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ИССЛЕДОВАНИЕ ТИПОВ ТУРБИН ДЛЯ ГИДРОЭЛЕКТРОСТАНЦИЙ

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Аннотация. Возобновляемые источники энергии, связанные с гидроэнергетикой, обеспечивают значительную часть электроэнергии в мире. При гидроэнергетическом методе энергия текущей воды преобразуется в электричество. Этот метод считается возобновляемым энергоресурсом, поскольку круговорот воды равномерно продолжается с помощью солнечного света. Одним из первых применений гидроэлектроэнергии было измельчение зерна, в то время как сегодня современные гидроэлектростанции используют турбины и генераторы для производства электроэнергии.

Целью данной работы является исследование факторов, влияющих на работу всех типов турбин гидроэлектростанций. Выявлено, что производство электроэнергии посредством процесса преобразования тепловой энергии имеет такие особенности, как незагрязнение окружающей среды, высокая эффективность, дешевизна энергии океана и др.

Ключевые слова: энергия, гидроэлектростанция, турбина, скорость, эффективность

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Scientific article

RESEARCH ON THE TYPES OF HYDROELECTRIC POWER TURBINES

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Abstract. Renewable energy resources related to hydroelectric power supply a large part of the electricity in the world. In the hydroelectric power method, the energy of water flowing is converted into electricity. This method is considered a renewable energy resource because the water cycle is uniformly continued with sunlight. One of the first hydroelectric power applications was in grain milling, while today, modern hydroelectric power plants use turbines and generators to produce electricity. This paper is aimed to investigate the influential factors in the performance of all types of hydroelectric power turbines. Electricity generation through the thermal energy conversion process has special features such as non-polluting the environment, good efficiency, cheapness of ocean power, etc.

Keywords: energy, hydropower plant, turbine, velocity, efficiency

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Introduction

Although electrical phenomena have been studied since ancient times, advances in theoretical understanding occurred slowly until the 17th and 18th centuries. Even then, electricity use was negligible and continued until the late 19th century (when engineers could use electricity in industrial and residential areas). Rapid advances in electrical technology have revolutionized industry and society. The wide use of electricity has led to its use in unlimited applications such as transportation, heating, lighting, telecommunications, and computing. Electricity has now formed the foundations of modern industrial society.

Electricity generation methods

The four types of power plants for generating electricity are: (1) hydropower plants; (2) thermal power plants; (3) wind power plants; (4) solar power plants. Hydroelectric power can be generated by: (1) dams; (2) rivers. In method (1), the energy of water stored behind the dams is used to generate electricity. There is a reservoir in the lower part of some dams where the water is pumped behind the dam in low-load conditions of the power grid. These two power plants are called pumped-storage hydroelectricity [1]. The flowing rivers are the second method of generating hydroelectric power, in which the turbine and generator are also used. However, depending on the amount of water natural flow, only a part of the river water enters the turbine, so it is not permanent [2].

Hydropower plants

There are three hydropower plants of different sizes [3]:

1. Large hydropower plants with a generation capacity of more than 30 MW.
2. Small hydropower plants with a generation capacity from 100 kW to 30 MW.
3. Micro hydropower plants with a generation capacity of less than 100 kW.

Hydro Turbine (Water Turbine)

Hydro Turbines convert water energy into mechanical energy to turn a turbine shaft. These turbines have high efficiency (over 90 % under full-load conditions), simple structure, and easy control [4]. Large turbines have rotation speeds of about 100 rpm, and small turbines about 1000 rpm [5]. There are two types of hydro turbines, including Reaction Turbine and Impulse Turbine, as well as turbines used in steam and gas power plants. The velocity and pressure of water decrease when it hits the moving blades of the Reaction Turbine in hydropower plants. Francis Turbine and Impeller Turbine are types of Reaction Turbines. Francis Turbine is used for medium water drop height and medium flow rate, while Impeller Turbine is used for low water drop height and high flow rate. Also, the Kaplan Turbine is a special type of Impeller Turbine that has an adjustable blade. But Impulse Turbines have moving blades. The water velocity decreases due to hit with moving blades, whereas the water pressure remains constant. This type of blade exists in Pelton Turbine (Pelton Wheel) and is available for power plants with high water drop height and low flow rate [6].

