Basic knowledge

Water turbines

Basic principles of water turbines

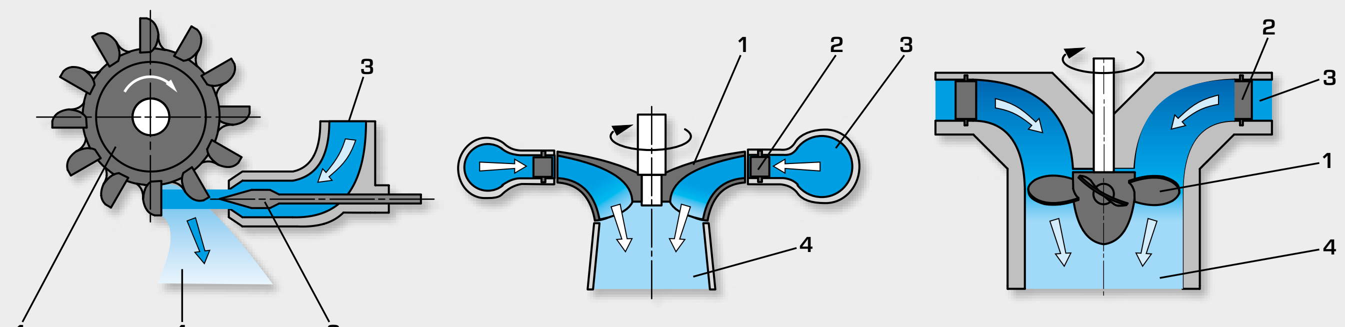
Water turbines are mainly used in power plants to generate electrical energy. To this end, river barrages or dams use the gravitational potential energy of the dammed water, also known as pressure energy. One special application is the use in pumped storage power plants. In times of low electricity demand 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.

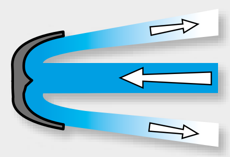
Depending on the location of the energy conversion a distinction is made between:

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

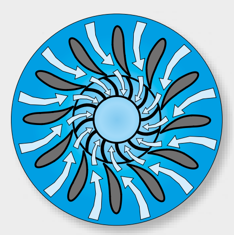


1 rotor, **2** distributor, **3** water inlet, **4** water outlet



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

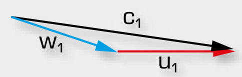
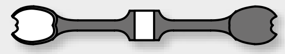
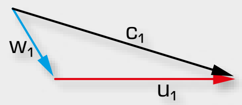
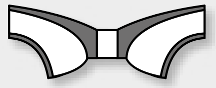
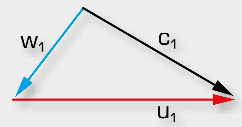
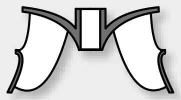
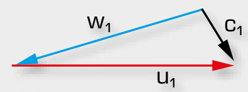
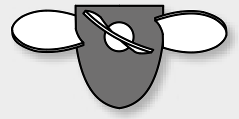
The drop heights stated above apply for high outputs. At low outputs the height of fall may be significantly lower. Run-of-river power plants are hydroelectric power plants without reservoirs that can be used for the operating water.

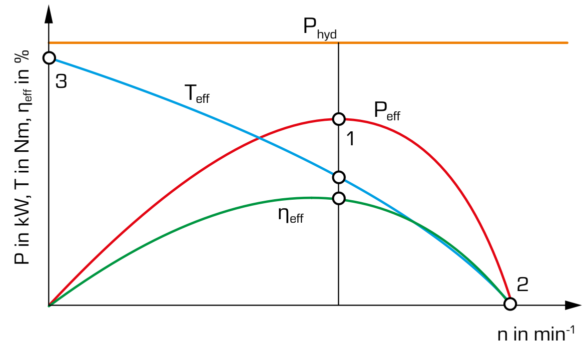
Characteristics of water turbines

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. c_1 is the absolute velocity, w_1 the relative velocity of the water and 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.

HM 150.19
Operating principle of a Pelton turbine

Learning objectives/experiments

- design and function of a Pelton turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

Description

- **model of an impulse turbine**
- **transparent operating area**
- **adjustable nozzle cross-section**
- **loading by band brake**

Water turbines are turbomachines utilising water power. The Pelton turbine is a type of impulse turbine; such turbines convert the pressure energy of water into kinetic energy entirely in the distributor. During the conversion, the water jet is accelerated in a nozzle and directed onto the blades of the Pelton wheel tangentially. The water jet is redirected by approximately 180° in the blades. The impulse of the water jet is transmitted to the Pelton wheel.

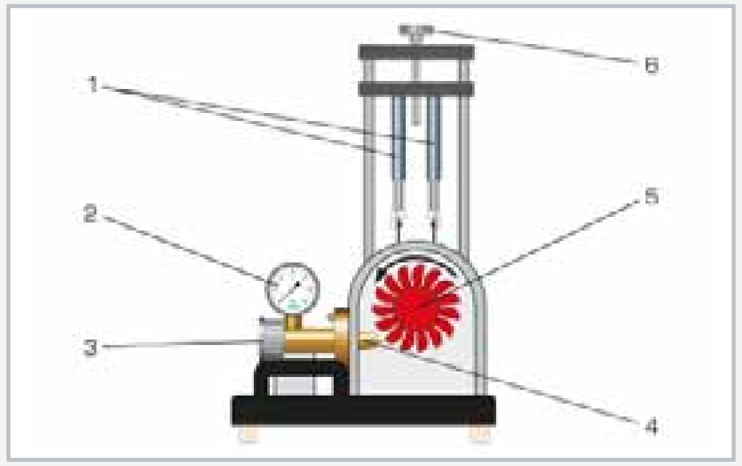
HM 150.19 is a model of a Pelton turbine demonstrating the function of an impulse turbine.

The experimental unit consists of the Pelton wheel, a needle nozzle used as distributor, a band brake for loading the turbine and a housing with a transparent front panel. The transparent cover enables to observe the water flow, the Pelton wheel and the nozzle during operation. The nozzle cross-section and thus the flow rate are modified by adjusting the nozzle needle.

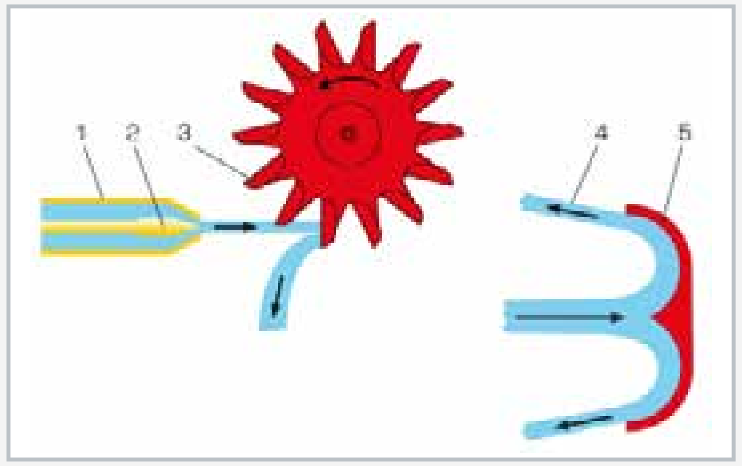
The turbine torque is determined by force measurement on a band brake and is read on spring balances. For measuring the rotational speed, a non-contact speed sensor, e.g. HM 082, is required. A manometer shows the water pressure at the turbine inlet.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

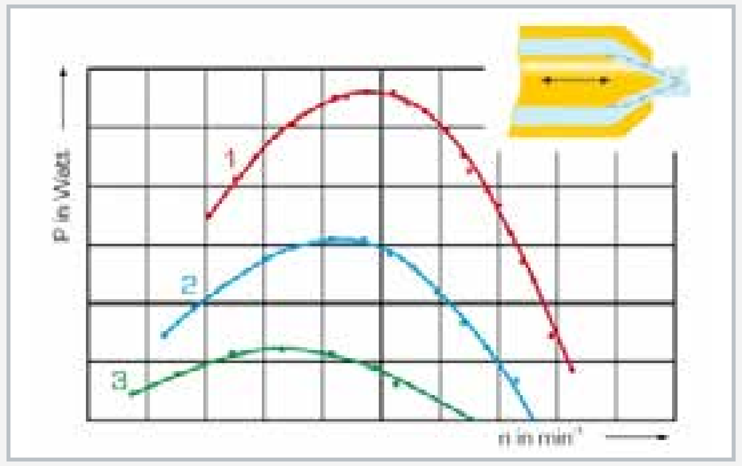
HM 150.19
Operating principle of a Pelton turbine



1 spring balance, 2 manometer, 3 adjustment of the nozzle cross-section, 4 needle nozzle, 5 Pelton wheel, 6 adjustment of the band brake



Operating principle of the Pelton turbine:
1 needle nozzle, 2 adjustable nozzle needle, 3 blade on the Pelton wheel, 4 redirected water jet, 5 profile of the blade



Turbine output curves at different positions of the nozzle needle:
1: Q=31,6L/min, 2: Q=18,8L/min, 3: Q=11,5L/min;
n speed, P turbine output

Specification

[1] function of a Pelton turbine
[2] transparent front panel for observing the operating area
[3] loading the turbine by use of the band brake
[4] adjustable nozzle needle for setting different nozzle cross-sections
[5] marking on brake drum for non-contact speed measurement
[6] instruments: spring balances for determining the torque, manometer shows pressure at turbine inlet
[7] flow rate determination by base module HM 150
[8] water supply using base module HM 150 or via laboratory supply

Technical data

Pelton turbine
- output: 5W at 500min^{-1}, approx. 30L/min, H=2m
- Pelton wheel
  - 14 blades
  - blade width: 33,5mm
  - external Ø: 132mm

Needle nozzle
- jet diameter: 10mm

Measuring ranges
- force: 2x 0...10N
- pressure: 0...1bar

LxWxH: 400x400x620mm
Weight: approx. 15kg

Required for operation

HM 150 (closed water circuit) or water connection, drain

Scope of delivery

1 experimental unit
1 set of instructional material

HM 150.20
Operating principle of a Francis turbine

Learning objectives/experiments

- design and function of a Francis turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

Description

- **model of a reaction turbine**
- **transparent operating area**
- **turbine with adjustable guide vanes**
- **loading by band brake**

Water turbines are turbomachines utilising water power. The Francis turbine is a type of reaction turbine which converts the pressure energy of the water into kinetic energy in the distributor and in the rotor. The water is fed in the distributor by means of a spiral housing. The flowing water is accelerated in the distributor by the adjustable guide vanes and directed onto the blades. The redirection and further acceleration of the water in the rotor generates an impulse which is transmitted to the rotor.

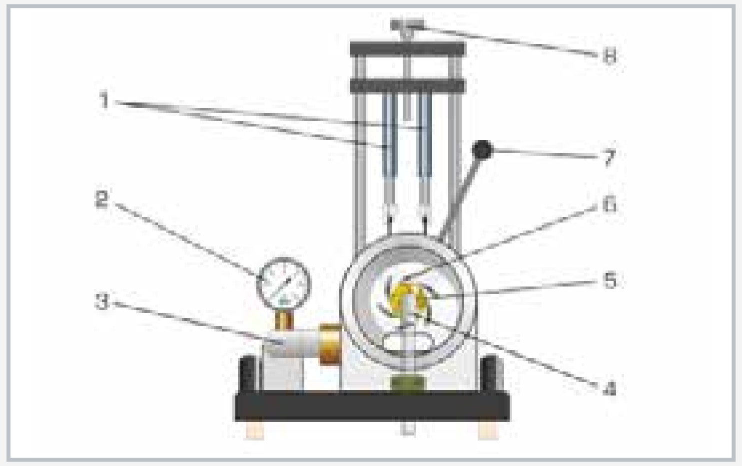
HM 150.20 is the model of a Francis turbine demonstrating the function of a reaction turbine.

The experimental unit consists of the rotor, the distributor with adjustable guide vanes, a band brake for loading the turbine and a housing with a transparent front panel. The transparent cover enables to observe the water flow, the rotor and the guide vanes during operation. The angle of attack and thus the power of the rotor are modified by adjusting the guide vanes.

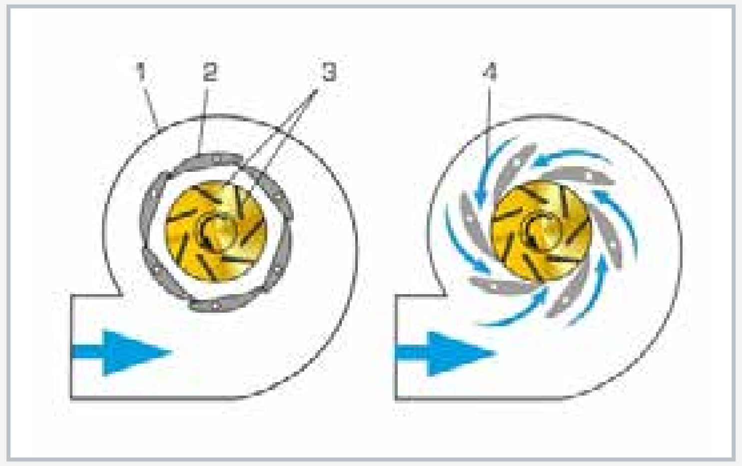
The turbine torque is determined by force measurement on a band brake and is read on spring balances. For measuring the rotational speed, a non-contact speed sensor, e.g. HM 082, is required. A manometer shows the water pressure at the turbine inlet.

The experimental unit is positioned easily and securely on the work surface of the HM 150 base module. The water is supplied and the flow rate measured by HM 150. Alternatively, the experimental unit can be operated by the laboratory supply.

