Wind energy in laboratory experiments

- aerodynamics fundamentals
- energy generation from wind power
- gear technology, plant control and machine monitoring for modern wind power plants

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Technology with a future

While traditional windmills have been widely used for hundreds of years for mechanical drives, generating electricity by means of large wind power plants is currently experiencing a breakthrough.

The current trend is heading towards large wind power plants with large rotors. This is mainly down to the fact that there are high wind speeds at high altitudes. Wind speed has a huge influence on the rotor's speed of rotation. Nowadays rotors with a diameter of 100m are the norm.

The process of energy recovery through wind power includes extensive theoretical principles in addition to the practical aspects. Therefore, in our didactic concept on the field of wind power, we differentiate between the subject areas listed on the right.

E-learning from GUNT offers extensive multimedia educational material online for the laboratory experiments and thus supports technical training and engineering studies.

Basic knowledge
Wind power

The success of modern wind power plants would be inconceivable without contributions from a wide variety of sub-disciplines. Condition Monitoring Systems (CMS) are becoming increasingly important for economic aspects in the operation of wind farms.

Aerodynamics

Aerodynamics is the science of the behaviour of bodies in a compressible gas (air). Aerodynamics describes the forces that make a windmill turn or that lift an aeroplane off the ground.

The design of a rotor blade for modern wind power plants has to take into account both the aerodynamic properties and the mechanical load-bearing capacity. Blade profiles which have been optimised in extensive simulations are often used in order to satisfy the requirements of large-scale wind power plants.

Energy generation from wind power

In order to be able to use wind energy, the kinetic energy of the wind first has to be converted into rotational energy. The rotational energy can then be used in a generator to produce electrical energy. As with all energy conversion processes, losses have to be monitored in each separate step. Assuming the maximum usable wind power (the Betz limit), aerodynamic, mechanical and electrodynamic losses occur.

Gear technology

When transferring power from the rotor axis to the generator, two principle requirements must be met:

- good synchronisation properties with as little fluctuation in the speed and torques as possible
- good adaptation of the speed range between rotor and generator

Although considerable progress has been made in recent years in the development of frequency converters, established drive train designs are based on the use of transmission gearing. The gears make it possible to adjust the speed and/or frequency of the generator to the requirements of the alternating current grid.

Plant control

The performance of wind turbines depends on mechanical and electrical components as well as on efficient plant control. The influence of the effective parameters under all relevant operating conditions must be known. For this purpose, the dependence of the rotor power on wind speed, rotor speed and rotor blade angle is taken into account in corresponding characteristic diagrams.

Machine monitoring

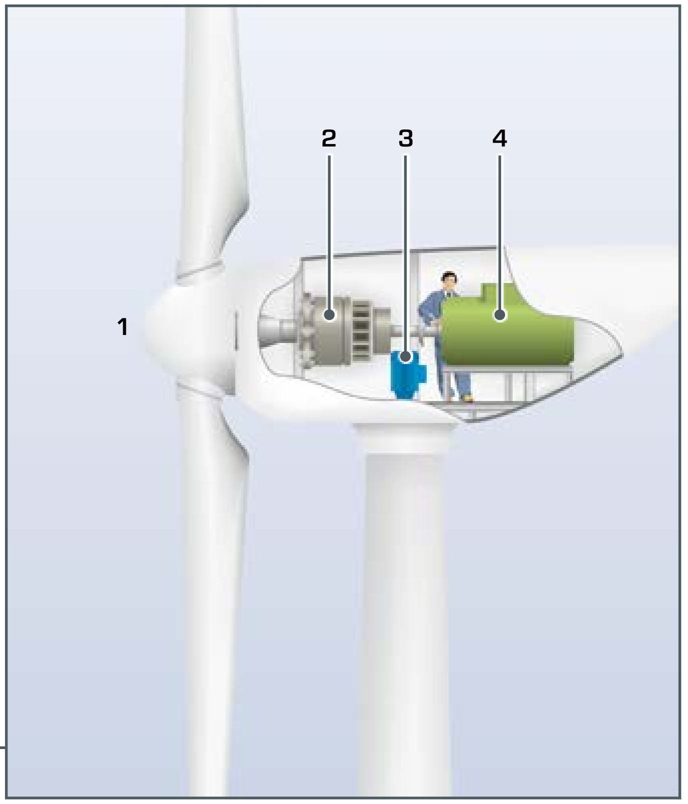
The construction and operation of a wind power plant go hand in hand with high investment costs. Failure of the rotor bearings, gears or rotor shaft leads to financial losses.

In order to avoid failure, wind power plants are continuously monitored by vibration analysis. The aim of these analyses is to detect and replace damaged components early, before the damage results in failure of the turbine.

Besides the rotor and the generator, wind power plants consist of lots of individual components which together form a functional and efficient wind power plant.

The following aspects play a key role in education specialist technicians and engineers in the field of wind energy engineering:

- functional principle and interaction of the individual components
- installation and operational monitoring