Specific Speed (SS)

The specific speed of a turbine is the speed of a model turbine that produces 1 kW power per 1 m water drop height and is calculated as follows:

$$N_s = \frac{N\sqrt{P_t}}{H^{\frac{1}{25}}}, \tag{1}$$

where N_s – Specific speed (rpm); N – Turbine rotation speed (rpm); P_t – Output power (kW); H – Water drop effective height (m).

The Table below shows the classification of turbines based on the water drop height and their specific speed.

Table

Classification of turbines based on the water drop height and their specific speed

Specific speed	Water drop height	Turbine type
10–60	above 200 m	pelton
50–400	30 to 200 m	francis
300–1 000	less than 30 m	impeller

According to table, turbines with high specific speeds are used at low water drop heights. Because otherwise, due to the high velocity of the fluid, the losses of the turbine will be high, and the system efficiency will be low. This can be seen in (1). According to (1), as the water drop height increases, the specific speed of the turbine decreases. Also, turbines with an exact low rate are used because the turbine automatically rotates faster in dams with a high water drop height [7].

Types of Hydro Turbines

1. Pelton Turbine.

Pelton Turbines are used in dams with high water drop heights (usually more than 200–250 m) and low water flow. Pelton Turbines are Impulse Turbines in which all the water pressure in the parallel nozzle is converted into kinetic energy. Then the water is directed at high velocity through the injector and the needle valve inside the turbine scopes (like moving blades). By controlling the position of the needle valve, the flow rate of the water entering the turbine scopes can be adjusted. The power plant governor system performs this operation. In the Pelton Turbine, the water outlet from the nozzle hits only one scope at any moment. If the outlet water hits several scopes at any moment, it is called a Turgo Turbine, shown in fig. 1 [8].

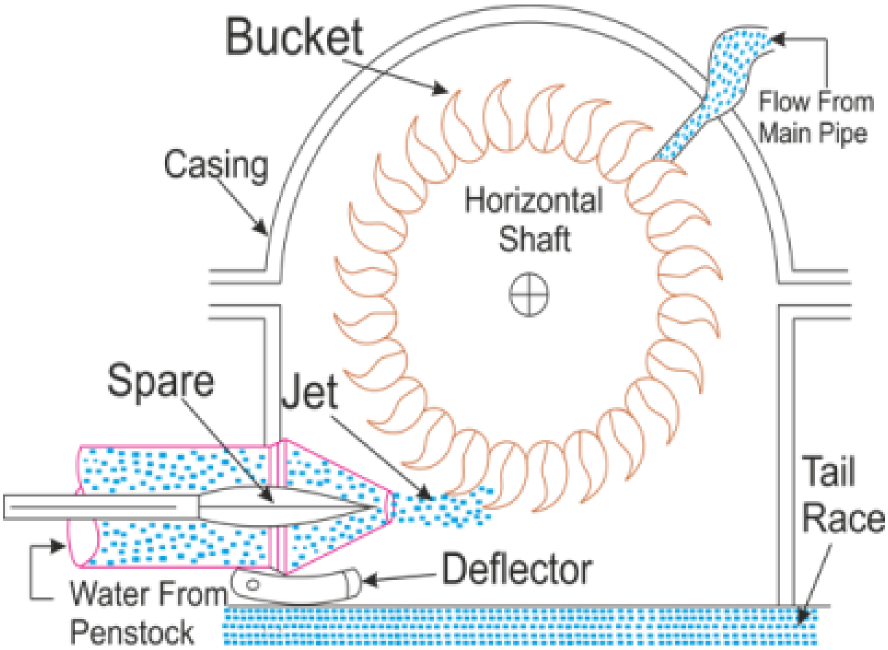

Fig. 1. **A general schematic of the Pelton Turbine**

Theoretically, the maximum efficiency of the turbine is obtained when the speed of the turbine shaft is equal to half the velocity of the water spraying that this situation occurs when the moving blades return the inlet water exactly 180 degrees. At this time, the discharge water velocity is 0, which is impossible in practice. The ratio of the rotation speed of the blades to the water spraying velocity is 0.46–0.47. As a result, the efficiency of this turbine is about 90 %.