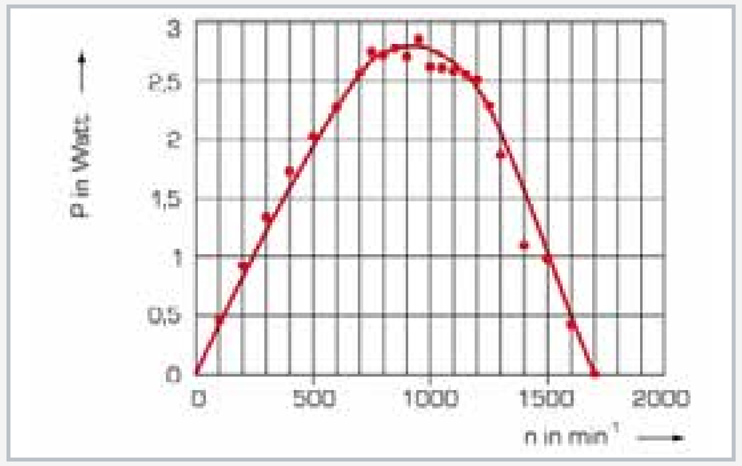
HM 150.20
Operating principle of a Francis turbine



1 spring balance, 2 manometer, 3 water inlet, 4 water outlet, 5 rotor, 6 guide vanes, 7 adjustment of the guide vanes, 8 adjustment of the band brake



Operating principle of the Francis turbine: 1 spiral housing, 2 guide vane, 3 rotor with blades, 4 flow; on the left: guide vane position closed, Q=0, P=0; on the right: guide vane position open, Q=max., P=max.



Characteristic curve for power output on the turbine shaft; P turbine power output, n speed

Specification

[1] function of a Francis turbine
[2] transparent front panel for observing the operating area
[3] loading the turbine by use of the band brake
[4] adjustable guide vanes for setting different angles of attack
[5] marking on brake drum for non-contact speed measurement
[6] instruments: spring balances for determining the torque, manometer shows pressure at turbine inlet
[7] flow determination by base module HM 150
[8] water supply using the base module HM 150 or via lab supply

Technical data

Turbine
- output: 12W at n=1100min^{-1}, approx. 40L/min, H=8m
- rotor
  - 7 blades
  - blade width: 5mm
  - external Ø: 50mm
- guide vanes
  - 6 vanes, adjustable (20 stages)

Measuring ranges
- force: 2x 0...10N
- pressure: 0...1,0bar

LxWxH: 400x400x630mm
Weight: approx. 17kg

Required for operation

HM 150 (closed water circuit) or water connection, drain

Scope of delivery

1 experimental unit
1 set of instructional material

HM 287
Experiments with an axial turbine

Description

- **illustrative model of an axial turbine**
- **transparent turbine housing**
- **adjustable, wear-free eddy current brake as turbine load**
- **GUNT software for data acquisition, visualisation and operation**
- **part of the GUNT-Labline fluid energy machines**

The axial turbine operates as a reaction turbine as used in gas tubines and steam turbines. The water flows through a stator where it is deflected and accelerated. Then, the water hits then the blades where it delivers kinetic energy and pressure energy and puts the rotor in motion. The water pressure steadily decreases from the inlet to the outlet.

The trainer provides the basic experiments to get to know the operating behaviour and the most important characteristic variables of axial turbines.

HM 287 features a closed water circuit with an axial turbine, a centrifugal pump and a water tank. The stator and the rotor of the turbine are mounted in a transparent housing and can be observed during operation.

The loading device is outside of the housing. The eddy current brake generates a defined load. The eddy current brake is specially developed by GUNT. It is wear-free and can be finely adusted. The flow rate is adjusted using a valve.

The trainer is fitted with a sensor for pressure (turbine inlet). The torque produced by the turbine is determined via an electronic force sensor. The speed is measured with an optical speed sensor. The flow rate is determined by an orifice plate with differential pressure measurement. The microprocessor-based measuring technique is well protected in the housing. The measured values are transmitted directly to a PC via USB where they can be analysed using the software included.

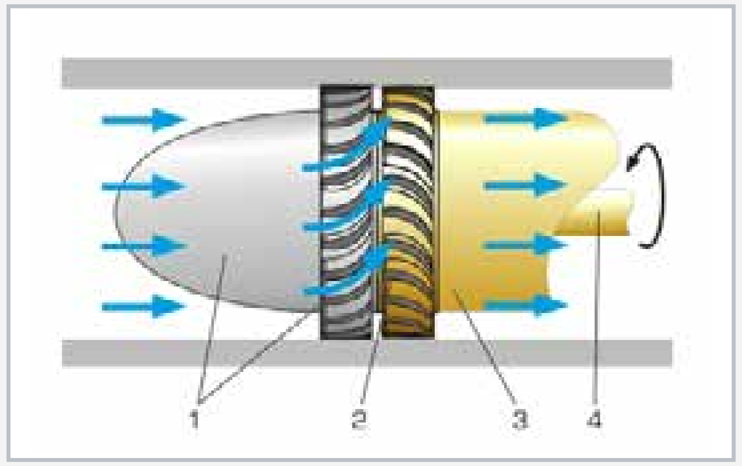
All the advantages of software-supported experiments with operation and evaluation are offered by the GUNT software and the microprocessor.

Learning objectives/experiments

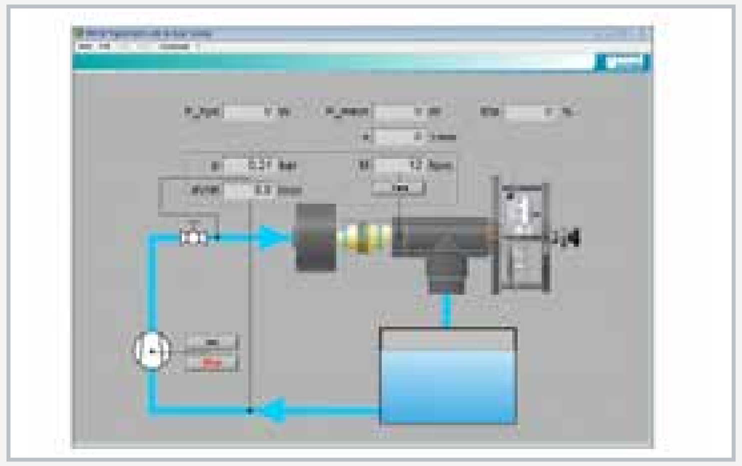
- principle of operation of an axial turbine
- determination of the power output
- determination of the efficiency
- recording of the characteristic curve
- comparison of experiment and calculation

HM 287
Experiments with an axial turbine

1 valve for adjusting the flow rate, 2 switch cabinet, 3 flow rate measurement with measuring orifice and differential pressure measurement, 4 pump, 5 tank, 6 eddy current brake, 7 axial turbine



Principle of operation of an axial turbine: 1 stator, 2 rotor, 3 housing, 4 shaft



Operating interface of the powerful software

Specification

[1] functioning and operating behaviour of an axial turbine
[2] closed water circuit contains axial turbine, pump and water tank
[3] transparent housing for observing the stator and the rotor
[4] turbine load using the wear-free and adjustable eddy current brake
[5] valve for adjusting the volumetric flow rate
[6] force sensor to determine the torque on turbine shaft
[7] measurement of turbine speed with optical speed sensor
[8] pressure measurement on inlet side
[9] determination of volumetric flow rate using differential pressure measurement across a measuring orifice
[10] due to integrated microprocessor-based instrumentation no additional devices with error-prone wiring are required
[11] display and evaluation of the measured values as well as operation of the unit via software
[12] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10

Technical data

Axial turbine
- power output: approx. 130W at $3500min^{-1}$
- rotor, outer diameter: 50mm
- blade length: 5mm

Pump
- power consumption: 1,02kW
- max. flow rate: approx. 375L/min
- max. head: 13,7m

Measuring orifice
- diameter: 44mm
- differential pressure sensor: 0...0,1bar

Measuring ranges
- flow rate: 500L/min
- pressure (inlet): 0...5bar
- torque: 0...2Nm

230V, 50Hz, 1 phase
120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 1200x800x950mm
Weight: approx. 135kg

Required for operation

PC with Windows

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 set of instructional material

HM 288
Experiments with a reaction turbine

The illustration shows HM 288 on top of the water tank in HM 290.

Description

- **illustrative model of a water turbine according to the reaction principle**
- **adjustable, wear-free eddy current brake as turbine load**
- **GUNT software for data acquisition, visualisation and operation**
- **part of the GUNT-Labline fluid energy machines**

The conversion of pressure energy into kinetic energy in the rotor is characteristic for reaction turbines.

The experimental unit is placed upon the base unit HM 290. The two units together provide the basic experiments to get to know the operating behaviour and the most important characteristic variables of reaction turbines.

The water jet discharged from the rotor which drives the turbine according to the reaction principle can be observed during operation. This facilitates the understanding of the principle of operation and the underlying laws (eg. momentum).

HM 288 consists of a rotor mounted in a transparent housing and a loading device outside of the housing. The eddy current brake generates a defined load. The eddy current brake is specially developed by GUNT. It is wear-free and can be finely adusted.

The torque delivered by the turbine is determined via an electronic force sensor. The speed is measured with an optical speed sensor. The measuring values are transferred to the base unit HM 290.

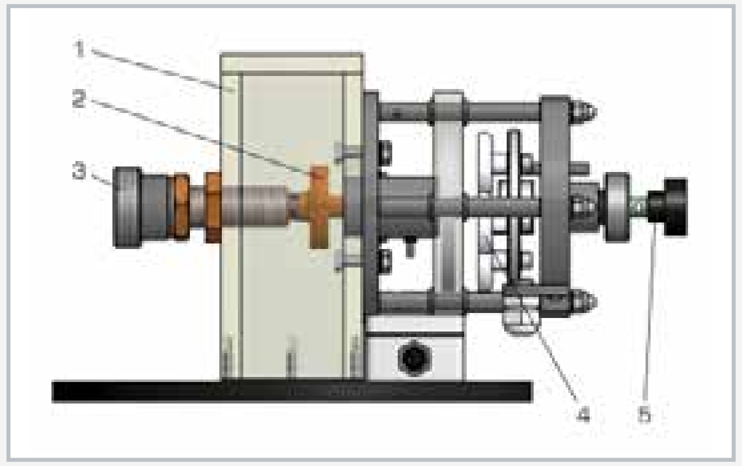
The water supply and the flow rate measurement are realised with the base unit HM 290. A pressure control included in HM 290 enables the recording of characteristics at a constant head.

All the advantages of software-supported experiments and evaluation are offered by the GUNT software in HM 290.

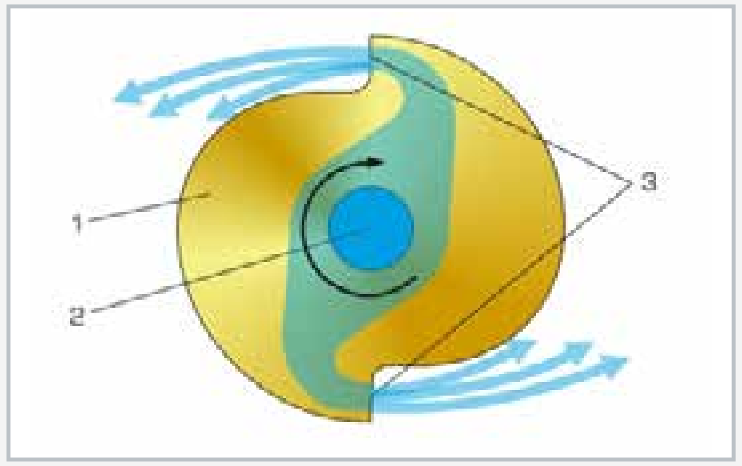
Learning objectives/experiments

- principle of operation of a reaction turbine
- characteristic curves at constant head
  - relationship between torque and speed
  - efficiency dependent on speed
  - flow rate dependent on speed
  - hydraulic power and mechanical power depending on speed
- evaluation of measuring values and characteristics based on the theory

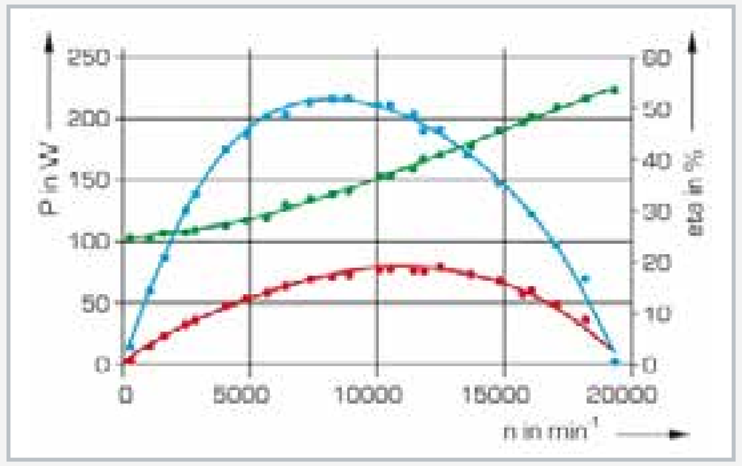
HM 288
Experiments with a reaction turbine



1 transparent housing, 2 rotor, 3 water supply, 4 eddy current brake, 5 adjustment of the eddy current brake



Principle of operation of a reaction turbine
1 rotor, 2 water inlet via hub, 3 water outlet via tangential nozzles



Characteristic curves of the reaction turbine dependent on the speed
red: mechanical power P_{mech}, blue: efficiency, green: hydraulical power P_{hydr}; P power, eta efficiency, n speed

Specification

[1] turbine to place upon the base unit HM 290
[2] functioning and operating behaviour of a reaction turbine
[3] transparent housing for observing the discharged water jet
[4] constant pressure of the turbine represents in practice the head and is adjusted via HM 290
[5] turbine load using the wear-free and adjustable eddy current brake
[6] force sensor to determine the torque on turbine shaft
[7] optical speed sensor for measuring the turbine speed
[8] water supply, flow rate measurement and unit-specific software data acquisition and operation via HM 290

Technical data

Turbine
- power output: approx. 60W at 8000min^{-1}
- rotor diameter: 50mm

Measuring ranges
- torque: 0...0,5Nm
- speed: 0...20000min^{-1}

LxWxH: 360x250x180mm
Weight: approx. 5kg

Scope of delivery

1 experimental unit
1 set of instructional material

HM 291
Experiments with an action turbine

The illustration shows HM 291 on top of the water tank in HM 290.

