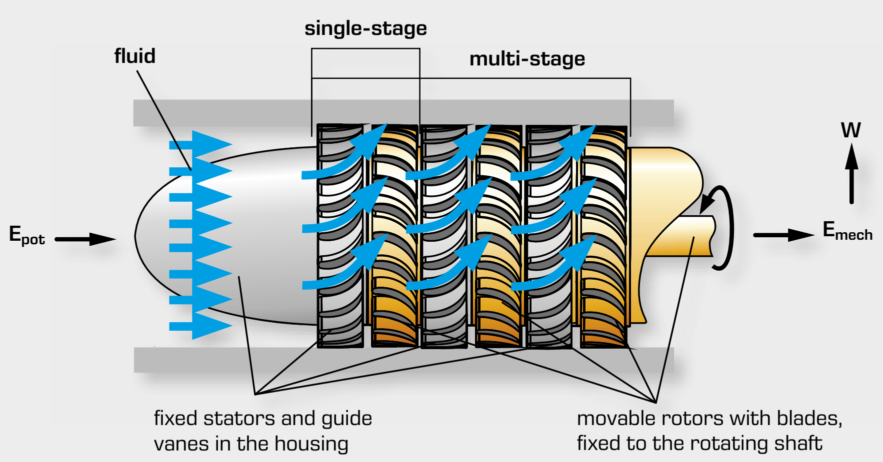
Basic knowledge

Turbines

Turbines are driving machines: energy is extracted from the flowing fluid and released to the surroundings in the form of mechanical work. The main components of a turbine are the revolving rotor and the fixed distributor. Together, they form a stage. The energy to be extracted from the fluid is often so large that it is not possible to do in one stage. If this is the case, several stages are switched in series, resulting in a multi-stage turbine. In practice, this occurs when the pressure differences are too high for a single stage.



E_{pot} potential energy, **E_{mech}** mechanical energy, **W** work output by the turbine

Turbines can be categorised according to the following features

1. working medium

- water turbines
- steam turbines
- gas turbines
- wind turbines

2. principle of operation

- action turbines: impulse turbines, free-jet turbines, cross-flow turbines
- reaction turbines

3. direction of flow

- axial turbines
- radial turbines
- diagonal turbines

The GUNT turbines are also categorised according to these features.

The following additional categories are common in the industrial sector:

- according to external design: e. g. according to the shaft position or type of water supply: vertical shaft turbines, spiral turbines, tube turbines, etc.
- according to operating mode: operation as a turbine only, or reverse operation as a pump turbine
- according to the control principle: single-regulated via the distributor only or double-regulated via the distributor and rotor settings

Due to the multiple features, the groups overlap and turbines may be allocated to more than one group.

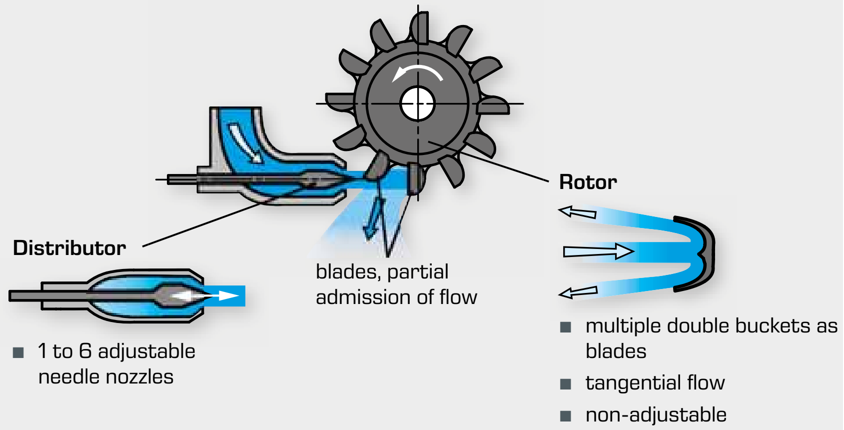
Categorisation according to the principle of operation

Despite the numerous differentiating factors, a general categorisation distinguishing **reaction turbines** from **action turbines** can be made. This categorisation is based on the way they convert energy. In all turbines the pressure of the working medium, and thus its potential energy, changes in the distributor. The rotors are the point at which action and reaction turbines differ.