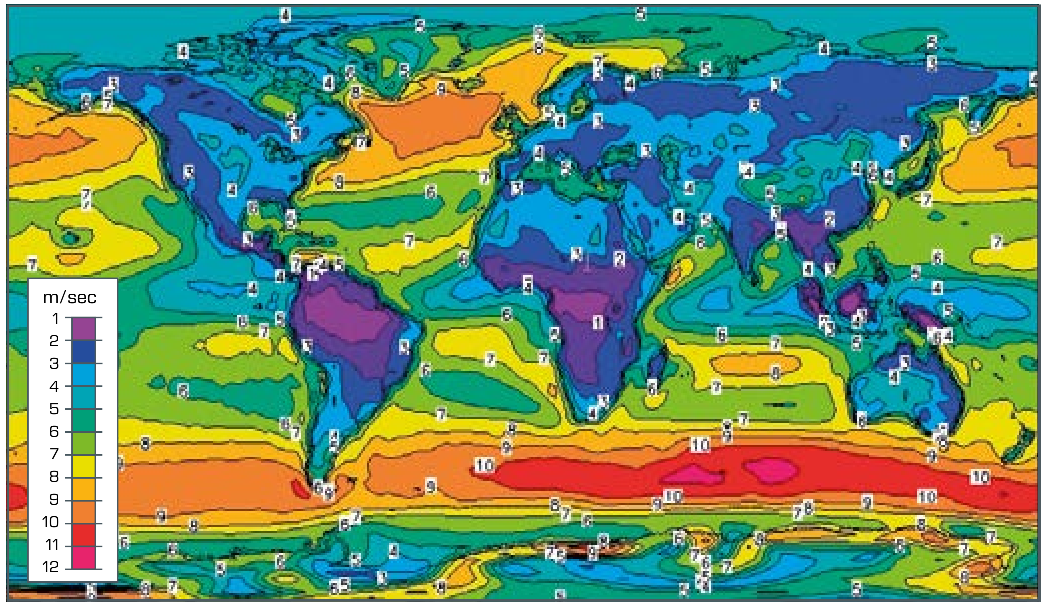


Setup of a typical wind power plant

1 rotor, **2** gearing, **3** yaw motor, **4** generator

Global wind energy supply

The graphic shows the average global wind energy supply as regions marked in colour

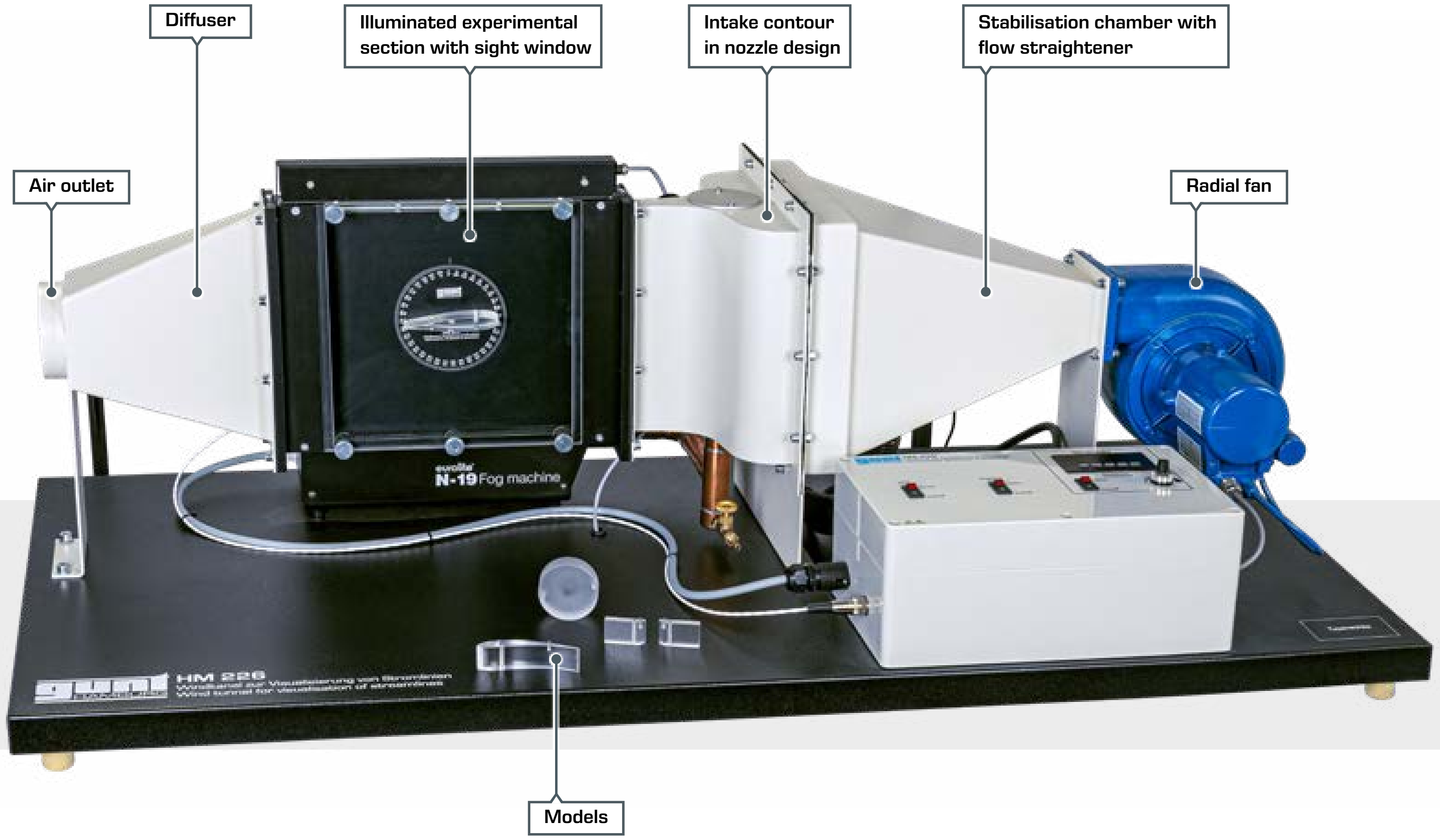


HM 226

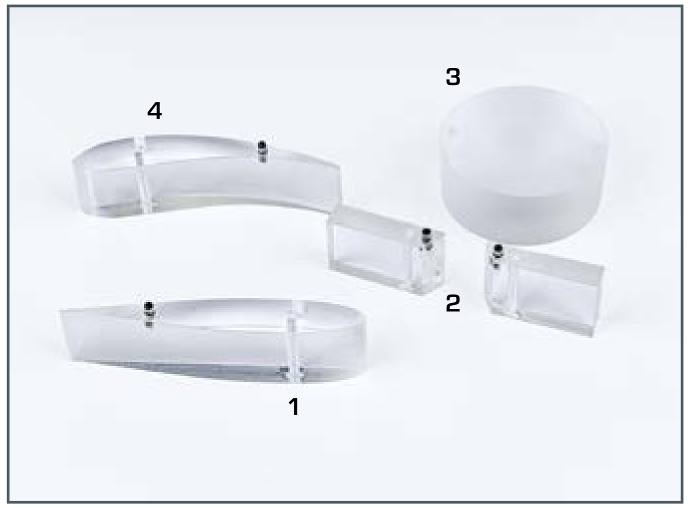
Wind tunnel for visualisation of streamlines