Description

- **illustrative model of an axial constant-pressure turbine**
- **adjustable, wear-free eddy current brake as turbine load**
- **GUNT software for data acquisition, visualisation and operation**
- **part of the GUNT-Labline fluid energy machines**

Action turbines operate according to the principle of equal pressure. The static pressures at the inlet and at the outlet of the rotor are equal.

The experimental unit is placed upon the base unit HM 290. The two units together provide the basic experiments to get to know the operating behaviour and the most important characteristic variables of action turbines.

The water jets are discharged at high velocity from the four nozzles of the distributor. The water jets are deflected in the rotor and put it in motion. The axially discharged water from the rotor can be observed.

HM 291 consists of a rotor, mounted in a transparent housing, a distributor with four nozzles and a loading device outside of the housing. The number of active nozzles can be adjusted by valves. The eddy current brake generates a defined load. The eddy current brake is specially developed by GUNT. It is wear-free and can be finely adusted.

The torque delivered by the turbine is determined via an electronic force sensor. The speed is measured with an optical speed sensor. The measuring values are transferred to the base unit HM 290.

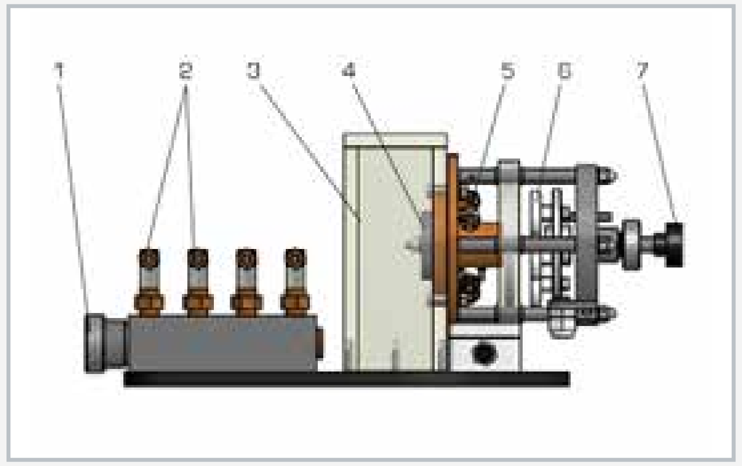
The water supply and the flow rate measurement are realised with the base unit HM 290. A pressure control included in HM 290 enables the recording of characteristics at a constant head.

All the advantages of software-supported experiments and evaluation are offered by the GUNT software in HM 290.

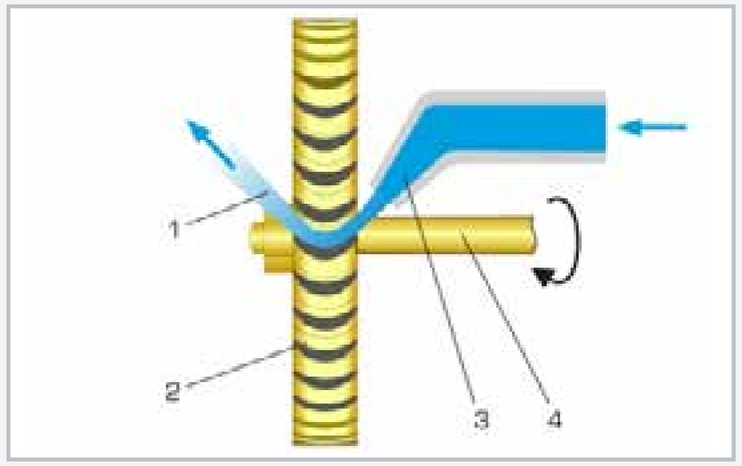
Learning objectives/experiments

- principle of operation of an action turbine
- characteristic curves at constant head
  - relationship between torque and speed
  - efficiency dependent on speed
  - flow rate dependent on speed
  - hydraulic power and mechanical power dependent on speed
- evaluation of measuring values and characteristics based on the theory
- partial load behaviour with controlling the number of nozzles in comparison to throttle control

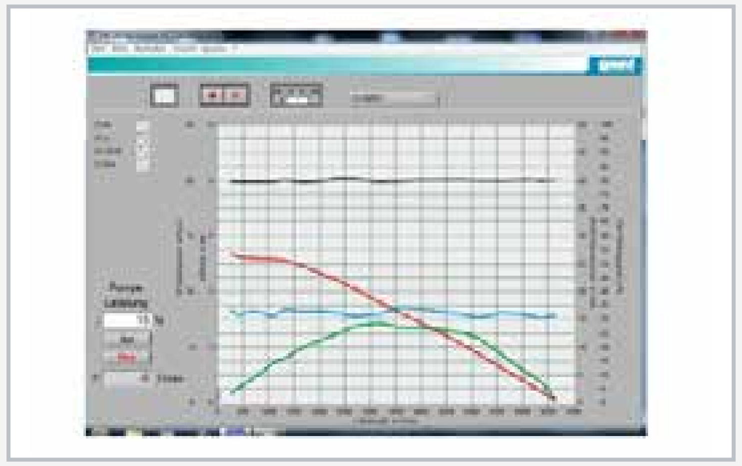
HM 291
Experiments with an action turbine



1 water supply, 2 nozzle valves, 3 transparent housing, 4 rotor, 5 distributor with 4 nozzles, 6 eddy current brake, 7 adjustment of the eddy current brake



Principle of operation of an action turbine
1 water outlet, 2 rotor, 3 water inlet from four nozzles, 4 turbine shaft



Software screenshot: characteristic curbes of the action turbine dependent on speed

Specification

[1] turbine to place upon the base unit HM 290
[2] functioning and operating behaviour of an action turbine
[3] transparent housing for observing the rotor
[4] distributor with 4 nozzles, active nozzles adjustable by valves
[5] constant pressure of the turbine represents in practice the head and is adjusted via HM 290
[6] turbine load using the wear-free and adjustable eddy current brake
[7] force sensor to determine the torque on turbine shaft
[8] optical speed sensor for measuring the turbine speed
[9] water supply, flow rate measurement and unit-specific software data acquisition and operation via HM 290

Technical data

Turbine
- power output: approx. 28W at 3600min^{-1}
- rotor diameter: 50mm

Measuring ranges
- torque: 0...0,5Nm
- speed: 0...9000min^{-1}

LxWxH: 420x320x180mm
Weight: approx. 7kg

Scope of delivery

1 experimental unit
1 set of instructional material

HM 289
Experiments with a Pelton turbine

The illustration shows HM 289 on top of the water tank in HM 290.

Description

- **illustrative model of a Pelton turbine**
- **adjustable, wear-free eddy current brake as turbine load**
- **GUNT software for data acquisition, visualisation and operation**
- **part of the GUNT-Labline fluid energy machines**

Pelton turbines are types of impulse turbine. They are driven by free jet nozzles. In the nozzles, the water is strongly accelerated. Ambient pressure exists at the nozzle outlet.

The experimental unit is placed upon the base unit HM 290. The two units together provide the basic experiments to get to know the operating behaviour and the most important characteristic variables of Pelton turbines.

The water jet is accelerated in a nozzle and hits the Pelton wheel tangentially. In the blades on the circumference of the Pelton wheel the water jet is deflected by approximately 180°. The impulse of the water jet is transmitted to the Pelton wheel.

HM 289 consists of a Pelton wheel and a needle nozzle, mounted in a transparent housing. The needle nozzle can be adjusted during operation. The loading device is outside of the housing. The eddy current brake generates a defined load. The eddy current brake is specially developed by GUNT. It is wear-free and can be finely adusted.

The torque delivered by the turbine is determined via an electronic force sensor. The speed is measured with an optical speed sensor. The measuring values are transferred to the base unit HM 290.

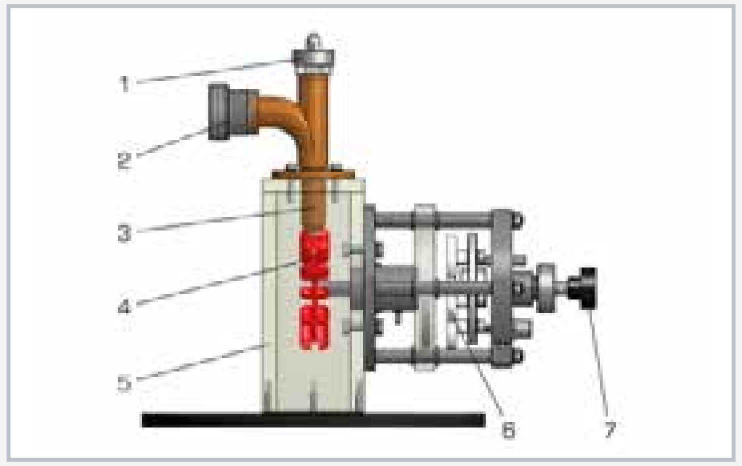
The water supply and the flow rate measurement are realised with the base unit HM 290. A pressure control included in HM 290 enables the recording of characteristics at a constant head.

All the advantages of software-supported experiments and evaluation are offered by the GUNT software in HM 290.

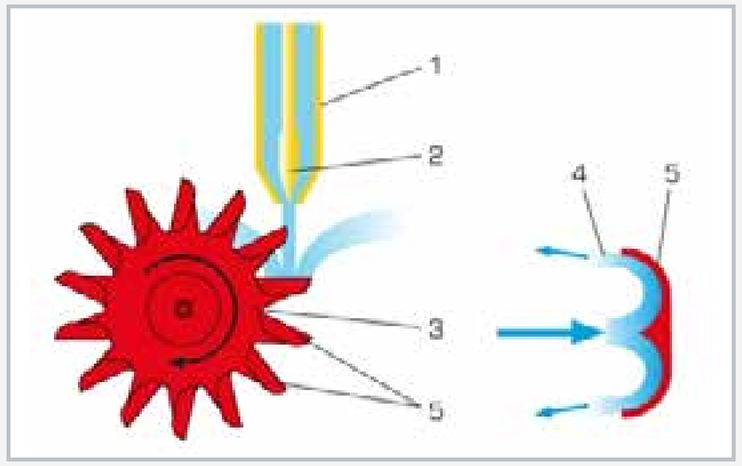
Learning objectives/experiments

- principle of operation of a Pelton turbine
- characteristic at constant head
  - relationship between torque and speed
  - efficiency dependent on speed
  - flow rate dependent on speed
  - hydraulic power and mechanical power dependent on speed
- evaluation of measuring values and characteristics based on the theory
- partial load behaviour with needle control in comparison to throttle control

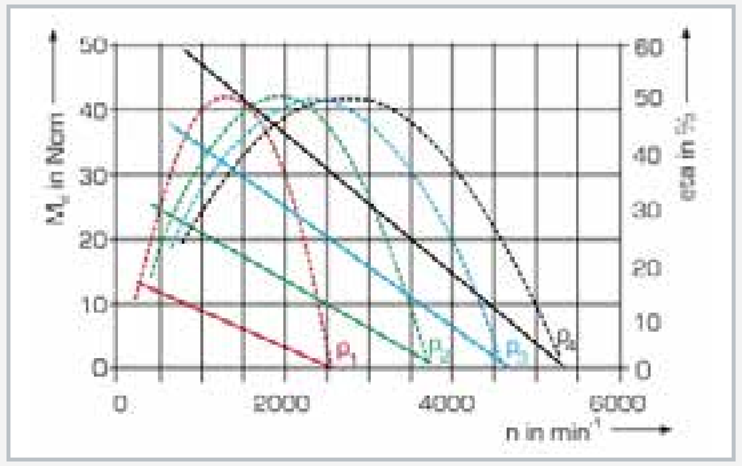
HM 289
Experiments with a Pelton turbine



1 adjustment of the needle nozzle, 2 water supply, 3 needle nozzle, 4 Pelton wheel, 5 transparent housing, 6 eddy current brake, 7 adjustment of the eddy current brake



Principle of operation of a Pelton turbine
1 needle nozzle, 2 adjustable nozzle needle, 3 Pelton wheel, 4 deflected water jet, 5 impinged blade



Characteristic curves of the Pelton turbine at different pressures (p_1...p_4); torque (continuous lines) and efficiency (dashed lines) dependent on speed; M_d torque, n speed, eta efficiency

Specification

[1] turbine to place upon the base unit HM 290
[2] functioning and operating behaviour of a Pelton turbine
[3] transparent housing for observing the Pelton wheel and needle nozzle
[4] different nozzle cross-sections via adjustable nozzle needle
[5] constant pressure of the turbine represents in practice the head and is adjusted via HM 290
[6] turbine load using the wear-free and adjustable eddy current brake
[7] force sensor to determine the torque on turbine shaft
[8] optical speed sensor for measuring the turbine speed
[9] water supply, flow rate measurement and unit-specific software data acquisition and operation via HM 290

Technical data

Pelton turbine
- power output: approx. 70W at 2700min^{-1}
- wheel diameter: 70mm

Measuring ranges
- torque: 0...0,5Nm
- speed: 0...9000min^{-1}

LxWxH: 350x250x300mm
Weight: approx. 5kg

Scope of delivery

1 experimental unit
1 set of instructional material

HM 290
Base unit for turbines

Description

- **closed water circuit for supplying turbines**
- **GUNT software for data acquisition, visualisation and operation**
- **basic experiments on centrifugal pumps**
- **part of the GUNT-Labline fluid energy machines**

The base unit HM 290 is required to supply different turbines. Additionally, the base unit enables basic experiments on a centrifugal pump.