Action turbines

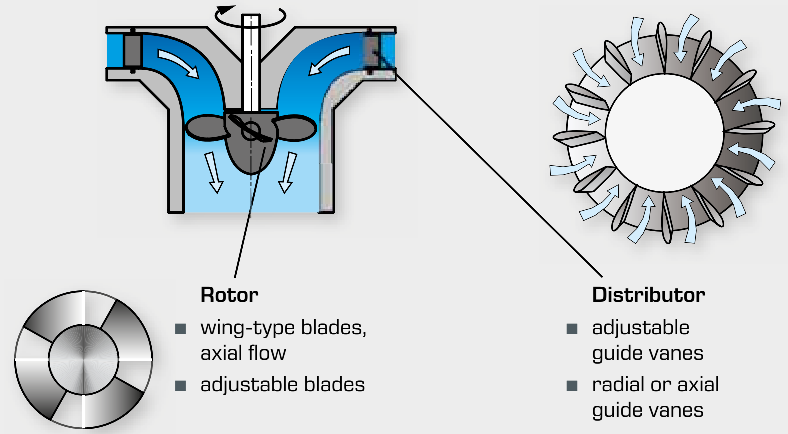
In action turbines the potential pressure energy in the distributor is completely converted into kinetic energy. The flow enters the rotor at atmospheric pressure and under partial admission conditions. Partial admission means that the force of the jet puts pressure on only some of the blades at any one time. A typical example of an action turbine is the **Pelton turbine**.

Rotor with double buckets as blades and needle nozzles



Reaction turbines

In reaction turbines, the rotor inlet pressure is higher than the outlet pressure. The conversion of the potential pressure energy is divided between the distributor and rotor. The kinetic energy is then converted into mechanical work at the rotor. The flow enters the rotor at full admission. Full admission means that the working medium flows through the entire circumference of the rotors. A typical example of a reaction turbine is the **Kaplan turbine**.



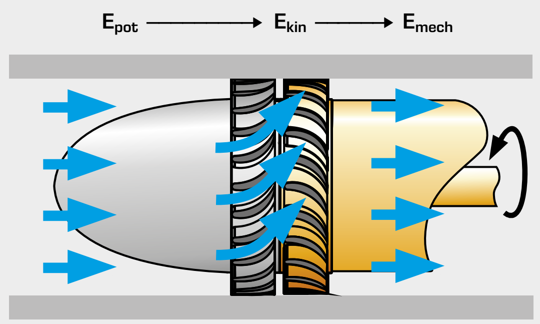
Basic knowledge

Turbines

Introduction to the theory of turbines, based on the example of a single-stage axial turbine

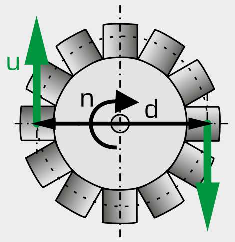
Axial turbines are very well suited to explain the basic principles of turbines, as they can be designed as both action turbines and reaction turbines.

Moreover, there is a clear distinction based on which working medium is used: they can be operated with water, steam, or gas. All of the information below refers to axial turbines.



Energy

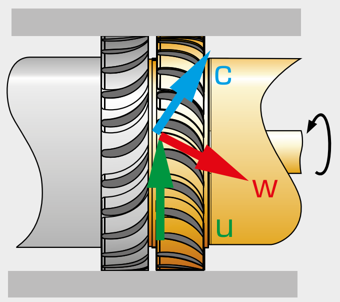
A turbine is an energy converter. The goal is to extract a usable portion of energy in the form of mechanical work from the energy of the flowing fluid. The fluid contains both potential energy (pressure) and kinetic energy (speed). In a first step, the potential energy is also converted into kinetic energy. Then, the kinetic energy of the fluid is converted into usable mechanical energy.



u circumferential velocity,
n speed,
d diameter

Velocities

The rotor with the diameter **d** rotates at the speed **n**, which means that the centre of the blade rotates at the circumferential velocity **u**. The direction of **u** is always perpendicular to the axis of rotation. This direction is referred to as the circumferential direction.

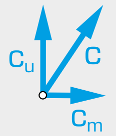


c absolute velocity,
w relative velocity,
u circumferential velocity

The **circumferential velocity u** refers to the rotor. It is the same at both the rotor inlet and the rotor outlet.

The **relative velocity w** corresponds to the velocity of the flow as compared with the turning rotor.

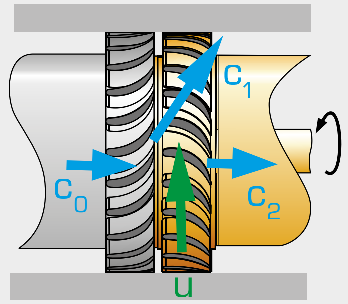
The **absolute velocity c** is the flow velocity relative to the stationary surroundings. It provides information on the kinetic energy of the fluid. The absolute velocity can be divided into two components: c_u in circumferential direction and c_m in axial direction.