The experimental unit HM 226 is an open wind tunnel, in which streamlines, flow separation and turbulence can be made visible by using fog. The evaporated fog fluid is non-toxic, water soluble and the precipitate does not affect common materials.

The experimental section has a black background and a sight window; additional lighting makes the streamlines clearly visible.

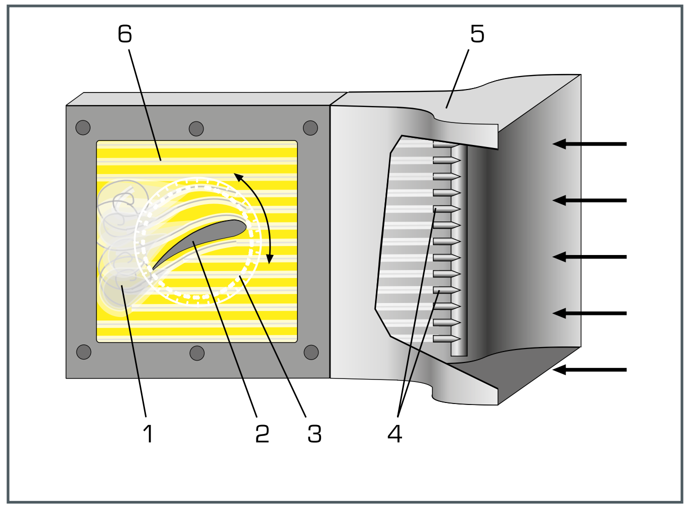


Four interchangeable models are included. The aerofoil's angle of attack is adjustable.



Models

1 aerofoil, **2** orifice plate, **3** cylinder, **4** guide vane profile



Setup of the experimental section

1 turbulence, **2** model, **3** scale for adjusting the angle of attack, **4** nozzles for injecting fog, **5** intake contour in nozzle design, **6** illuminated experimental section

About the product:

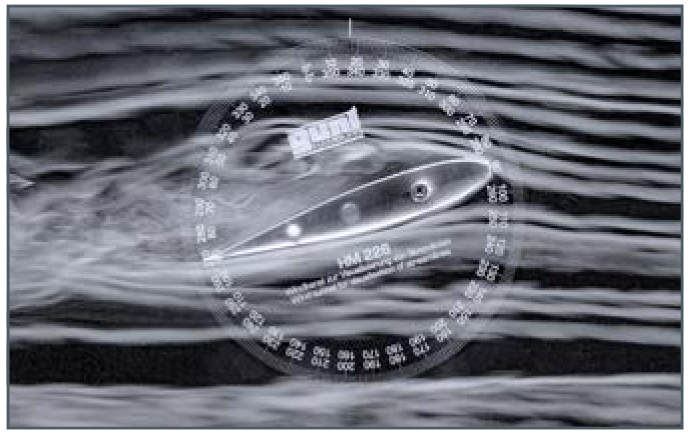
WWW

Learning objectives

- visualisation of streamlines
- flow around or through differently shaped models
- flow separation and turbulence
- stall as a function of the angle of attack

Features

- transparent, illuminated viewing area for optimal observation of streamlines
- low-turbulence flow
- streamline field is generated by injecting fog from multiple nozzles
- fog generator is included in the scope of delivery



Detailed view of the experimental section

Stall as a function of the angle of attack

HM 170

Open wind tunnel

with accessories

Fundamentals of converting wind energy

The chain effect of a wind power plant starts with the rotor. How much energy is converted into mechanical work essentially depends on the aerodynamic properties of the rotor blade.

The HM 170 wind tunnel can be used to conduct experiments with different profile shapes and drag bodies. As a result it is possible to measure, for example, how the angle of incidence affects the pressure distribution on the profile. Lift and drag forces resulting from this determine the conversion of the kinetic energy of the wind into mechanical energy on the rotor shaft.

HM 170 is an "Eiffel" type open wind tunnel used to demonstrate and measure the aerodynamic properties of various models. For this purpose, air is drawn in from the environment through a flow straightener and accelerated. The air flows around a model, such as an aerofoil, in a measuring section. Then the air is pumped back into the open by the fan.

An extensive range of accessories is available for individual experiments with HM 170.

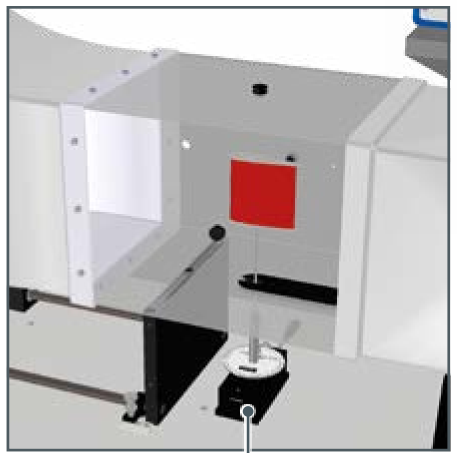
About the product:

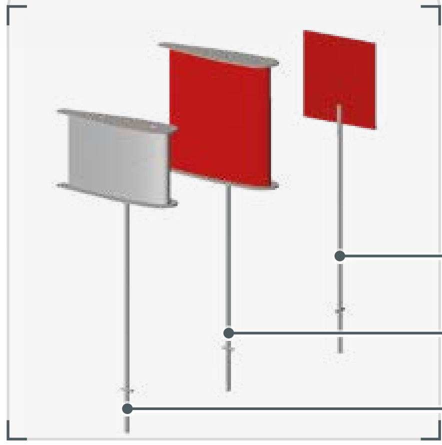
Features

- open wind tunnel for a variety of aerodynamic experiments
- homogeneous flow through the flow straightener and special nozzle contour
- transparent measuring section

Learning objectives

- investigations on flow around bodies
- record pressure distribution on an aerofoil under surrounding flow
- measure lift and drag force
- lift and flow separation as a function of the angle of incidence and the flow velocity





For a detailed introduction to the aerodynamics of wind power plants, we recommend experiments with the following accessories:

HM 170.05
Drag body square plate

HM 170.09
Lift body aerofoil NACA 0015

HM 170.22
Pressure distribution on an aerofoil NACA 0015

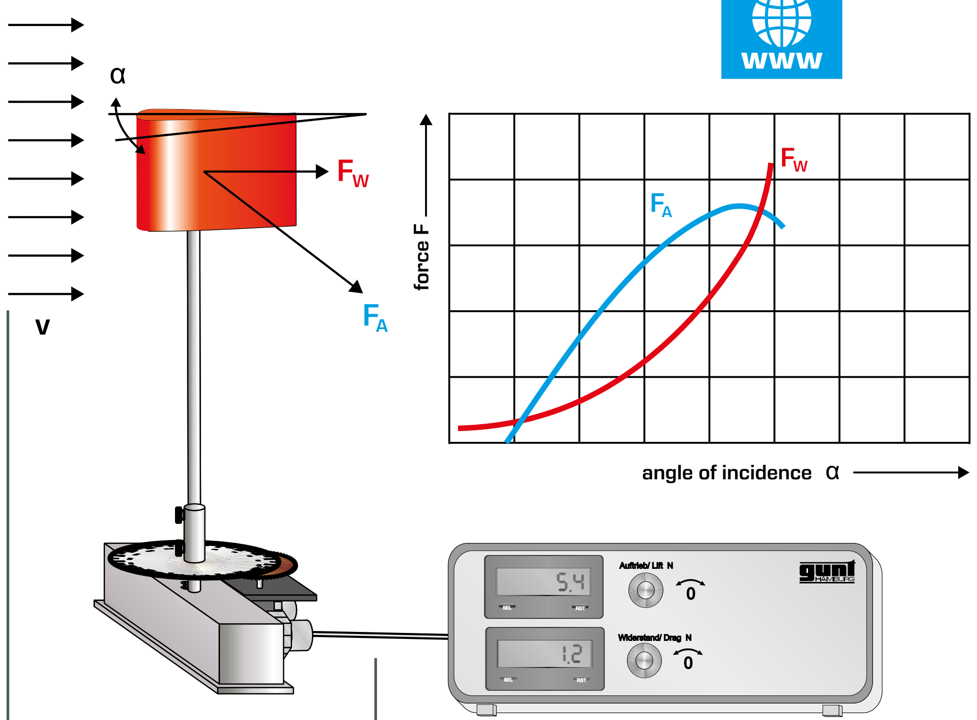
HM 170
Open wind tunnel
with accessories

HM 170.09
Lift body aerofoil NACA 0015

The lift force is by definition perpendicular to the inflow direction. At a given wind velocity, the maximum lift force under an angle of incidence characteristic for the blade profile being used can be observed.

Using HM 170.09 you can systematically log the forces acting on a blade profile.

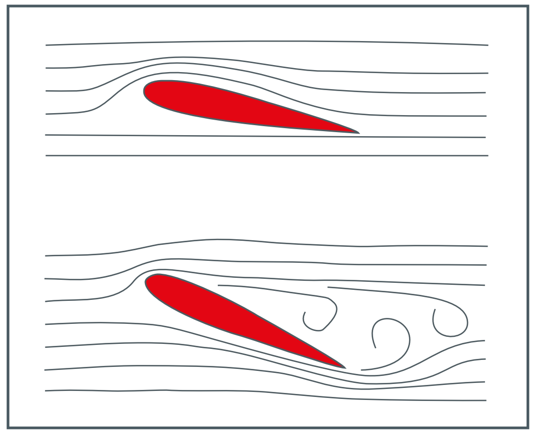
About the product:



α angle of incidence
F_A lift force
F_W drag force
v wind velocity

Learning objectives

- experiments on bodies immersed in a flow
- determination of the drag coefficient (c_d factor)
- determination of the lift coefficient
- together with the force sensor HM 170.40
  - determination of the moment coefficient



"Pitch" and "stall" determine the operating behaviour of the wind power plant.

The effective force on the rotor blade can be adjusted via the angle of incidence (pitch).

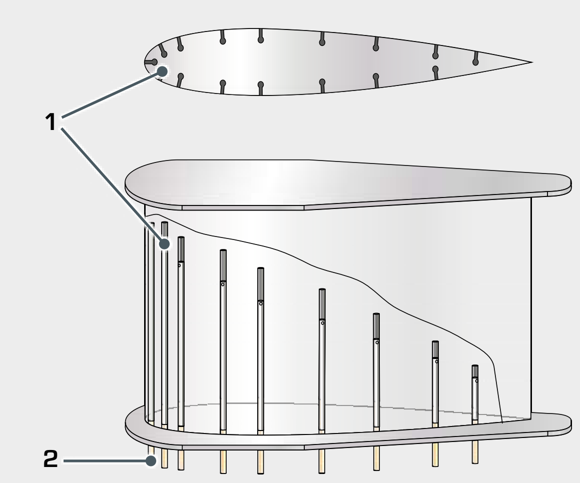
Stall is used specifically in smaller wind power plants to limit the speed of the rotor.