The closed water circuit of HM 290 features a water tank and a centrifugal pump with variable speed via a frequency converter. The turbine to be investigated (HM 288, HM 289, HM 291) is placed on the tank cover and is connected to the base unit via a hose. The flow rate hence the pressure applied to the turbine is adjusted by pump speed. The head and the pressure upstream of the turbine can be kept constant by a pressure control. A damping plate inside the tank ensures a low air entry into the circulating water. Basic pump experiments can be performed using the throttle valve included. The throttle valve is placed upon the tank cover instead of the turbine.

The base unit is fitted with sensors for pressure and flow rate. The microprocessor-based measuring technique is well protected in the housing. The measured values are transmitted directly to a PC via USB where they can be analysed using the software included.

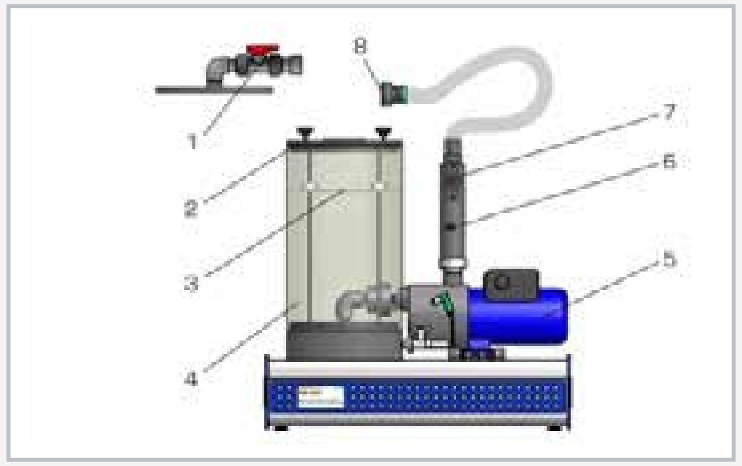
All the advantages of software-supported experiments with operation and evaluation are offered by the GUNT software and the microprocessor.

Following turbines are available: a reaction turbine (HM 288), a Pelton turbine (HM 289) and an action turbine (HM 291).

Learning objectives/experiments

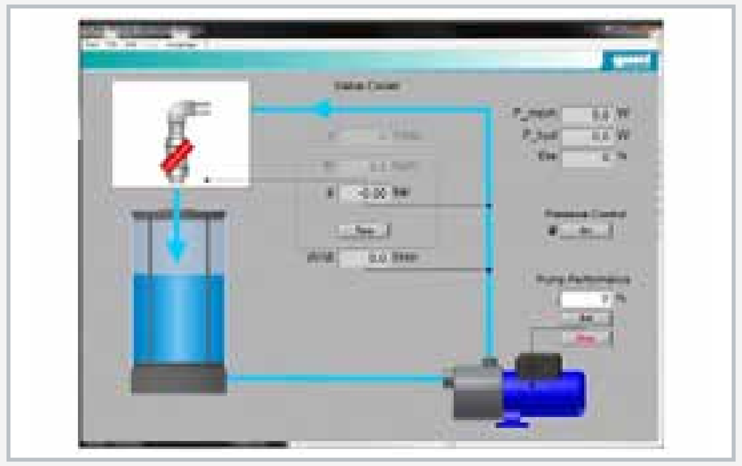
- basic experiments on a centrifugal pump
- together with the turbines HM 288, HM 289 or HM 291
  - determination of typical turbine curves
  - performance curves at varying turbine speeds
  - determination of efficiencies

HM 290
Base unit for turbines



1 throttle valve for pump experiments, 2 tank cover, 3 damping plate, 4 water tank, 5 pump with motor, 6 pressure sensor, 7 flow meter, 8 water connection

The illustration shows the base unit HM 290 together with the reaction turbine HM 288. The turbines HM 289 or HM 291 can be investigated after easily interchanging them.



Operating interface of the powerful software: experiment with the pump

Specification

[1] supplying the turbines HM 288, HM 289 or HM 291 with water under pressure
[2] basic experiments on centrifugal pumps
[3] together with the turbines: investigation of operating behaviour and recording of turbine characteristics
[4] includes pump and transparent water tank
[5] low air entry into circulating water ensured by damping plate inside the tank
[6] variable pump speed via frequency converter
[7] sensors for flow rate and pressure
[8] due to integrated microprocessor-based instrumentation no additional devices with error-prone wiring are required
[9] display and evaluation of the measured values as well as operation of the unit via software
[10] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10

Technical data

Pump
- power consumption: 670W
- max. flow rate: 70L/min
- max. head: 35,4m

Water tank: approx. 15L

Measuring ranges
- flow rate: 3,9...50L/min
- pressure: -1...5bar

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 670x600x630mm
Weight: approx. 37kg

Required for operation

PC with Windows

Scope of delivery

1 experimental unit
1 GUNT software CD + USB cable
1 set of instructional material

HM 365.31
Pelton and Francis turbine

Description

- **comparison of impulse and reaction turbines**
- **constant speeds and torques can be adjusted in combination with HM 365**
- **part of the GUNT-FEMLine**

Water turbines are turbomachines utilising water power. They convert pressure and flow energy into mechanical energy and mostly are used for driving electrical generators. Water turbines can be divided into impulse and reaction turbines depending on their operating principle.

The HM 365.31 accessories contain a Pelton turbine as an example for an impulse turbine and a Francis turbine as an example for a reaction turbine. The two turbine types are examined and compared with each other together with the supply unit HM 365.32 and the brake unit HM 365. The brake unit offers the possibility to set constant speeds resp. torques. Thus you can realise experiments in different realistic operating modes.

The Pelton turbine is a free-jet turbine which converts the pressure energy of the water into kinetic energy entirely in the distributor. As the complete pressure difference is reduced exclusively in the nozzle, the pressure is constant in the Pelton wheel. The turbine is also known as a constant pressure turbine. The turbine output is adjusted by adjusting the nozzle cross-section.

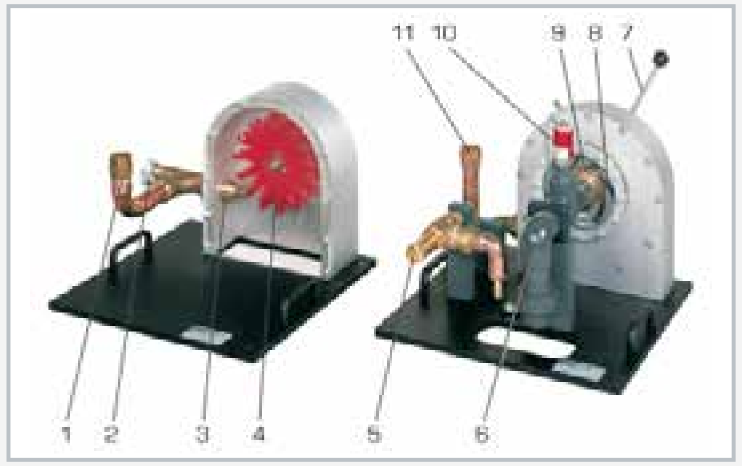
The Francis turbine converts the pressure energy of the water into kinetic energy in the distributor and in the rotor. The pressure at the rotor inlet is higher than at the rotor outlet. The turbine output is adjusted by adjusting the guide vanes.

HM 365.32 provides the water supply, the pressure measurement at the turbine inlet and the flow rate measurement. In order to measure the pressure at the turbine outlet, the Francis turbine is equipped with an additional pressure sensor. The brake unit HM 365 measures the braking torque and the speed.

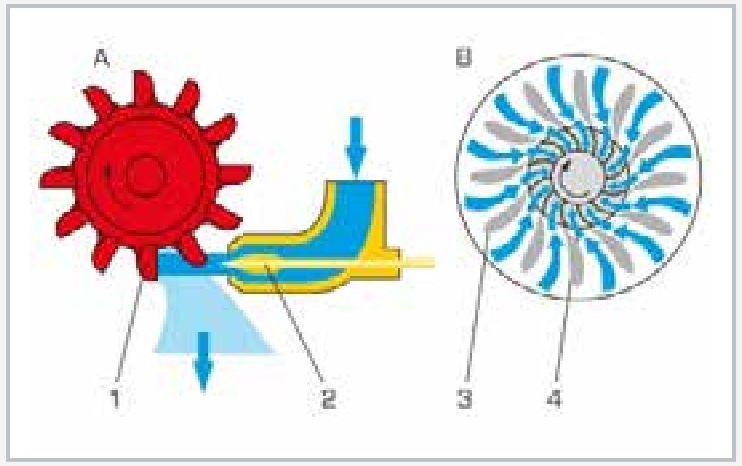
Learning objectives/experiments

- in combination with HM 365 and HM 365.32
  - comparison of impulse and reaction turbines
  - determination of the mechanical and hydraulic power
  - determination of the efficiency
  - recording of characteristic curves
  - influence of the nozzle cross-section of the Pelton turbine on the characteristics
  - influence of the guide vane position of the Francis turbine on the characteristics

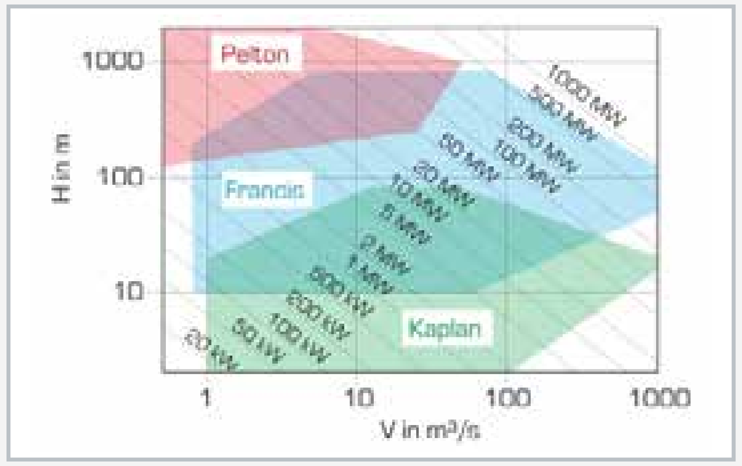
HM 365.31
Pelton and Francis turbine



1 water inlet, 2 adjustment of the nozzle cross-section, 3 nozzle, 4 Pelton wheel, 5 safety valve, 6 water outlet, 7 lever for adjusting the guide vanes, 8 guide vanes, 9 rotor of Francis turbine, 10 pressure sensor at the turbine outlet, 11 water inlet



A operating principle of the Pelton turbine: 1 Pelton wheel with blades, 2 adjustable nozzle needle; B operating principle of the Francis turbine: 3 guide vanes, 4 rotor



Operative ranges of the different turbine types in practice; H head, V flow rate

Specification

[1] comparison of a Pelton turbine as impulse turbine and a Francis turbine as reaction turbine
[2] operation by use of the HM 365.32 Turbine supply unit
[3] turbine load by use of the HM 365 Universal brake and drive unit
[4] constant torques and speeds can be adjusted with HM 365
[5] transparent front panel in the turbines for observing the operating area
[6] adjustable nozzle needle for setting different nozzle cross-sections (Pelton turbine)
[7] adjustable guide vanes for setting different angles of incidence (Francis turbine)
[8] pressure sensor at the Francis turbine for measuring the pressure at the turbine outlet
[9] digital display for flow rate, pressure and temperature in HM 365.32
[10] braking torque and speed measured in HM 365

Technical data

Transmission ratio between brake and turbine: 1,44:1

Pelton turbine
- output: 1,5kW at 2750min^{-1} at 6,5bar
- wheel diameter: 165mm
- variable nozzle setting

Francis turbine
- output: 1kW at 3500min^{-1} and 4,2bar
- rotor diameter: 80mm
- variable guide vane setting

Measuring ranges
- pressure (outlet): 0...1,6bar

LxWxH: 590x370x490mm (Pelton turbine)
Weight: approx. 25kg
LxWxH: 560x510x400mm (Francis turbine)
Weight: approx. 50kg

Scope of delivery

1 Pelton turbine
1 Francis turbine

HM 365.32
Turbine supply unit

Description

- **closed water circuit for supplying turbines**
- **different operating modes can be selected via HM 365**
- **GUNT software for data acquisition and visualisation**
- **part of the GUNT-FEMLine**

Together with HM 365.31, the HM 365.32 supply unit can be used to operate a Pelton or Francis turbine, whose characteristic operating behaviour can then be investigated.

The separate turbines from HM 365.31 are placed on the working surface of the supply unit and screwed in place. The turbine is connected to the supply unit via a hose. After the water has flowed through the turbine, it flows back into the tank. Thanks to its closed water circuit, the trainer is independent from the mains water supply and can be used in mobile applications. The flow rate and/or the pressure present at the turbine can be adjusted by a flow control valve.

The supply unit is equipped with sensors for pressure and flow rate. The measured values are displayed digitally. The mechanical turbine output is measured via the HM 365 Universal Drive and Brake Unit, which is also required. The brake unit is used to adjust constant speeds or torques, allowing experiments to be carried out in different operating modes.