Mathematically, the three velocities have the following relationship: $\vec{c} = \vec{u} + \vec{w}$

All velocities are vector values and can be divided into their components in circumferential direction as well as in radial and axial direction.

Using the energy: how is the energy in the fluid converted in the turbine?



index 0 defines the inlet of the stator,
index 1 the outlet of the stator or the rotor inlet, and
index 2 the rotor outlet

The fluid enters the stator at the velocity c_0. Due to the geometry of the guide vanes, the fluid's velocity increases to c_1 as it reaches the blade. The blade deflects the working medium. This deflection generates a force on the blade and leads to the rotation of the rotor at the circumferential velocity **u**.

Due to this energy transfer to the rotor, the absolute velocity of the fluid is reduced from c_1 to c_2 when it flows through the rotor.

The force at the blade can be used to calculate the work that is transferred from the fluid to the turbine. This is called **specific work**, because the work transferred within the turbine is related to the mass of the fluid. In the technical literature, this is also described as **specific blade work**.

Euler's main equation for turbomachinery

$$Y = \Delta (u \cdot c_u)$$

Y specific work, **u** circumferential velocity,
c_u component of absolute velocity in the circumferential direction

The specific work is an indication of the energy grade line between the inlet and outlet and corresponds to the usable portion of energy. The specific work is calculated with the help of **Euler's main equation for turbomachinery**.

The following equation applies for turbines:

$$Y = u_1 \cdot c_{1u} - u_2 \cdot c_{2u}$$

In turbines, the velocities at the rotor inlet have an accelerating effect on the rotor, while the velocities at the rotor outlet slow down the rotor. Therefore, they are subtracted.

The energy gain or the total specific work is due to the velocity reduction from c_1 to c_2 in the circumferential direction.

The velocity reduction or the energy gain is clearly evident in the velocity triangles.

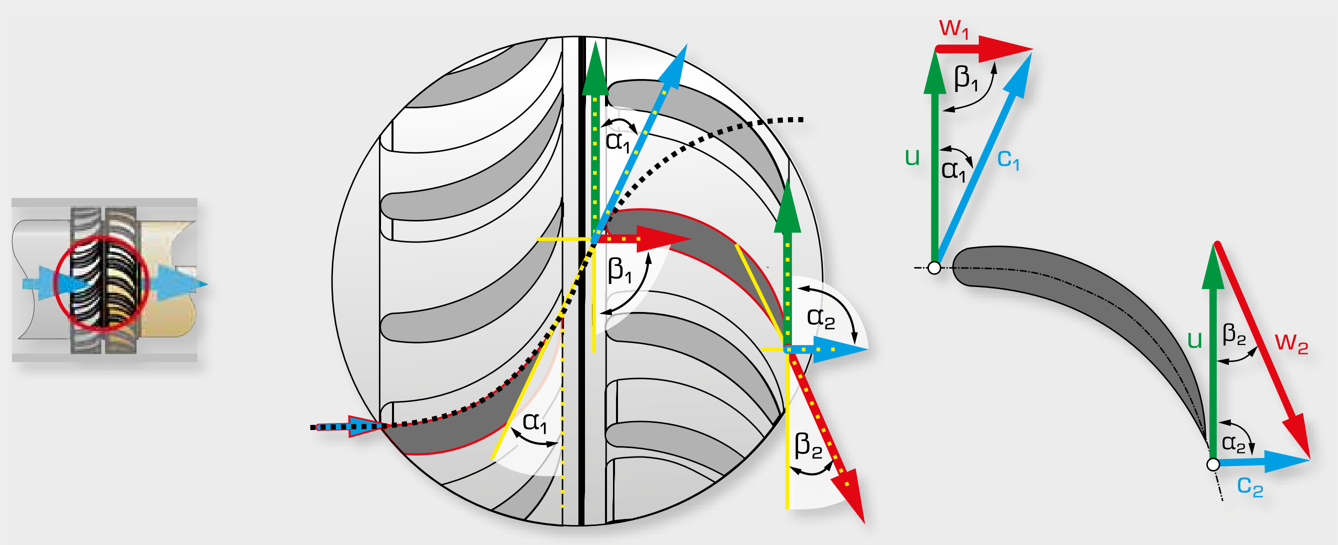
Basic knowledge

Turbines

Velocity triangles

Velocity triangles are used to illustrate flow conditions. The corresponding status of the flow is described by the flow velocities. In order to identify kinetic energy differences, flow velocities are determined according to the magnitude and / or direction. This is done with the help of velocity triangles.