HM 170.22
Pressure distribution on an aerofoil NACA 0015

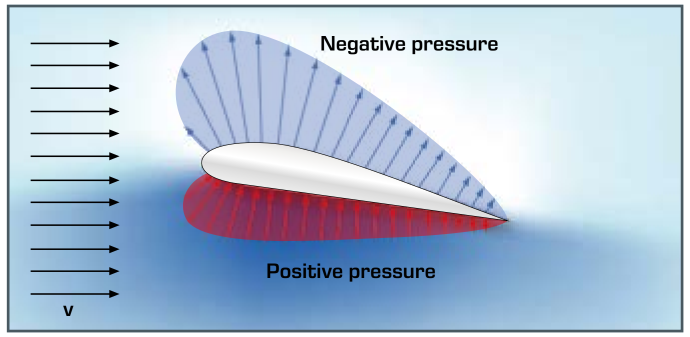
Measurement of the pressure distribution around an aerofoil profile under surrounding flow teaches students fundamental knowledge about the occurrence of lift force.

HM 170.22 demonstrates the pressure distribution on the NACA 0015 blade profile.

About the product:



The blade profile has openings **1** for pressure measurement at regular distances on the upper side and the underside. Hoses **2** connect the blade profile to pressure sensors.



In order for lift to occur on a body under surrounding flow, there must be positive pressure on the underside of the body and negative pressure on the upper side.

Learning objectives

- record pressure distribution on an aerofoil immersed in a flow
  - as a function of the angle of attack

HM 170.70 Wind power plant with rotor blade adjustment

HM 170.70, together with the HM 170 wind tunnel, allows you to demonstrate a wind turbine with rotor blade pitching and variable-speed generator. The axial fan in the wind tunnel has a variable speed and provides the air flow required for the experiments. The generator is driven directly by a 3-blade rotor. A servo motor is used to change the angle of the rotor blades.

In order to approach different operating points, the nominal speed of the generator can be set via a controller. The rotor speed is precisely measured by Hall sensors built into the generator. For the investigation of different shapes, rotor blades with straight and with optimised profile are included in the scope of delivery.

About the product:

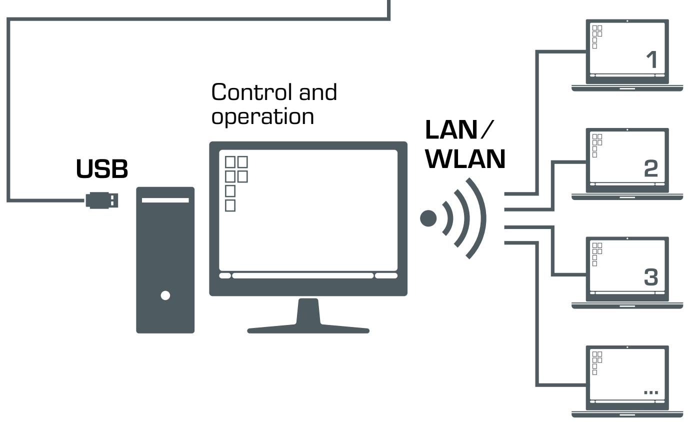
www

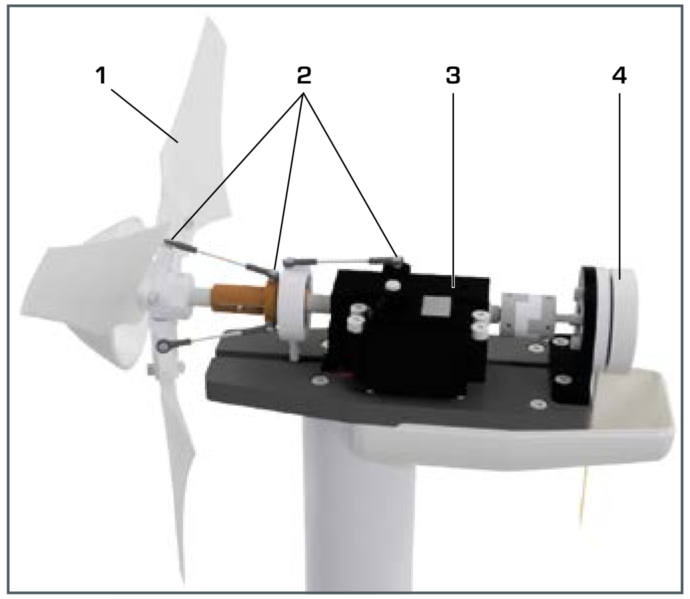
Features

- wind turbine with variable speed
- rotor blades adjustment angle adjustable via servo motor
- investigation of own rotor blade shapes (3D printing) possible
- network capability: observe, acquire, analyse experiments via customer's own network

Learning objectives

- conversion of kinetic energy into electrical energy
- power adjustment by means of
  - speed adjustment
  - rotor blade adjustment
- behaviour in the case of oblique flow
- determine the power coefficient tip-speed ratio characteristic diagram
- comparison of different rotor blade shapes

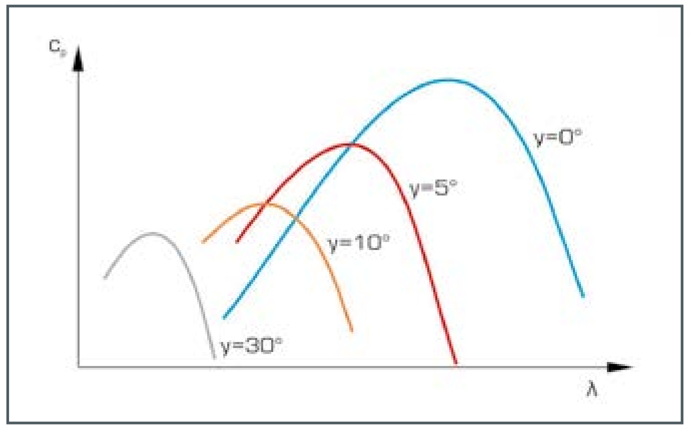




Components of the wind power plant

1 rotor blade, **2** rotor blade pitching, **3** servo motor, **4** generator

HM 170.70 connected to the open wind tunnel HM 170



Power coefficient via tip-speed ratio at different rotor blade angles and constant wind velocity

ET 210

Fundamentals of wind power plants

In modern wind power plants, the power output from the wind is adapted to the changing wind conditions. In the strong wind range, power output is limited to protect the turbine. The rotor blade adjustment serves this purpose. By adjusting the angle, this changes the forces acting on the rotor blade. In the normal wind range, power consumption is optimised by means of generator systems with variable speed.

