Basic knowledge

Water turbines

Basic principles of water turbines

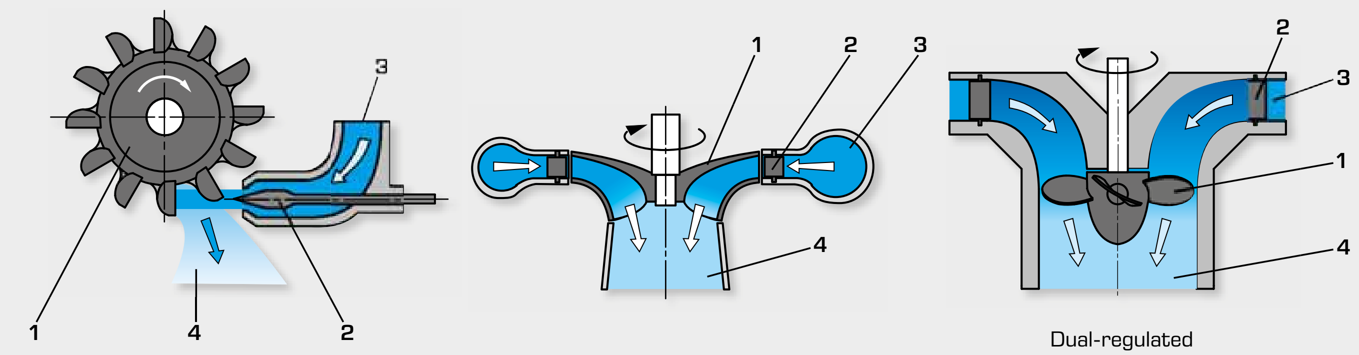
Water turbines are mainly used in power plants to generate electrical energy. To this end, river barrages or dams use the gravitational potential energy of the dammed water, also known as pressure energy. One special application is the use in pumped storage power plants. In times of low electricity demand an elevated storage reservoir is filled with water by means of electrically driven pumps. When electricity demand is higher, the reservoir is drained and additional electricity generated by water turbines.

Water turbines are turbomachines. They convert the potential energy of the water into mechanical work. The gravitational potential energy is first converted into kinetic energy. The flowing water is accelerated to as high a speed as possible in a distributor or a nozzle. The momentum of the fluid is made usable as peripheral force by deflection in a rotor.

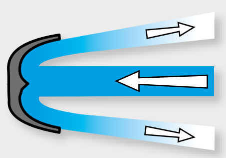
Depending on the location of the energy conversion a distinction is made between:

Action turbine: All of the potential energy is converted into velocity in the fixed distributor. There is no pressure gradient between the rotor inlet and the rotor outlet. The flow is only deflected in the rotor.
Example: Pelton turbine

Reaction turbine: The potential energy is converted partly in the distributor and partly in the rotor. In the rotor there is a pressure difference between inlet and outlet. The flow is deflected and accelerated in the rotor.
Examples: Francis turbine and Kaplan turbine

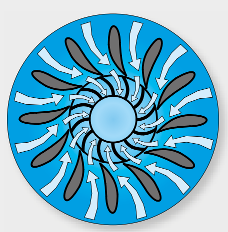


1 rotor, **2** distributor, **3** water inlet, **4** water outlet



Action turbine (Pelton)

Pure deflection of the water jet in the guide vane without changing the speed



Reaction turbine (Francis)

Flow cross-section are changed. Acceleration of the water jet in guide vanes and blades

The individual turbine types have different fields of application

- Pelton turbine: very high heads, 130 m to 2000 m, dams, mountain reservoirs
- Francis turbine: average height of fall, 40 m to 730 m, dams, run-of-river power plants
- Kaplan turbine: small height of fall, 5 m to 80 m, run-of-river power plants

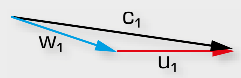
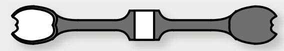
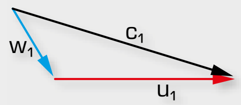
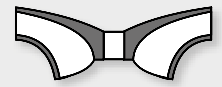
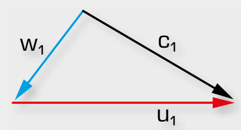
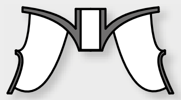
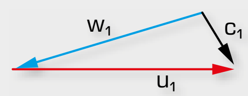
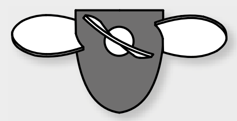
The drop heights stated above apply for high outputs. At low outputs the height of fall may be significantly lower. Run-of-river power plants are hydroelectric power plants without reservoirs that can be used for the operating water.

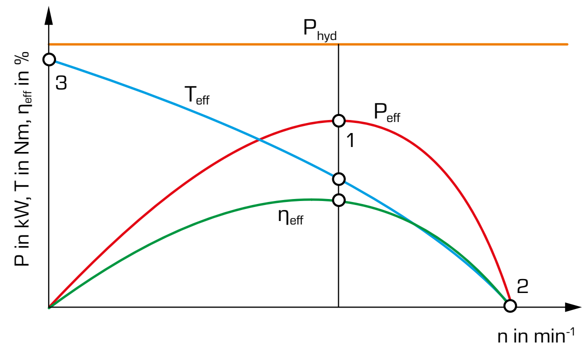
Characteristics of water turbines

The specific speed n_q is the most important characteristic for water turbines. It is a measure of the ratio of water velocity to rotational speed. A distinction is made between low-speed turbines, where the water velocity is significantly higher than the peripheral speed, and high-speed turbines, where the situation is reversed.

$$n_q = n \cdot \frac{\sqrt{Q}}{H^{3/4}}$$

Here, **n** is the rotational speed, **Q** the flow rate and **H** the head of the water turbine. The ratios are made clear in the velocity triangle. The following list shows the velocity triangles for the inlet side of the rotor. $\mathbf{c_1}$ is the absolute velocity, $\mathbf{w_1}$ the relative velocity of the water and $\mathbf{u_1}$ the peripheral speed of the rotor.

Specific speed		Velocity triangle	Rotor shape
$n_q = 10$	Low-speed turbine		 Pelton turbine
$n_q = 30$			 Francis turbine, low-speed
$n_q = 90$			 Francis turbine, high-speed
$n_q = 200$	High-speed turbine		 Kaplan turbine



Speed-torque characteristic of a water turbine

P_{hyd} hydraulic input power of the turbine,
P_{eff} mechanical power generated in the rotor,
T_{eff} torque on the rotor,
η_{eff} efficiency of the turbine, **n** speed

Operating behaviour and operating points of a water turbine

The turbine characteristic curve shows the typical behaviour of a water turbine.

The water turbine is preferably operated at the operating point (**1**), where it has the highest efficiency. The torque in a Pelton turbine corresponds to roughly half of the stall torque (**3**). The turbine speeds up to the runaway speed (**2**) when it is not under load. This overspeed can be up to twice the design speed and may result in severe damage to the turbine. A speed controller must prevent this by closing the distributor and throttling the water supply.