The measured values are read from digital displays on the supply unit and can be transmitted simultaneously via USB directly to a PC where they can be analysed using the software included.

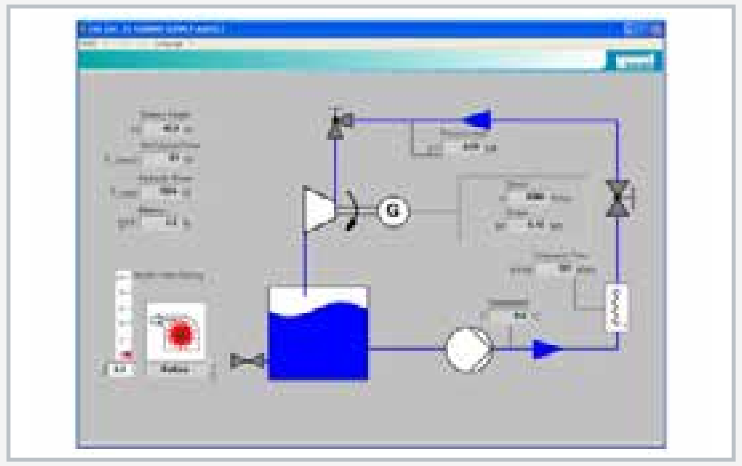
Learning objectives/experiments

- in conjunction with HM 365 and a Pelton or Francis turbine from HM 365.31
  - determination of the mechanical output of the turbines
  - determination of the hydraulic output of the turbines
  - determine the efficiencies of the turbines
  - plot characteristic curves
  - influence of the guide vane position on the characteristic curve when using the Francis turbine
  - influence of the nozzle cross-section on the characteristic curve when using the Pelton turbine

HM 365.32
Turbine supply unit

1 turbine water supply, 2 tank, 3 centrifugal pump, 4 pressure measuring point, 5 temperature measuring point, 6 flow control valve, 7 flowmeter

1 measuring amplifier with digital display of measured values, 2 HM 365 Universal Drive and Brake Unit, 3 HM 365.32, 4 HM 365.31 Pelton and Francis Turbine



Software screenshot: process schematic

Specification

[1] supply unit for turbines from HM 365.31
[2] closed water circuit contains multistage centrifugal pump, tank, inductive flowmeter and flow control valve
[3] connection to the turbines via flexible hose with quick-release coupling
[4] constant torques and speeds can be adjusted via HM 365
[5] digital display for flow rate, pressure and temperature
[6] braking torque and speed measured in HM 365
[7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Centrifugal pump, 3 stages
- power consumption: 3kW
- max. flow rate: 29m^3/h
- max. head: 45m
- speed: 2900min^{-1}

Tank: 96L

Measuring ranges
- pressure (turbine inlet): -1...9bar
- pressure (Francis turbine outlet): 0...1,6bar
- temperature: 0...100°C
- flow rate: 0...600L/min

400V, 50Hz, 3 phases
230V, 60Hz, 3 phases
LxWxH: 1300x800x1200mm
Empty weight: approx. 120kg

Required for operation

PC with Windows recommended

Scope of delivery

1 trainer
1 measuring amplifier
1 GUNT software CD + USB cable
1 hose with quick-release couplings
1 set of instructional material

HM 450C
Characteristic variables of hydraulic turbomachines

Hydraulic turbomachines are a type of fluid energy machine. They work continuously and feature a steady pressure difference between inlet and outlet. HM 450C is a modular trainer for basic experiments in the field of hydraulic turbomachines. HM 450C forms the base unit. A centrifugal pump is included, which is used to conduct experiments on the topic of driven machines. A closed water circuit means the trainer can be used anywhere.

The trainer is equipped with all major sensors for data acquisitions in order to ensure meaningful results. Key measuring values are displayed during the experiments on displays on the trainer and on a PC.

Measurement analyses such as dimensionless parameters and pump characteristics can be displayed and saved on a PC using the GUNT software.

A special feature of HM 450C is the ability to operate pump and turbine at the same time. Relevant measured values are recorded contemporaneously at both turbomachines. Thus the trainer can be used as a **pumped storage plant**.


HM 450C as a pure pump trainer

The Pelton turbine HM 450.01 and Francis turbine HM 450.02 offer an expansion to the range of experiments on the topic of driving machines. The two turbines are easy to install on the trainer. They are connected with handles on the delivery side of the centrifugal pump. The sensors are connected via plugs on the trainer's switch cabinet.


HM 450.01
Pelton turbine

HM 450.02
Francis turbine

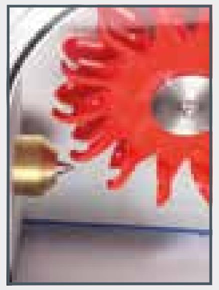
HM 450C
trainer with
water turbines

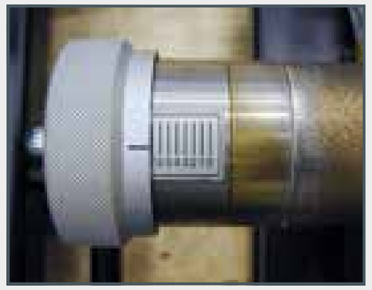

Adjusting the guide vanes of a Francis turbine


Flow measurement with electromagnetic sensor


Centrifugal pump with measurement of the drive torque


Band brake on the turbine


Needle nozzle and impeller of the Pelton turbine


Adjusting knob for the needle nozzle

Position of the guide vanes in the Francis turbine


Vanes and impeller of the Francis turbine

HM 450C
Characteristic variables of hydraulic turbomachines

The illustration shows HM 450C together with the two turbines HM 450.01 (left) and HM 450.02 (right).

Description

- **characteristic variables of water turbines and centrifugal pumps**
- **pelton turbine HM 450.01 and Francis turbine HM 450.02 extend the scope of experiments**
- **pumped storage plant**

Turbomachines such as pumps and turbines are energy converters. Turbines convert flow energy into mechanical energy and pumps convert mechanical energy into flow energy.

HM 450C can be used to investigate a centrifugal pump. Experiments can be performed on two key water turbine designs: Pelton and Francis turbine, available as accessories HM 450.01 and HM 450.02.

The closed water circuit comprises a tank, a standard centrifugal pump with variable speed and a flow control valve to adjust the back pressure.

The speed is detected contact-free by means of an inductive displacement sensor on the motor shaft. To determine the drive power, the drive motor is mounted on swivel bearings and equipped with a force sensor to measure the drive torque. Pressures at the inlet and outlet of the pump are measured. The flow rate is measured by means of an electromagnetic flow meter. The measured values are displayed digitally and processed further on a PC. The PC is used to calculate the power output data of the examined turbomachine and to represent them in characteristics.

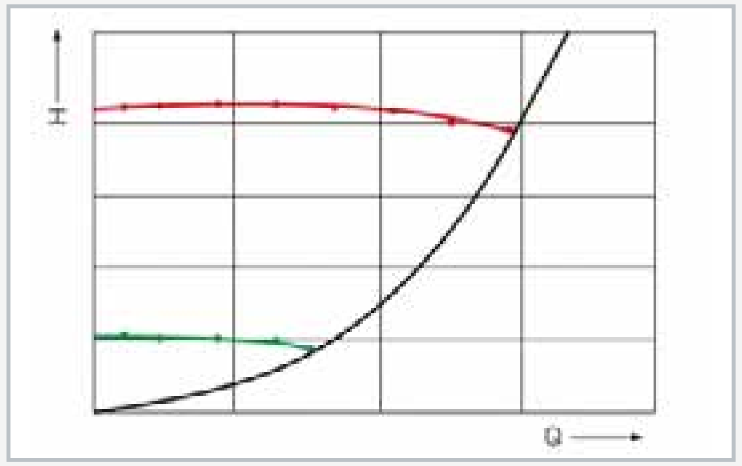
One of the turbines HM 450.01 or HM 450.02 can also be placed on top of the storage tank. The centrifugal pump supplies the turbine with water. The measured values of the turbine are transfered via cable to HM 450C. A special feature of HM 450C is the ability to operate pump and turbine at the same time. Relevant measured values are recorded contemporaneously at both turbomachines. Thus the trainer can be used as a pumped storage plant.

Learning objectives/experiments

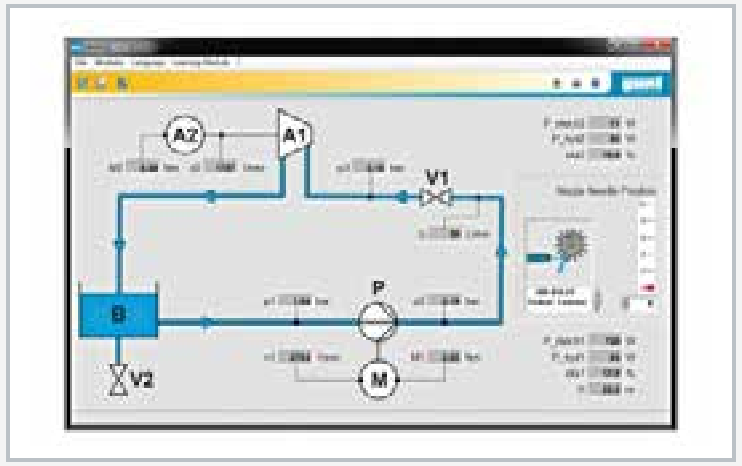
- centrifugal pump
  - measuring inlet and outlet pressures of the pump
  - determining delivery height
  - determining hydraulic output
  - determining mechanical output
  - recording characteristics at various speeds
  - determining the efficiency
- with accessories Pelton turbine HM 450.01 or Francis turbine HM 450.02
  - measuring torque and speed
  - determining efficiency of the turbine
  - recording characteristics
  - demonstration of a pumped storage plant

HM 450C
Characteristic variables of hydraulic turbomachines

1 electromagnetic flow meter, 2 flow control valve, 3 storage tank, 4 ressure sensor at pump inlet, 5 centrifugal pump, 6 drive motor including measurement of torque, 7 pressure sensor at pump outlet, 8 switch cabinet with displays and controls



Pump characteristics: H head, Q flow rate; red: characteristics at n=2900min^{-1}, green: characteristics at n=1450min^{-1}, black: system characteristic



Software screenshot: Francis turbine process schematic

Specification

[1] determining characteristic variables of a centrifugal pump
[2] determining characteristic variables of water turbines together with the accessories HM 450.01 and HM 450.02
[3] experiments on a pump in a closed water circuit with storage tank and flow control valve to adjust the back pressure
[4] experiments on turbines: closed water circuit for supplying turbines
[5] pipes and fittings made of PVC
[6] 3-phase AC motor for pump with variable speed via frequency converter
[7] non-contact speed measurement at the turbine shaft and force sensor at the brake for measuring the torque
[8] digital displays for pressures, flow rate, speed and torque
[9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Standard centrifugal pump
- max. head: 23,9m
- max. flow rate: 31m^3/h

Drive motor with variable speed
- power output: 2,2kW
- speed range: 0...3000min^{-1}

Storage tank: 250L

Measuring ranges
- pressure: 2x 0...4bar abs.
- flow rate: 0...40m^3/h
- torque: 0...20Nm
- speed: 2x 0...4000min^{-1}

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase
230V, 60Hz, 3 phases
UL/CSA optional
LxWxH: 1900x790x1900mm
Weight: approx. 243kg

Required for operation

PC with Windows recommended

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 set of instructional material

HM 450.01
Pelton turbine

Description

- **Pelton turbine with visible operating area**
- **closed water circuit and data processing software for use with the HM 450C trainer**

The Pelton turbine is a type of free-jet resp. impulse turbine which convert the pressure energy of water into kinetic energy entirely in the distributor. Pelton turbines are used at large heads and relatively low flow rates. The turbine power is adjusted by means of the nozzle cross-section. In practice, Pelton turbines are used for driving synchronous generators, where they run at constant speed.

The Pelton turbine HM 450.01 is an accessory for the HM 450C trainer. The experimental unit consists of the Pelton wheel, a needle nozzle used as distributor, a band brake for loading the turbine and a housing with a transparent front panel. The transparent cover enables you to observe the water flow, the Pelton wheel and the nozzle during operation. You can change the nozzle cross-section and thus the flow rate by adjusting the nozzle needle.

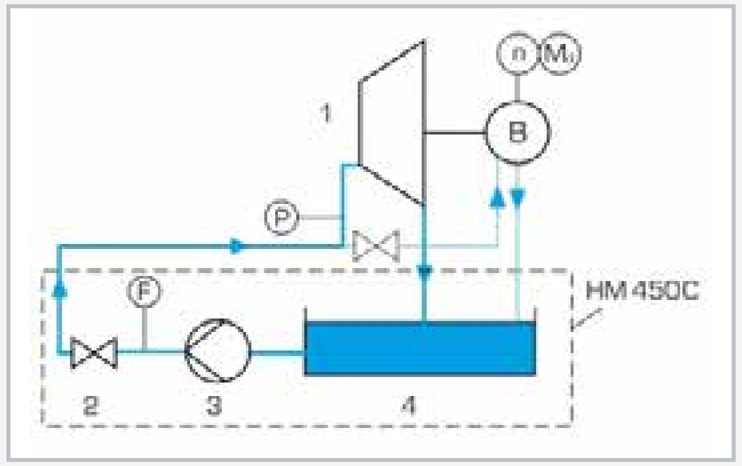
The pressure at the turbine inlet is recorded with a pressure sensor. A force sensor and a speed sensor are attached to the band brake. Thus, the mechanical power output of the turbine can be determined. Speed, torque and pressure are displayed on the switch cabinet of HM 450C and processed further in the software. Water supply and flow rate measurement are provided by HM 450C.