2. Francis Turbine.

A schematic of the Francis Turbine is illustrated in fig. 2. As mentioned, the Francis Turbine is used for power plants with medium water drop heights and medium water flow rates. The water behind the dam enters the spiral tubes through channels. The cross-sectional area in the spiral tubes uniformly decreases so that the fluid can contact the main turbine blades at a uniform speed. After passing through the spiral casing, the water hits the main blades at a high velocity by the guide vanes. The role of the guide vanes is to increase the final velocity of the water and guide the water correctly to hit the main blades (as radially). By changing the angle of the guide vanes, the intensity of the water flow can be changed, which subsequently changes the number of specific cycles. In other words, the edges of the adjacent blades touch each other when these blades are completely closed, which cuts off the water flow to the main blades. The degree of opening of these blades changes the amount and direction of the water flow and, subsequently, the turbine power. As a result, with the radial impact of the water on the main moving blades, the kinetic energy is converted into rotational mechanical energy. The maximum efficiency of this type of turbine is 94–95 % [9].

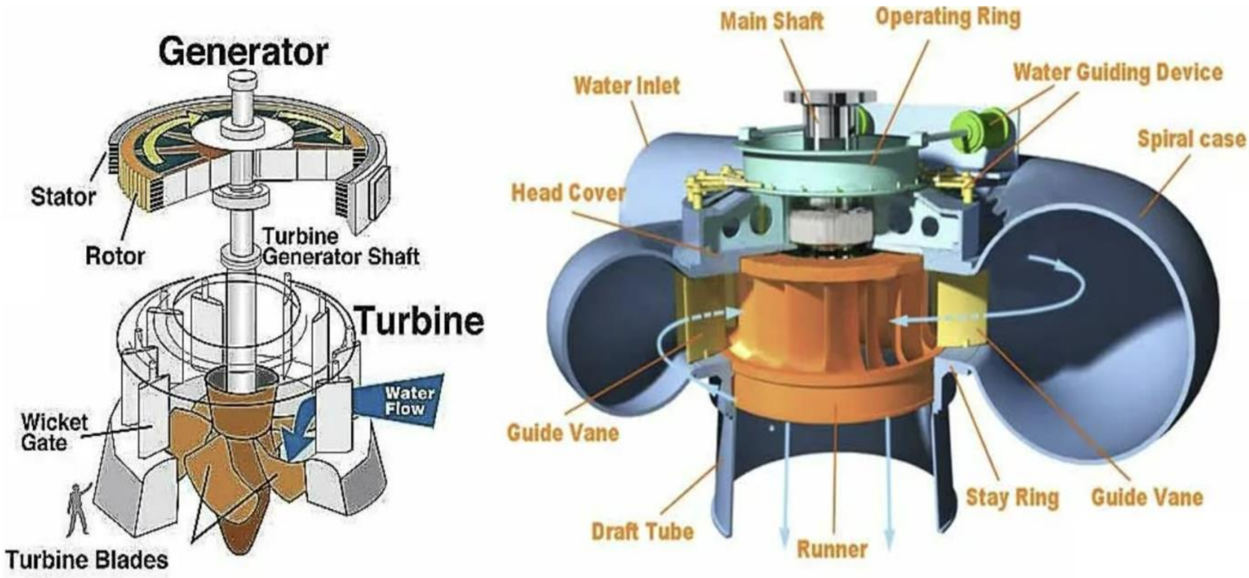

Fig. 2. **A general schematic of the Francis Turbine**

