hydraulic motor may be determined from the formula

$$N = \rho v^3 S_\Sigma \eta/2,$$

where $\rho = 1000$ kg/m^3 is the water density; v is the flow rate, m/s; S_Σ is the total area of the working blades; and η is the motor efficiency.

Thus, when $v = 1$ m/s and $S_\Sigma = 1$ m^2, we may obtain up to 500 W of energy. With increase in the area of the working blades, more power is generated. In addition, the motor efficiency may be increased by specific design measures.

When using a hydraulic motor immersed in a reservoir, the flow rate of the water is decreased at that point but is restored some distance away. This distance may be determined experimentally. To increase energy output, several hydraulic motors may be employed.

In hydropower systems, the following types of the energy are utilized: the potential energy of the flowing water; the kinetic energy derived from the potential energy; both kinetic and potential energy; potential energy derived from kinetic energy; and kinetic energy.

The first three are the most effective for hydraulic systems and hydrogenerators. However, they require an artificial cascade from a considerable height. That entails constructing a dam and barriers, at an expense far greater than that of the power unit itself. Hence, it is more efficient to use natural water flows. Such systems may be installed anywhere and used to generate power for enterprises on the banks of rivers or canals.

On the basis of existing patents, a hydraulic system was developed in [5].

This system meets the following requirements [6]:

(1) power no less than 2.5 kW (based on the average daily consumption of a family);

(2) motor mass no more than 50 kg, so that it can be installed by two people;

(3) motor size no more than 1 m^3 (for ease of transportation);

(4) a simple, reliable design, with a minimum of parts, ease of maintenance, and ease of operation;

(5) low cost;

(6) working life no less than five years and recoupment of costs within six months.

The only operating costs must be associated with maintenance: the cost of replacing the bearings and chain transmission once or twice a year.

The hydraulic motor in Fig. 1 consists of a housing, several shafts (with rigidly attached blades), a chain transmission, and an output shaft. The shafts sit in bearings. There are three wheels on the middle shaft and four on the others.

The motor is immersed in water so that the blades are perpendicular to the water flow; the output shaft is above the water. The feet of the housing are securely fastened to the floor of the water body. The flowing water turns the blades and the shaft. The torques at the shafts are transmitted by the chain system to the output shaft.

Since the blades, shafts, and chain components are the same, the blades rotate synchronously. That facilitates faster water flow and so increases the output power.

A prototype motor is tested in a river with clear water (width 5 m, mean depth 0.5 m, water speed 1.5 m/s). We determine the speed of the shafts attached to the blades immersed in the water and the corresponding torques.

When two blades are immersed in water at different points of the flow, the downstream blade will turn more slowly. As they are moved closer together, the output power will fall.

Beyond the hydraulic motor, the water level falls; cavitation is observed beyond the blades.

In Fig. 2, we show the dependence of the torque M and shaft speed n on the blade inclination α. With increase in α, the shaft speed decreases. The torque is greatest when $\alpha = 45°–60°$.

In Fig. 3, we plot the power N against the blade inclination α. The energy is greatest when $\alpha = 45°–60°$. With $\alpha = 30°$ and 65°, we may obtain the same output power. However, the load on the blade is

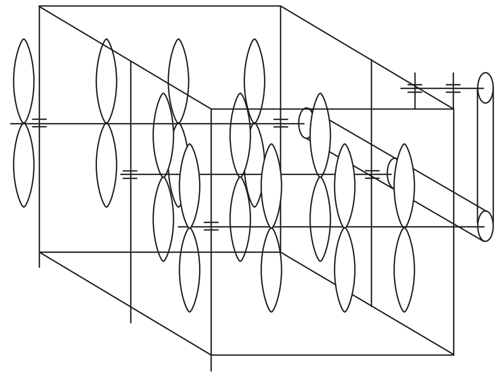

Fig. 1. Structure of hydraulic motor.

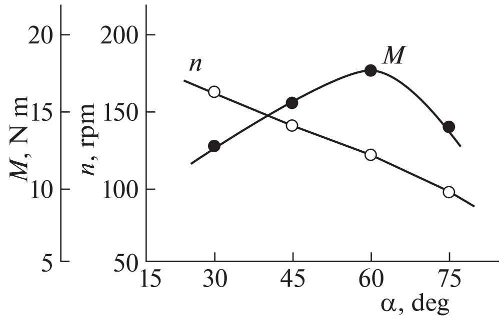

Fig. 2. Dependence of the torque M and shaft speed n on the blade inclination α.

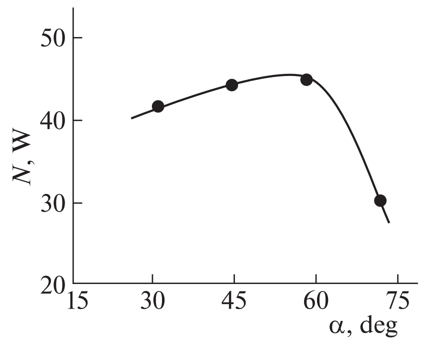

Fig. 3. Dependence of the power N on the blade inclination α.

greater when $\alpha = 30°$; that leads to deformation and fracture of the blades. Therefore, $\alpha = 45°–60°$ is optimal.

The blades attached to the same shaft must turn at the same speed. That entails a distance between the blades no less than 40–50 cm; the inclination of each successive blade must be less by 5°–10°. Parallel wheels will not interfere with one another in the course of operation.

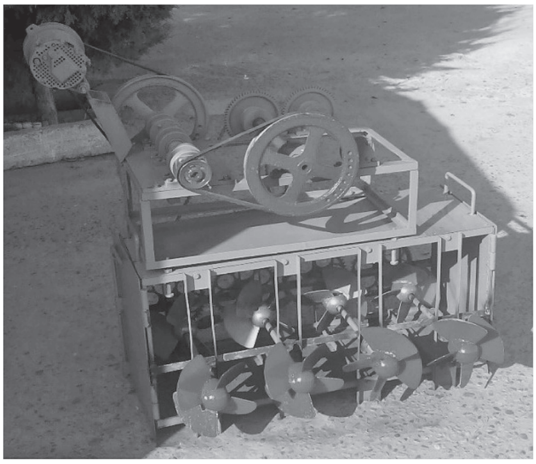

Fig. 4. Prototype hydraulic motor.

To decrease cavitation between the wheels, the rear of the blades must be somewhat convex.

Thus, experiments show that power generation is best with four working shafts, each of which has three wheels: blade diameter 40 cm; distance between the wheels on a single shaft 50 cm; distance between shafts 45 cm; blade inclination $\alpha = 60°$ in the first row, with 5°–10° decrease for each successive wheel; wheel hub diameter 8–10 cm; and blade thickness at least 1.5 mm.

The prototype hydraulic motor is shown in Fig. 4: dimensions 1800 × 1100 × 500 mm. The output power is 2.1 kW at a flow rate of 1.5 m/s, 4.5 kW at 2 m/s, 8.7 kW at 2.5 m/s, and 15 kW at 3 m/s.

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