Learning objectives/experiments

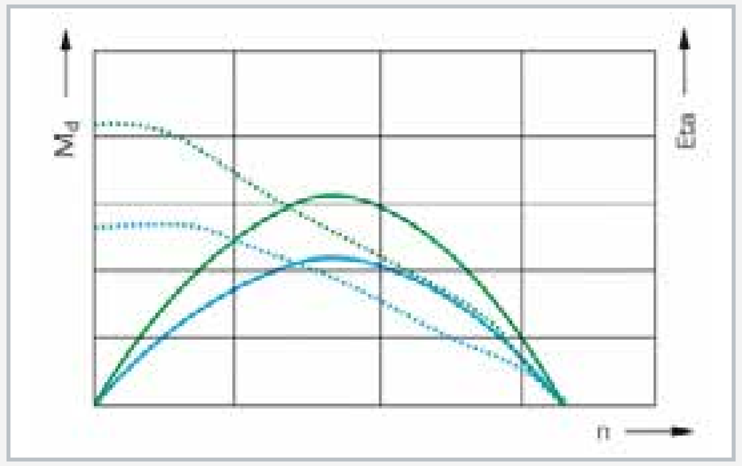
- determination of mechanical output
- determination of efficiency
- recording of characteristic curves
- investigation of the influence of the nozzle cross-section on the power output

HM 450.01
Pelton turbine

1 band brake, 2 pressure sensor, 3 handwheel for adjusting the brake, 4 handwheel for adjusting the nozzle cross-section, 5 needle nozzle, 6 water inlet, 7 connecting cable to HM 450C, 8 Pelton wheel



1 Pelton turbine, 2 flow control valve, 3 pump, 4 tank; blue dashed lines: cooling water; B brake; F flow rate, P pressure, n speed, M_d torque



Efficiency and torque (dashed lines) depending on the speed at different powers and fully opened nozzle: green: 100% power, blue: 65% power, Eta: efficiency, n speed, M_d torque

Specification

[1] recording the curves of a Pelton turbine and investigating the influence of the nozzle cross-section
[2] transparent front panel for observing the operating area
[3] loading the turbine by use of a band brake
[4] adjustable nozzle needle for setting different nozzle cross-sections
[5] non-contact speed measurement at the turbine shaft and force sensor at the brake for measuring the torque
[6] force sensor at the turbine inlet
[7] speed, torque and pressure displayed on the switch cabinet of HM 450C
[8] water supply, flow rate measurement and data processing software via HM 450C

Technical data

Turbine
- output: approx. 350W at 1000min^{-1}, 150L/min, H=20m
- max. speed: 1500min^{-1}
- Pelton wheel
  - 14 blades
  - medium diameter: 165mm

Measuring ranges
- torque: 0...9,81Nm
- pressure: 0...4bar abs.
- speed: 0...4000min^{-1}

LxWxH: 600x490x410mm
Weight: approx. 27kg

Scope of delivery

1 experimental unit
1 set of instructional material

HM 450.02
Francis turbine

Description

■ **Francis turbine with visible operating area**
■ **closed water circuit and data processing software for use with the HM 450C trainer**

The Francis turbine is part of the reaction turbines which convert the pressure energy of water into kinetic energy in the distributor and in the rotor. Francis turbines are used at medium heads and large flow rates. The turbine power is controlled by adjusting the guide vanes. In practice, Francis turbines are used in run-of-the river power plants and in storage power plants.

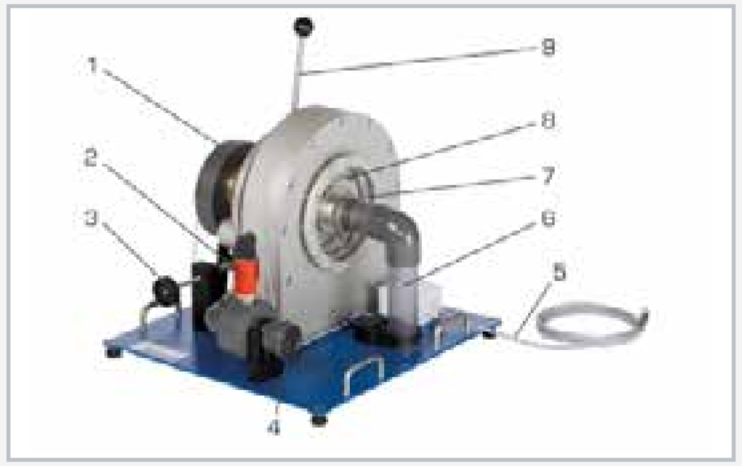
The Francis turbine HM 450.02 is an accessory for the HM 450C trainer. The experimental unit consists of the rotor, the distributor with adjustable guide vanes, a band brake for loading the turbine and the spiral housing with a transparent front panel. The transparent cover enables you to observe the water flow, the rotor and the guide vanes during operation. The angle of attack and the cross-section of flow are adapted to the speed and power of the turbine by adjusting the guide vanes.

The pressure at the turbine inlet is recorded with a pressure sensor. A force sensor and a speed sensor are attached to the band brake. Thus, the mechanical power output of the turbine can be determined. Speed, torque and pressure are displayed on the switch cabinet of HM 450C and processed further in the software. Water supply and flow rate measurement are provided by HM 450C.

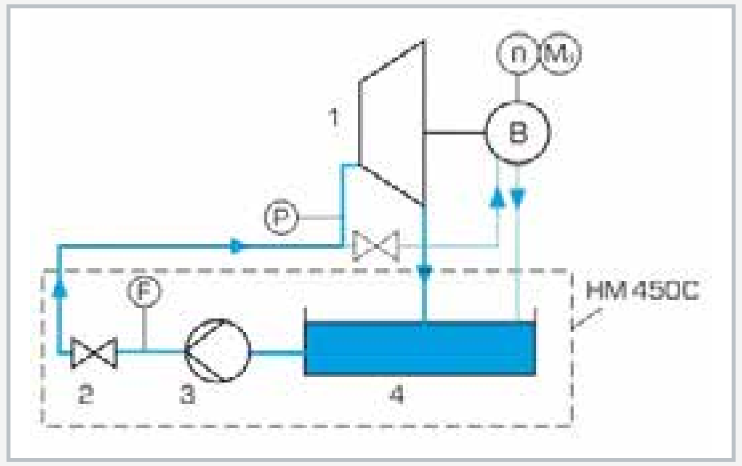
Learning objectives/experiments

■ determination of mechanical output
■ determination of efficiency
■ recording of characteristic curves
■ investigation of the influence of the guide vane position on the power output
■ velocity triangles

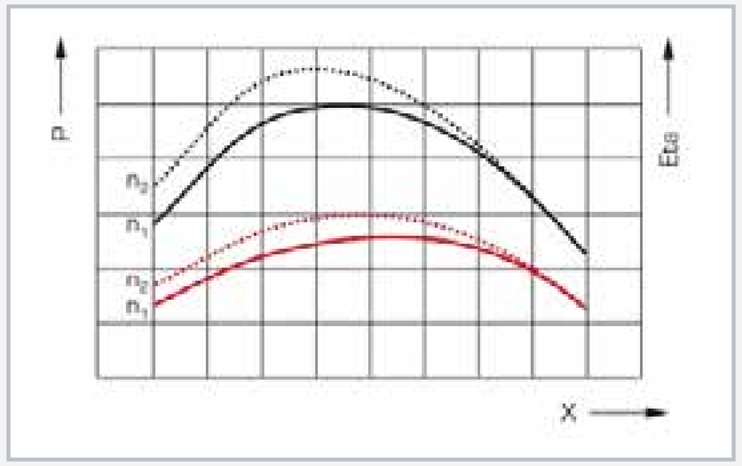
HM 450.02
Francis turbine



1 band brake, 2 pressure sensor, 3 handwheel for adjusting the brake, 4 water inlet, 5 connecting cable to HM 450C, 6 water outlet, 7 rotor, 8 guide vanes, 9 lever for adjusting the guide vanes



1 Francis turbine, 2 flow control valve, 3 pump, 4 tank; blue dashed lines: cooling water; B brake; F flow rate, P pressure, n speed, M_d torque



Efficiency and mechanical power depending on the guide vane position at different speeds: black: power output, red: efficiency, n speed, Eta efficiency, P mechanical power, X guide vane position

Specification

[1] recording the curves of a Francis turbine and investigating the influence of the guide vane position
[2] transparent front panel for observing the operating area
[3] loading the turbine by use of the band brake
[4] adjustable guide vanes for setting different angles of attack
[5] recording the torque via band brake and force sensor
[6] force sensor at the turbine inlet
[7] speed, torque and pressure displayed on the switch cabinet of HM 450C
[8] water supply, flow rate measurement and data processing software via HM 450C

Technical data

Turbine
■ output: approx. 350W at 1500min^{-1}, 270L/min, H=15m
■ max. speed: 3000min^{-1}
■ rotor
  ▸ 11 blades
  ▸ medium diameter: 60mm
■ distributor
  ▸ 7 vanes
  ▸ angle of attack: 0...20°

Measuring ranges
■ torque: 0...9,81Nm
■ pressure: 0...4bar abs.
■ speed: 0...4000min^{-1}

LxWxH: 510x490x410mm
Weight: approx. 38kg

Scope of delivery

1 experimental unit
1 set of instructional material

HM 430C
Francis turbine trainer

Description

- **characteristics of a powerful Francis turbine**
- **optimal view of the operating area of the turbine**
- **adjustable guide vanes for setting the output**

The Francis turbine belongs to the reaction turbines which convert pressure energy of the working medium into kinetic energy in the guide vanes and in the rotor. Francis turbines are used for medium heads. The turbine power is controlled by adjusting the guide vanes. In practice, Francis turbines are used in run-of-river power plants and in pumped storage plants.

HM 430C enables examinations of the function and operating behaviour of a Francis turbine. The dimensions of the trainer guarantee realistic measured values. The closed water circuit consists of a tank with optional cooling, a centrifugal pump and a flow control valve for adjusting the inlet pressure. The transparent operating area of the turbine enables an optimal view of water flow, rotor and guide vanes during operation.

By adjusting the guide vanes the angle of attack, the cross-section and thus the output of the turbine are changed. An asynchronous machine is used as a generator for loading the turbine. A pump with variable speed via frequency converter provides for an energy efficient operation.

The speed of the turbine is recorded by means of an inductive, non-contact position sensor at the generator shaft. The generator is equipped with a pendulum bearing and with a force sensor to determine the torque.

The pressures at the inlet and outlet of the turbine, the temperature and the flow rate are recorded by sensors. The measured values are displayed digitally and can be processed further on a PC.

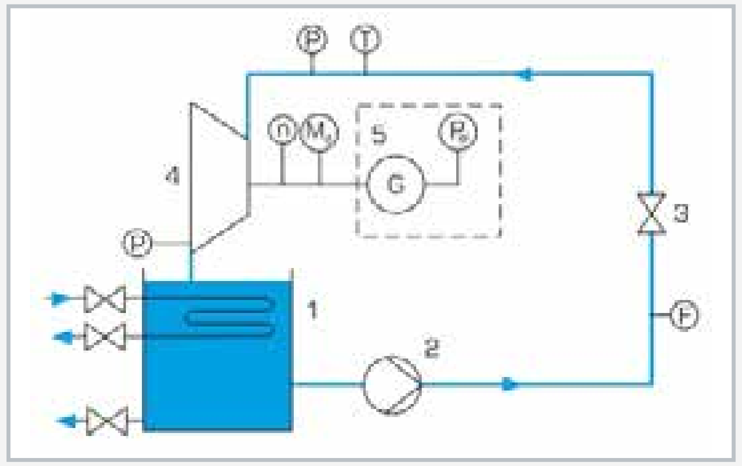
The output data of the examined turbine are determined and can be represented by characteristic curves.