3. Kaplan Turbine.

A schematic of the basic design of the Kaplan Turbine can be observed in fig. 3. In Kaplan Turbine, the water flow axially hits the moving blades. The spiral tube and guide vanes have a design and operation similar to the Francis turbine. After passing through the guide vanes and before hitting the moving blades, the water takes the axial direction at a high velocity to transfer its maximum energy to the moving blades. Usually, the number of moving blades is between 4 and 6, which are generally adjustable in power plants. This increases the efficiency of this type of turbine and reaches 94 % in large turbines. By changing the angle of the moving blades, the number of flowing water changes, and finally, the shaft mechanical power changes. Generally, the shaft of these turbines is installed vertically [10].

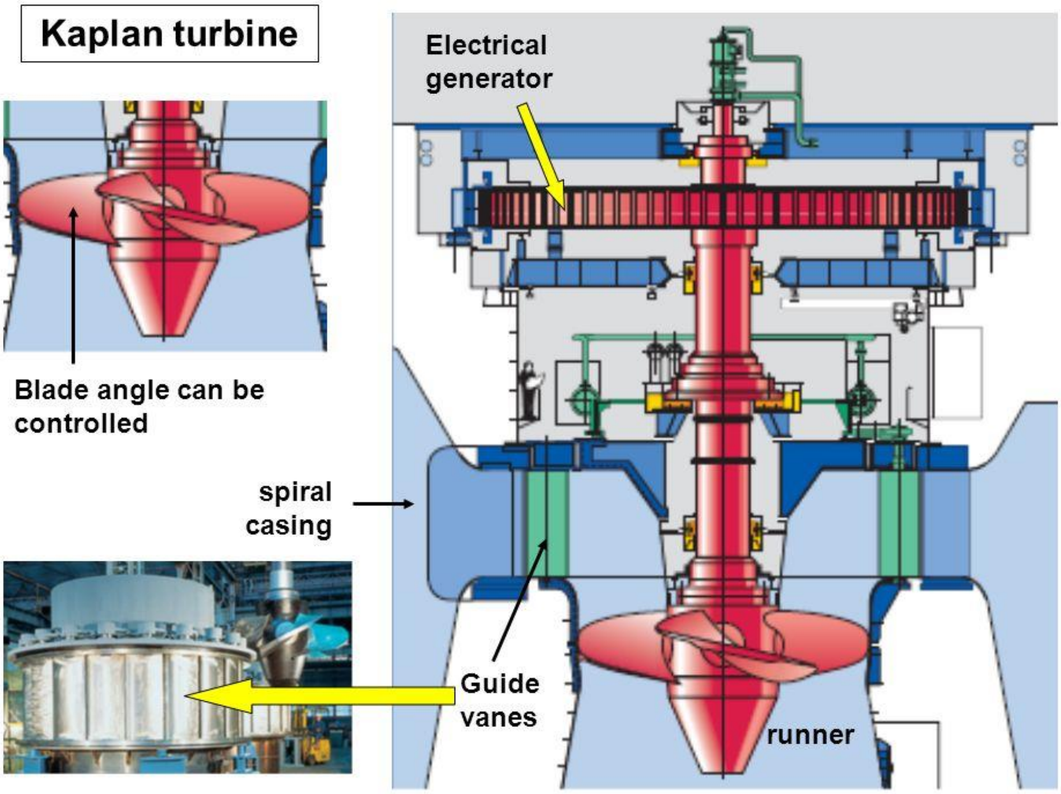

Fig. 3. **A general schematic of the Kaplan Turbine**

4. Tubular Turbines.

Tubular Turbine is widely used in rivers, and the water height is very low. Of course, these plans are associated with some problems, such as [11]:

1. In an immersing system in water, we need to drill to prevent cavitation, which entails many costs.

2. Several changes in the direction of water in narrow tubes cause the need to design the piping system, which increases hydraulic losses.