ET 210 demonstrates a wind power plant with rotor blade adjustment and generator with variable speed. The air flow is generated by an fan. A flow straightener ensures consistent and low-turbulence flow. A three-blade rotor drives the generator directly. For the investigation of different shapes, rotor blades with straight and with optimised profile are included in the scope of delivery.

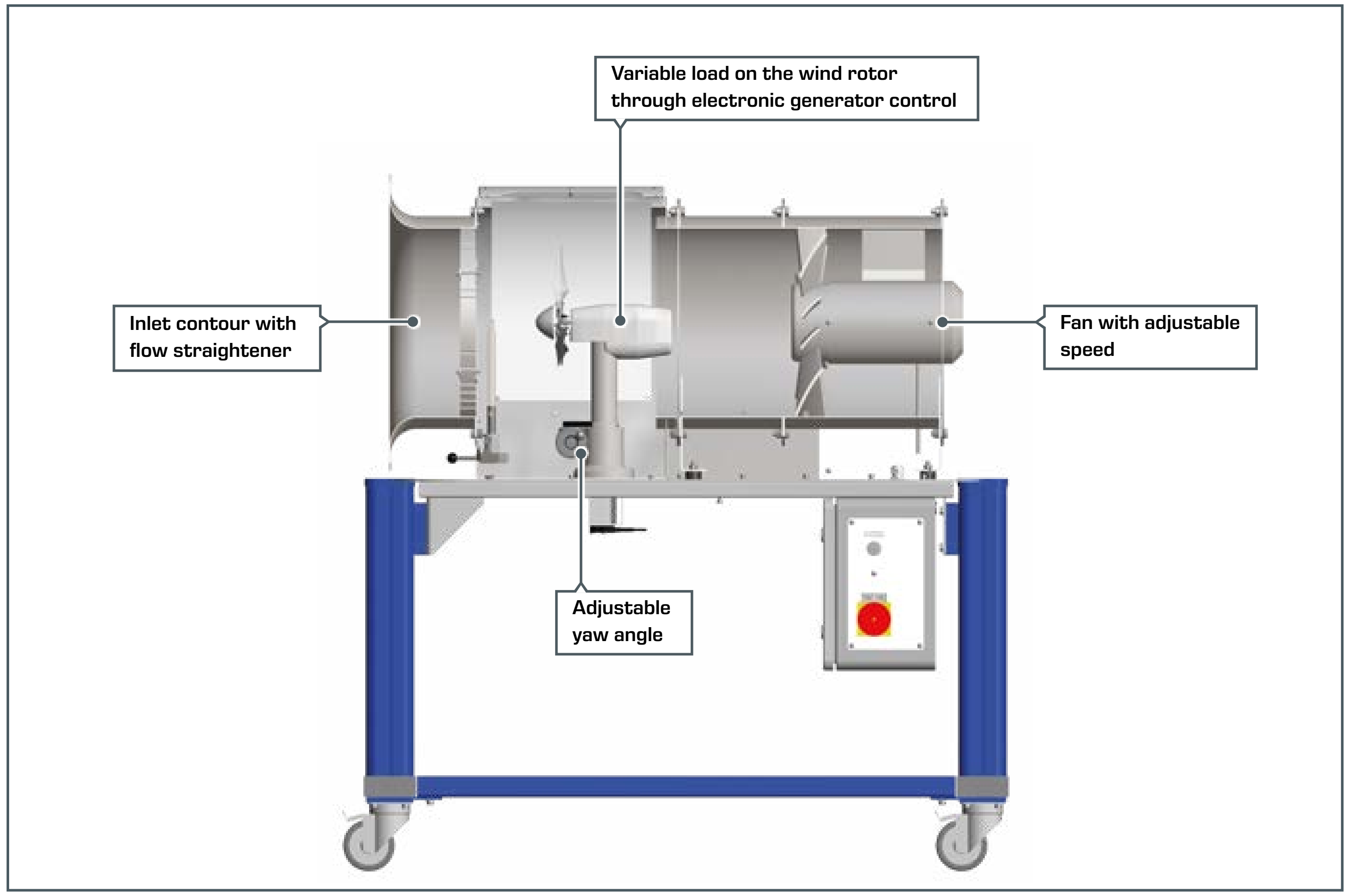
About the product:

Features

- compact unit, experiments can be carried out without additional accessories
- wind power plant with variable speed
- adjustment of rotor blade and yaw angle
- network capability: observe, acquire, analyse experiments via customer's own network