Learning objectives/experiments

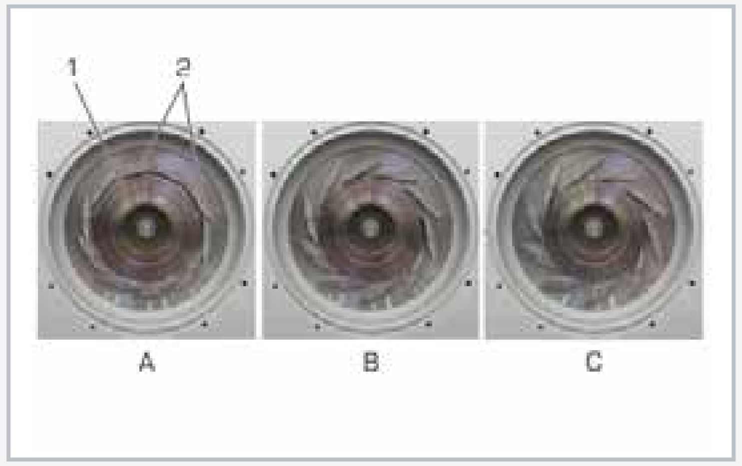
- investigation of the conversion of hydraulic into mechanical energy
- determination of the mechanical power and hydraulic power of the turbine
- determination of efficiency
- recording of characteristic curves
- investigation of the influence of the guide vane position
- velocity triangles

HM 430C
Francis turbine trainer

1 asynchronous machine, 2 pump, 3 tank, 4 pressure display at turbine outlet, 5 turbine, 6 adjustment of guide vanes, 7 pressure display at turbine inlet, 8 flow control valve, 9 switch cabinet with displays and controls



1 tank with optional cooling, 2 centrifugal pump, 3 flow control valve, 4 Francis turbine, 5 generator; P pressure, T temperature, F flow rate, n speed, M_d torque, P_{el} electrical power



Front view of the Francis turbine: 1 rotor, 2 adjustable guide vanes; guide vane position: A closed, B half open, C open

Specification

[1] investigation of a Francis turbine
[2] closed water circuit with pump, motor, flow control valve and tank with optional cooling
[3] pump with variable speed via frequency converter
[4] adjustment of flow rate via flow control valve
[5] loading the turbine by use of the asynchronous machine as generator
[6] rotor and guide vanes of the turbine completely visible
[7] adjustable guide vanes for setting different angles of attack
[8] non-contact speed measurement at the generator haft and force sensor for measuring the driving torque
[9] digital display for temperature, flow rate and ressures (additional manometer within scope of supply), speed, torque and electrical power of generator
[10] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Francis turbine
- hydraulic power: 2,1kW at 1500min^{-1}
- mechanical power: approx. 1,4kW at 1500min^{-1}
- rotor, D: 120mm, 15 blades
- 10 guide vanes, angle of attack adjustable: 0...23°

Centrifugal pump, multistage
- variable speed
- power consumption: 5,5kW
- max. flow rate 900L/min
- pump head 42m

Asynchronous machine as generator
- output: 2,2kW at 1440min^{-1}

Tank: 550L

Measuring ranges
- temperature:: 0...100°C
- pressure (inlet): ±1bar (turbine)
- pressure (outlet): 0...6bar (turbine)
- flow rate: 0...1000L/min
- torque: 0...20Nm
- speed: 0...3000min^{-1}
- power: 0...2200W (generator)

400V, 50Hz, 3 phases
400V, 60Hz, 3 phases, 230V, 60Hz, 3 phases
UL/CSA optional
LxWxH: 2350x1050x2050mm
Weight: approx. 580kg

Required for operation

PC with Windows recommended

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 set of instructional material

HM 421
Kaplan turbine trainer

Learning objectives/experiments

- determination of power output curves at different speeds
  - hydraulic power output
  - mechanical power output
- determination of the head
- determination of turbine efficiency
- investigation of the influence of the guide vane position on power output and efficiency

Description

- **characteristics of a Kaplan turbine**
- **adjustable guide vanes for setting the power output**
- **GUNT software for data acquisition**

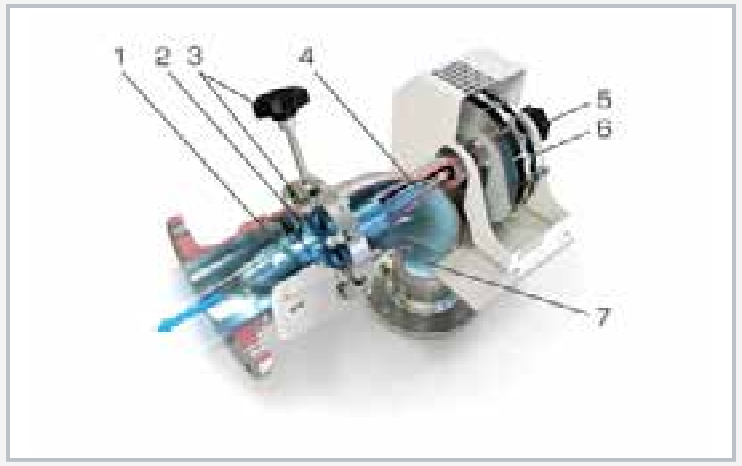
Water turbines are turbomachines which convert water energy into mechanical energy. Mostly, they are used for driving generators for power generation purposes. The Kaplan turbine is a reaction turbine with an axial through flow. It has a high specific speed and is suitable for large water flows and small to medium heads. Therefore, the Kaplan turbine is used as a "classic" water turbine in run-of-the-river power plants.

The HM 421 helps to investigate the characteristic behaviour of a simple-regulated Kaplan turbine during operation. The trainer is provided with a closed water circuit with tank, submersible pump and throttle valve for adjusting the flow rate. The angle of attack of the rotor, and thus the power output of the turbine, are changed by adjusting the guide vanes. The turbine is loaded with a wear-free eddy current brake.

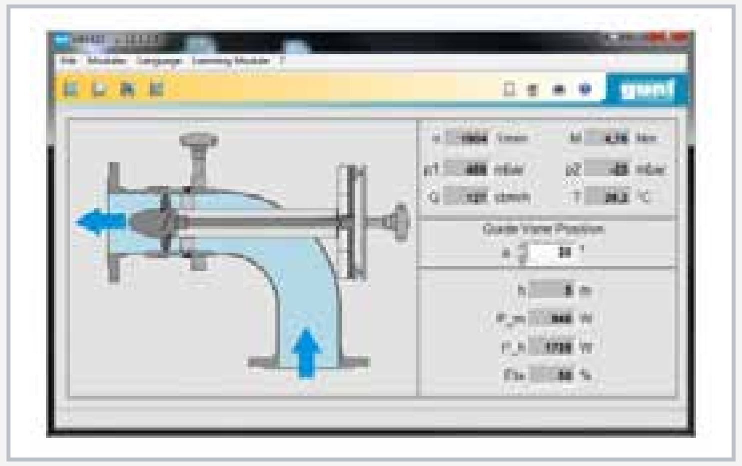
The speed is captured by means of an inductive, non-contact position sensor at the turbine shaft. For determining the turbine power, the eddy current brake is equipped with a force sensor for torque measurement. The pressures at the inlet and outlet of the turbine, the temperature and the flow rate are recorded with sensors. The recorded measured values are displayed digitally and processed further in a PC. The PC is used to calculate the power output data of the examined turbine and to represent them in characteristic curves.

HM 421
Kaplan turbine trainer

1 lever for adjusting the guide vanes, 2 Kaplan turbine, 3 brake, 4 tank with submersible pump, 5 flow rate sensor, 6 handwheel for throttle valve, 7 switch cabinet, 8 level indicator for tank



Sectional drawing of a Kaplan turbine
1 rotor with fixed blades, 2 adjustable guide vanes, 3 adjustment of guide vanes, 4 turbine shaft, 5 adjustment of the brake, 6 eddy current brake, 7 water inlet



Software screenshot

Specification

[1] function of a Kaplan turbine
[2] closed water circuit with submersible pump, throttle valve and tank
[3] adjustment of flow rate with throttle valve
[4] loading the turbine by use of air-cooled eddy current brake
[5] rotor with fixed blades
[6] adjustable guide vanes for setting different angles of attack
[7] non-contact speed measurement at the turbine shaft and force sensor at the brake for measuring the torque
[8] digital display for pressures, temperature, flow rate, speed and torque
[9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Kaplan turbine
- max. output: 1000W
- max. speed: 3700min^{-1}
- distributor

8 guide vanes, adjustable: -15°...45°
external Ø: 120mm,
internal Ø: 60mm
- rotor, 4 blades, fixed

external Ø: 120mm,
internal Ø: 60mm,
pitch: 80mm

Submersible pump with motor
- max. flow rate: 250m^3/h
- max. pump head: 11m
- nominal power: 3,1kW

Tank: approx. 350L

Measuring ranges
- temperature: 0...100°C
- pressure (at turbine inlet): 0...1bar rel.
- pressure (at turbine outlet): -1...0,6bar rel.
- flow rate: 13...200m^3/h
- torque: 0...10Nm
- speed: 0...6500min^{-1}

400V, 50Hz, 3 phases
LxWxH: 1450x1250x1650mm
Weight: approx. 430kg

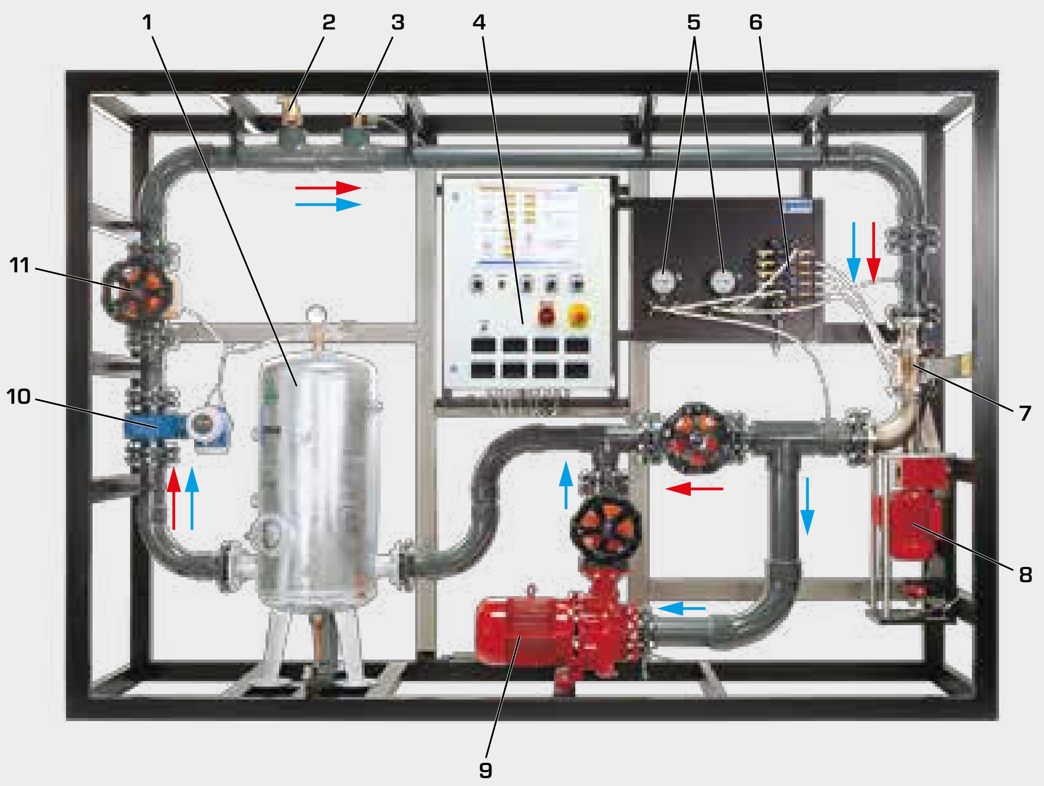
Required for operation

PC with Windows recommended

Scope of delivery

1 trainer
1 GUNT software CD + USB cable
1 set of instructional material

HM 405
Axial-flow turbomachines



1 water tank with air cushion,
2 bleed valve,
3 solenoid valve for venting,
4 switch cabinet with displays and controls,
5 manometer for inlet and outlet pressure,
6 differential pressure sensor,
7 axial turbomachine,
8 motor/generator with torque measurement,
9 centrifugal pump for turbine operation,
10 electromagnetic flow meter,
11 valve for flow adjustment;

red arrows pump operation,
blue arrows turbine operation

The experimental plant HM 405 illustrates the function of an axial turbine with interchangeable rotors and stators. By replacing these, the turbomachine can be operated as a turbine or pump. Different rotors and stators respectively impellers and guide vane systems are provided so that their influence on the power characteristics can be investigated.

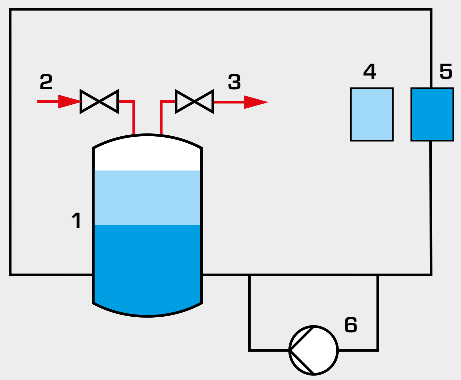
The housing is made of transparent material in order to provide insight into the flow processes upstream, between and downstream of rotor and stator respectively impeller and guide vane system.

In turbine mode the electric motor operates as a generator to generate electricity. In pump mode it operates as a drive for the pump. The electricity produced from the generator is fed into the centrifugal pump for turbine operation.

Practical experiments and calculations on the following topics can be performed depending on the operating mode:

- record characteristics
- determine dimensionless characteristic variables
- velocity triangles and pressure curves
- investigation of energy conversion within the turbomachine
- how blade / vane shape affects power and efficiency
- determine the outlet angular momentum and its effect on the power
- cavitation effects

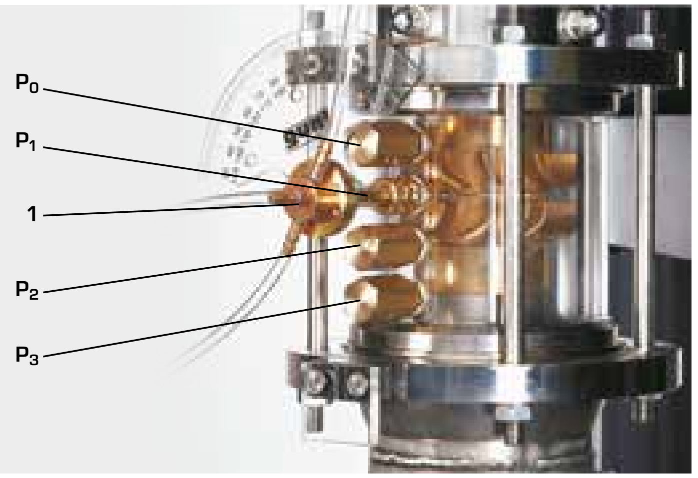
The system can be depressurised in order to attach the guide vanes and blades. In this way the pump is emptied with no loss of water. The water runs back into the tank. Admitting compressed air to the tank refills the system. The compressed air is also used to adjust the upstream pressure. An automatic bleed valve removes the remaining air from the pipe system.