These problems have caused the increasing use and development of Tubular Turbines. The rotating system is Kaplan-type with fixed or variable blades, and its shaft is more or less horizontal. Therefore, as much as possible, the direction of the water deviates from the axial state. The efficiency of these types of turbines is similar to Kaplan Turbine. The kinds of Tubular Turbine are:

1. Bulb turbine.
2. Tube turbine.
3. Rim generator turbine.

Description of efficiencies

The efficiency of a turbine can be divided into three parts [12]:

1. Volumetric efficiency.
2. Hydraulic efficiency.
3. Mechanical efficiency.

Only English units of measurement can be used in this section. If the units are SI, they must be converted to English units before using in the equations. Because otherwise, they will not be correct in terms of dimension. The overall efficiency of a turbine is expressed as follows:

$$e = \frac{\mathrm{T}\omega}{\gamma Q h},$$

where T – The torque transmitted to the shaft by the turbine; ω – The rotational speed (Rad/s); h – The turbine head.

Volumetric efficiency (e_v) is related to the possibility of efficiency loss during rotation, for example, leakage around the outer part of the rotor (the presence of cracks or any other defects) or rotor components. In other words, all flowing liquids are not necessarily effective in energy transfer. For a turbine, the term Q_L shows this leakage, while the term Q is the net flow through the turbine, and the term $Q\text{-}Q_L$ shows a good flow that is effective on the rotor [13].

As a result, the volumetric efficiency is represented as follows:

$$e_v = \frac{Q-Q_L}{Q}.$$

The hydraulic efficiency of a turbine has defined the ratio of $Y(Q\text{-}Q_L)h''$ (the power transferred from the water to the turbine blades (rotor)) to $[Y(Q\text{-}Q_L)h]$ (the usable power in the liquid that effectively flows through the blades to the turbine). From the past, the head used by the rotor was equal to:

$$h'' = (u_1 V_1 cos\alpha_1 - u_2 V_2 cos\alpha_2).$$

Which can be expressed as $h'' = h - h_f$. Here, h_f is the missing head friction in the turbine, which includes the output losses.

The hydraulic efficiency of the turbine is as follows:

$$e_h = \frac{h - h_f}{h} = \frac{h''}{h}.$$

The mechanical efficiency (e_m) of a turbine is defined as the ratio of the usable power on the shaft to the power used by the water on the turbine blades. Thus, we have:

$$e_m = \frac{\mathrm{T}\omega}{(T + T_f)} = \frac{bp}{bp + fp}.$$

A pump has an efficiency similar to a turbine but is basically reversed.

If there is a leakage in the Q_L value returned from the high pressure to the low pressure of a pump, we will have energy losses because the work is also done on the leaked liquid. For a pump, volumetric efficiency is as follows:

$$e_v = \frac{Q}{Q + Q_L}.$$

Where Q shows the real released flow, the hydraulic efficiency of a pump is as follows:

$$e_h = \frac{h}{h''}.$$

The mechanical efficiency of a pump is as follows:

$$e_m = \frac{b_p - f_b}{b_p}.$$

In general, the efficiency of a pump can be calculated by b_p-f_b. The power transferred from the rotor to the water can be expressed by $Y(Q+Q_L)(h+h_f)$. By relating this equation to the previous equation, the overall efficiency of a pump is obtained:

$$e = \text{(fluid power) / (the usable power by shaft (axis))} = \gamma Qh/T\omega = e_v e_h e_m.$$

The same equations can be used for compressors, air blowers, and fans. But if there is a significant change in the fluid concentration, some corrections may be necessary.

Conclusions

According to the previous points, electricity generation through the thermal energy conversion process has special features such as non-polluting the environment, good efficiency, cheapness of ocean power, etc. On the other hand, the location limitation for these power plants' operation, electricity transmission problems, and large initial investments have led to a slow expansion of this method. However, due to the increasing cost of fossil fuels, it is necessary to investigate the use of electricity generation methods with the help of different techniques through technical and economic studies.

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