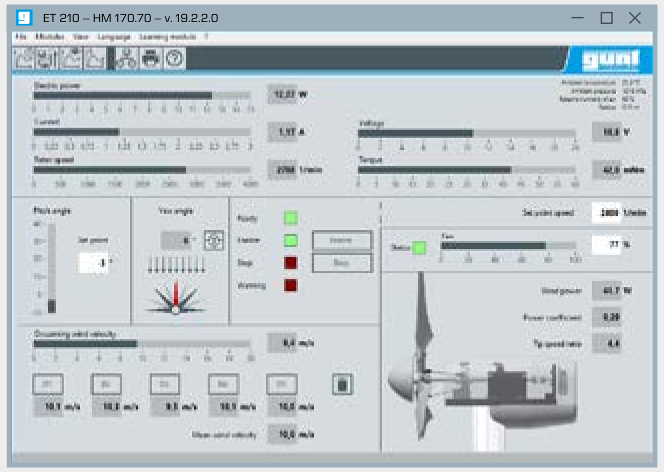
Learning objectives

- conversion of kinetic energy into electrical energy
- power adjustment by means of
  - speed adjustment
  - rotor blade adjustment
- behaviour in the case of oblique flow
- determine the power coefficient tip-speed ratio characteristic diagram
- comparison of different rotor blade shapes

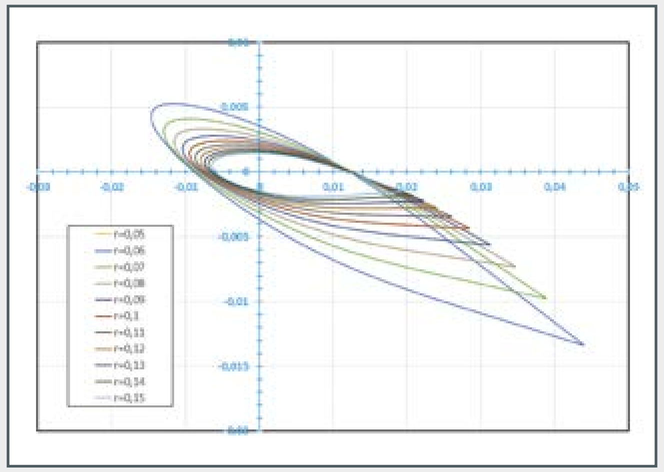


Software

The software calculates the converted electrical power, the generator torque and system-specific parameters.



GUNT software for unit control and measurement data acquisition via PC



Calculated results for a sequence of segments on a rotor blade. Change in blade depth and twist as a function of blade radius.

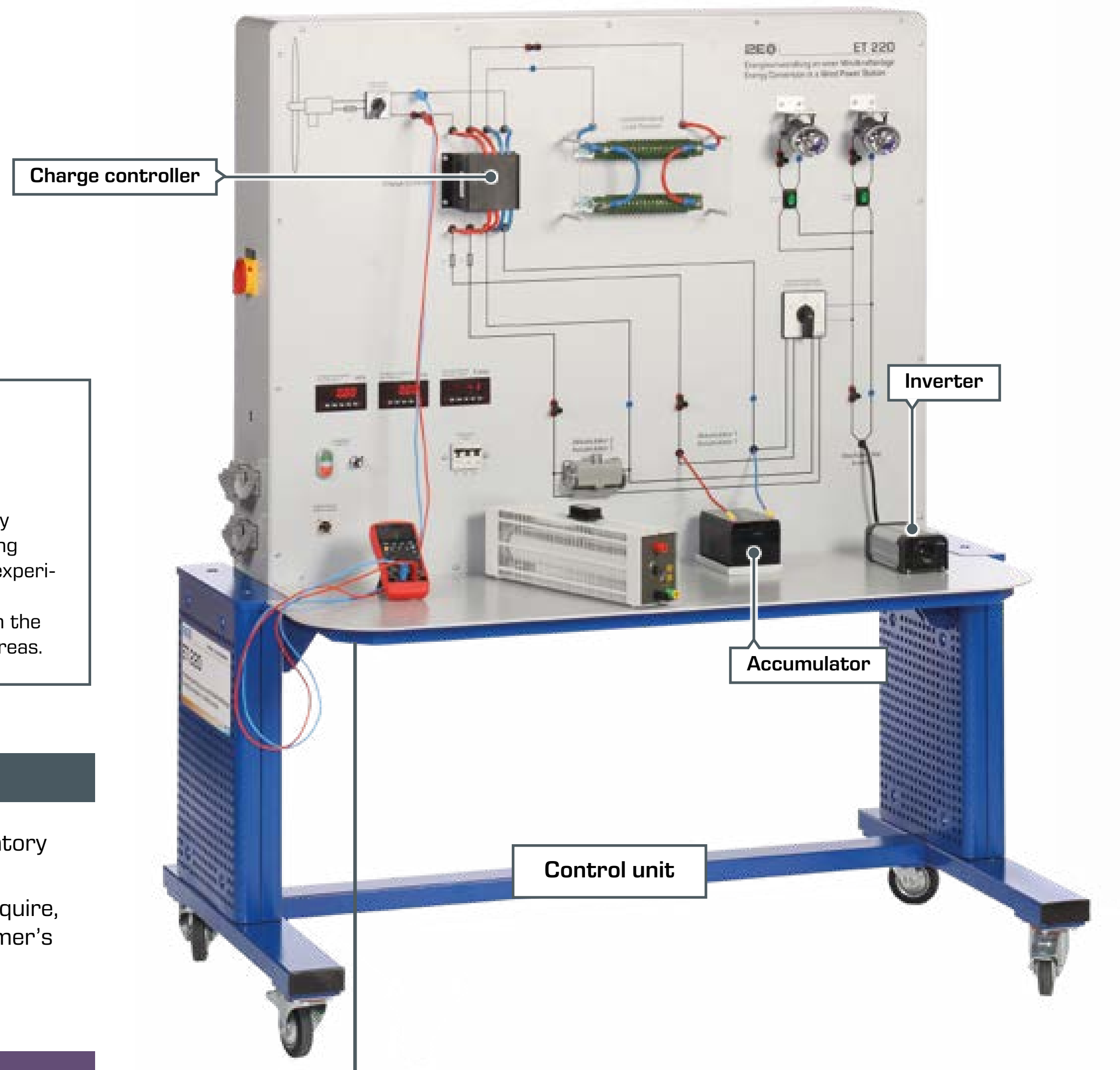
ET 220

Energy conversion in a wind power plant

The ET 220 device allows you to teach the individual stages from conversion of wind flow into rotational energy through to storing the electrical energy in accumulators, in clear and easy-to-understand steps.