1 water tank with air cushion, **2** compressed air, **3** bleeding,
4 empty turbomachine, **5** filled turbomachine, **6** centrifugal pump;
refill system,
drain system

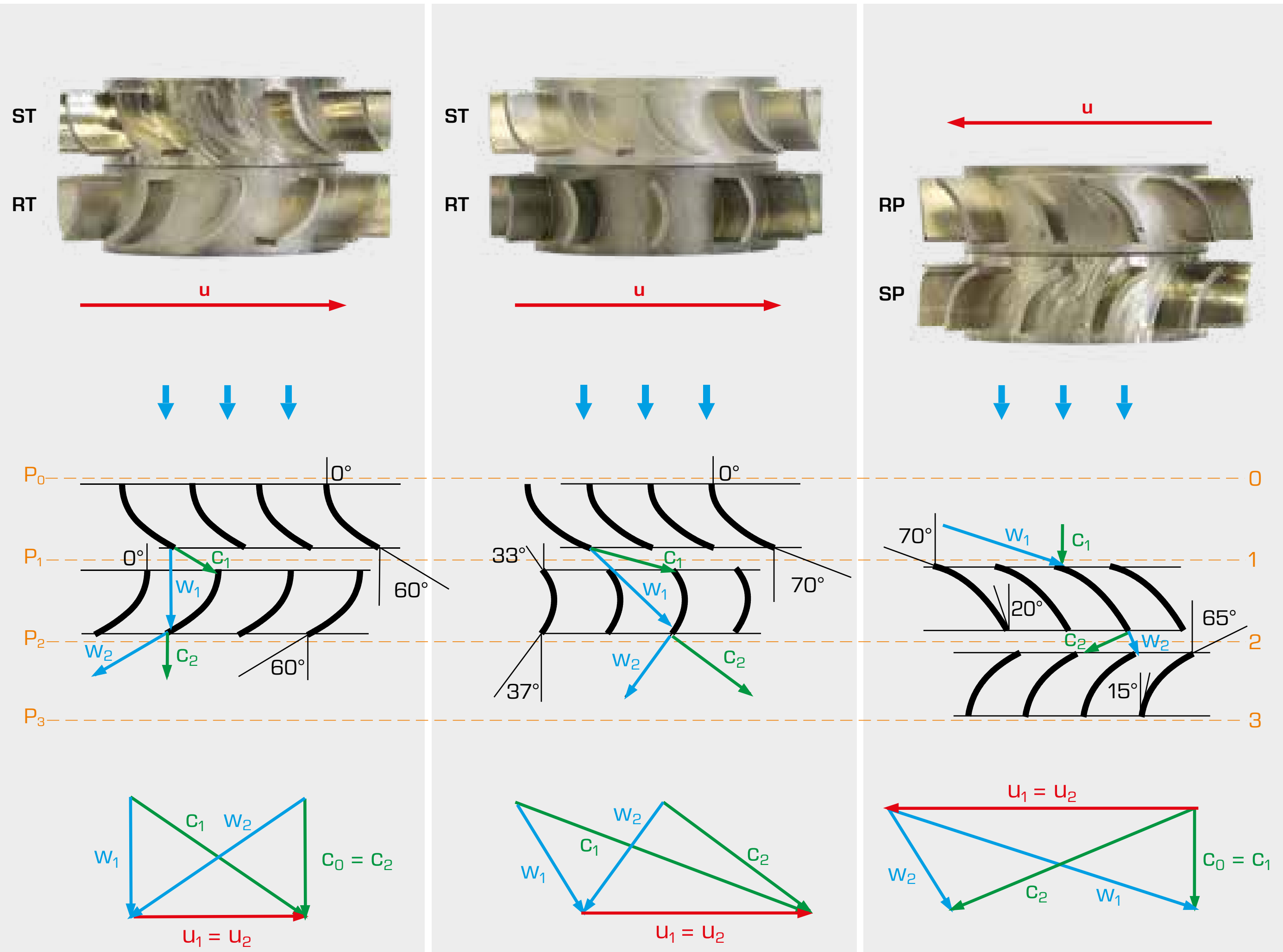
The 3-hole probe (1) can be used to measure the direction and velocity in the flow field directly upstream of, between and downstream of rotor and stator respectively impeller and guide vane system. These values are used to record the velocity triangles for the blade / vane shapes.

Varying load, speed and flow rate offers a wide range of experiments.



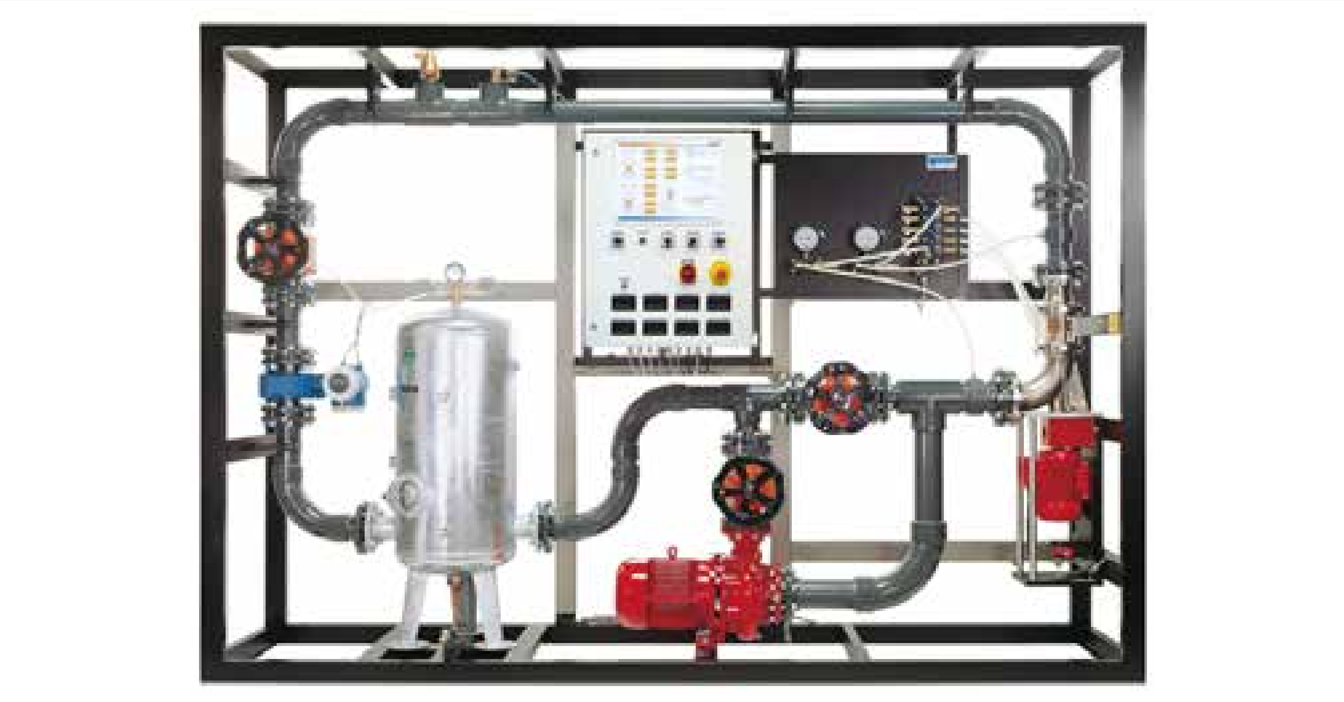
Velocity triangles on turbines or pumps

Reaction turbine	Action turbine	Pump



ST turbine stator, **SP** pump guide vane system, **RT** turbine rotor, **RP** pump impeller, **w** relative water velocity,
c absolute water velocity, **u** circumferential velocity, **P_0...P_3** pressure measuring points

HM 405
Axial-flow turbomachines



Description

- **investigation of a single-stage axial turbomachine**
- **can be operated as pump or turbine by changing rotor, impeller and stator, guide vane system**
- **probe to determine flow conditions at inlet and outlet of rotor, impeller and stator, guide vane system**
- **transparent working area**

The core piece of the experimental plant is the axial turbomachine with attached asynchronous motor. It can be operated either as a pump or turbine. To this end, different rotors, impellers and stators, guide vane systems are used. Included in the scope of delivery are four rotors, impellers and four stators, guide vane systems supplied with different blade, vane angles. The experimental plant contains a closed water circuit with expansion tank and centrifugal pump. The compressed-air powered expansion tank allows the turbomachine to be converted without loss of water.

The asynchronous motor functions during turbine operation as a generator, and during pump operation as a drive. A powerful pump generates flow and pressure during turbine operation. The power that is generated by the turbine is fed into this pump.

The transparent housing allows a full view of the rotor, impeller and stator, guide vane system and flow processes. The 3-hole probe can be used to measure the direction and velocity in the flow field directly upstream of, between, and downstream of rotor, impeller and stator, guide vane system. These values are used to record the velocity triangles for the blade, vane shapes.

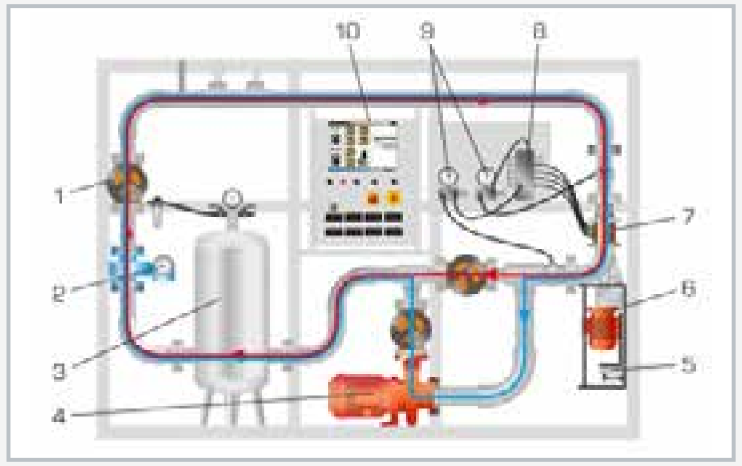
Operation under different pressure levels is possible in order to study cavitation.

The speed is detected contact-free by means of an inductive displacement sensor on the motor shaft. To determine the drive power, the asynchronous motor is mounted on swivel bearings and equipped with a force sensor to measure the drive torque. Manometers measure the pressures at inlet and outlet. Pressure sensors measure the differential pressures at rotor, impeller and stator, guide vane system. The flow rate is measured by an electromagnetic flow meter. The measured values are read from digital displays.

Learning objectives/experiments

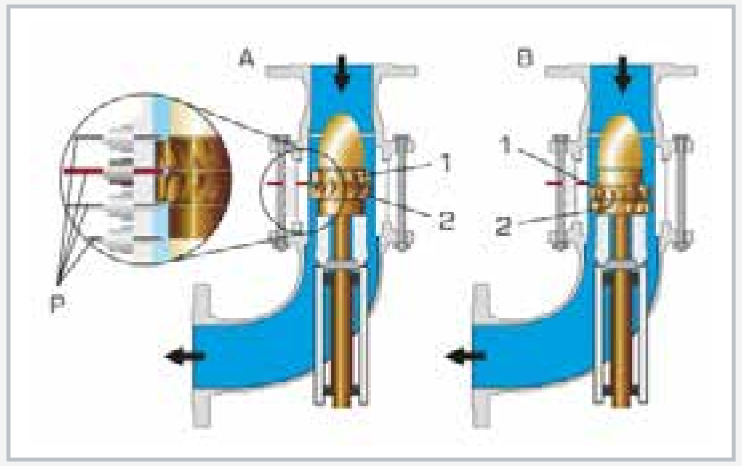
- recording characteristic curves
- determining dimensionless characteristics
- velocity triangles and pressure curves
- investigation of energy conversion within the turbomachine
- how blade, vane shape affects power and efficiency
- determining the outlet angular momentum and its effect on the power
- cavitation effects

HM 405
Axial-flow turbomachines



1 valve for adjusting the flow, 2 flow meter, 3 expansion tank with air cushion, 4 centrifugal pump for turbine mode, 5 force sensor for measuring the torque, 6 asynchronous motor, 7 axial-flow turbomachine, 8 differential pressure sensor, 9 manometer, 10 switch cabinet; red: pump mode, blue: turbine mode

The illustration shows cavitation effects in the working area of the axial flow turbomachine



A: axial flow turbomachine as a turbine, 1 stator, 2 rotor;
B: axial flow turbomachine as a pump, 1 impeller, 2 guide vane system;
P pressure sensor

Specification

[1] investigation of an axial flow turbomachine
[2] closed water circuit with expansion tank and centrifugal pump
[3] turbomachine may be operated as a turbine and as a pump
[4] two sets of impellers and guide vane systems for pump mode and two sets of rotors and stators for turbine mode with different inlet and outlet angles
[5] asynchronous motor with 4-quadrant operation via frequency converter
[6] recovery of the brake energy
[7] motor with pendulum bearing, torque measurement via lever arm and force sensor
[8] inductive speed sensor on the motor
[9] manometers for measuring the inlet and outlet pressures
[10] measuring probe and differential pressure sensor for recording the pressure curve in the turbomachine
[11] electromagnetic flow meter
[12] display of power consumption, torque, speed, pressure, differential pressure and flow rate

Technical data

Centrifugal pump
- power: 5,5kW
- max. flow rate: 150m^3/h
- max. head: 10m

Asynchronous motor
- power: 1,5kW
- torque: 0...5Nm
- speed: 0...3000min^{-1}

Expansion tank: 150L

Measuring ranges
- pressure (manometer): 2x -1...5bar
- differential pressure: 5x 0...500mbar
- flow rate: 0...100m^3/h
- speed: 0...3000min^{-1}
- torque: 0...9,81Nm

400V, 50Hz, 3 phases
LxWxH: 3300x750x2300mm
Weight: approx. 620kg

Required for operation

compressed air connection: 3...10bar

Scope of delivery

1 experimental plant
4 rotors
4 distributors / guide vanes
1 set of accessories
1 set of instructional material