When designing a turbine, velocity triangles are crucial for determining the maximum amount of usable energy. When the design parameters are changed, velocity triangles can clearly illustrate what effects this may have.



c absolute velocity, **w** relative velocity, **u** circumferential velocity,
α and β angles, **index 0** at the stator inlet, **index 1** between stator and rotor, **index 2** at the rotor outlet

The **absolute velocity c** is the flow velocity relative to the stationary surroundings. The direction of $\mathbf{c_1}$ corresponds to the tangent of the stator curvature (angle α1) at the outlet of the stator.

At the stator inlet the absolute velocity $\mathbf{c_0}$ and the relative velocity $\mathbf{w_0}$ are equal.

The **relative velocity w** corresponds to the velocity of the flow as compared to the turning rotor. The direction of **w** corresponds to the tangent of the blade curvature (angles β1 / β2) at the observed location.

The **circumferential velocity u** refers to the rotor. It is the same at the rotor inlet and the rotor outlet.

The black dotted line corresponds to the streamline of a fluid particle passing through the turbine. On the blade, the corresponding velocity triangle for each point along the streamline can be drawn using the three velocities according to the magnitude and direction.

The graph avove shows velocity triangles at the rotor inlet and the rotor outlet. The yellow lines are reference lines used to represent the tangents of the blade curvature and to determine the angles.

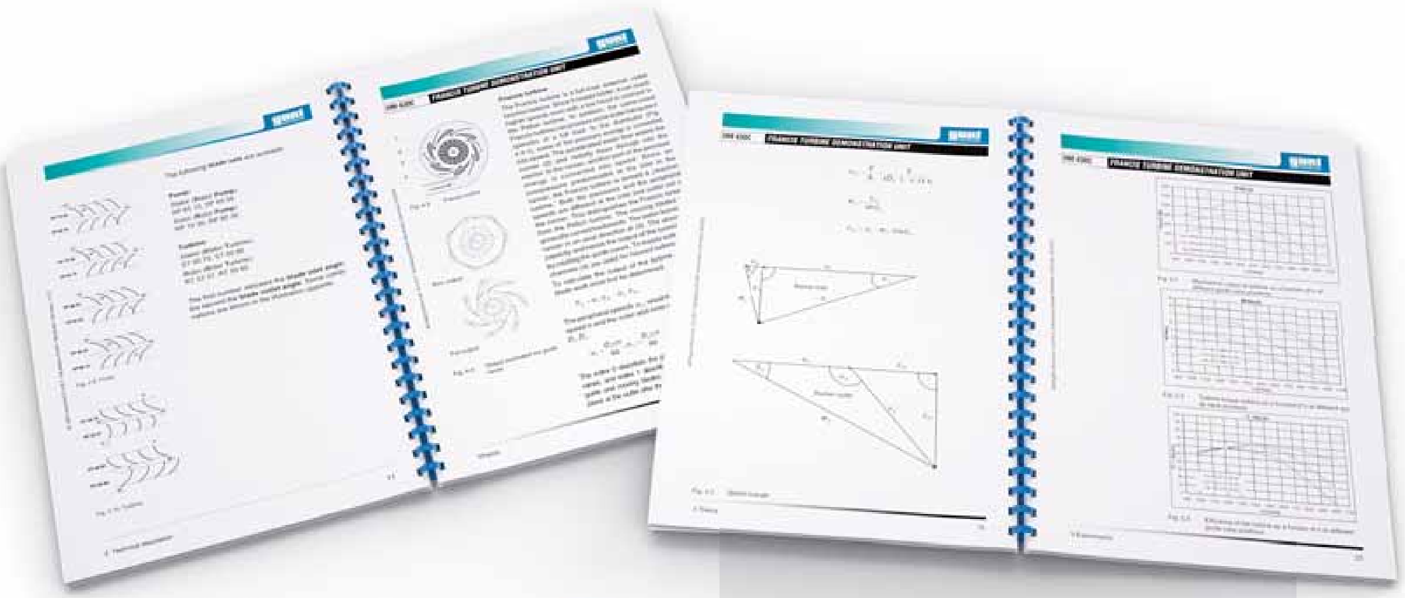
All information on velocity angles applies for operation at design-point conditions with optimal incident flow at the corresponding point.

The instructional material

All experimental units from the GUNT range also include corresponding instructional material. This material is far more than simple operating instructions.

Our instructional material contains the following:

- an in-depth description of the device including detailed operating instructions
- theories and background knowledge
- selected reference experiments
- material for experiments, such as template tables and diagrams
- suggestions on how to evaluate experiments and how to interpret test results. These are partially provided in digital form using the supplied GUNT software



The documents for the GUNT fluid machinery provide details on the velocity diagrams. This includes detailed information on how to create velocity triangles. It also includes the differences between the velocity triangles of driving and driven machines.