About the product:

To investigate the operation of a wind power plant under real weather conditions outdoors, ET 220 can be operated together with ET 220.01.

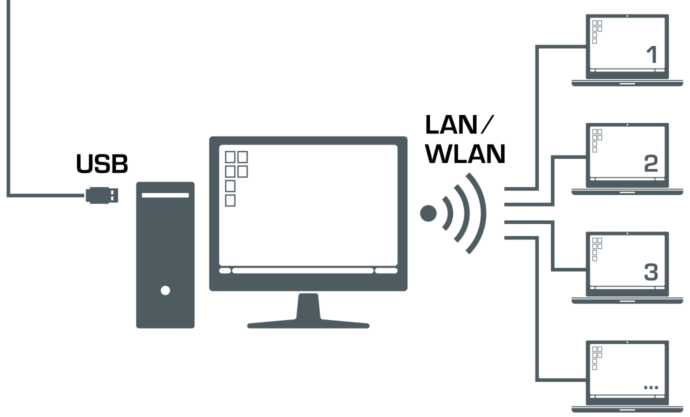


UNIVERSITY OF LEEDS

ET 220 is also used at the University of Leeds, UK, for teaching engineering students. Extensively documented experiments are available for a variety of educational situations to cover both the fundamentals and more advanced areas.

Features

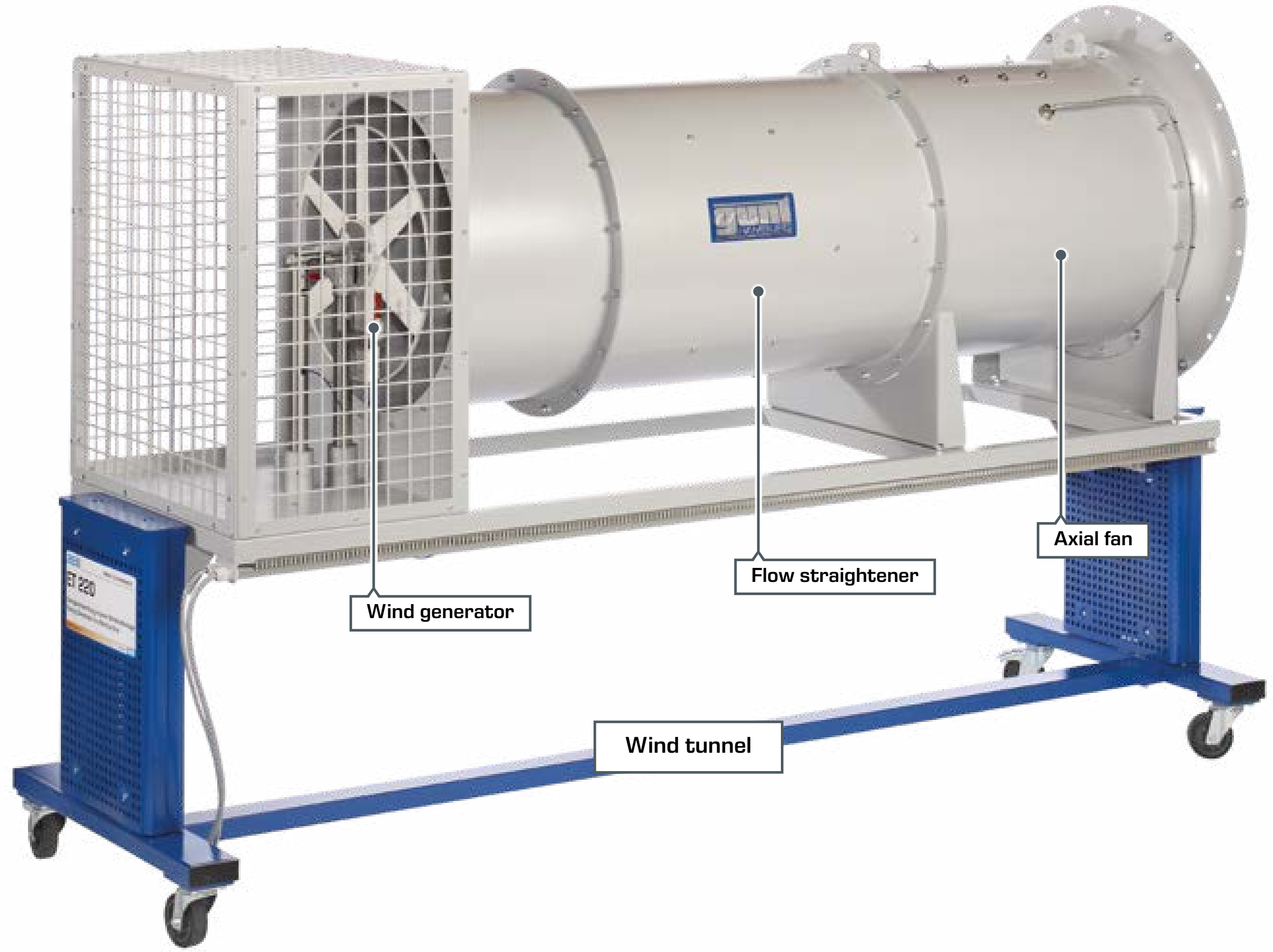
- practical experiments in laboratory scale
- network capability: observe, acquire, analyse experiments via customer's own network



Learning objectives

- conversion of kinetic wind energy into electrical energy
- function and design of a stand-alone system with a wind power plant
- determining the power coefficient as a function of tip speed ratio
- energy balance in a wind power plant
- determining the efficiency of a wind power plant

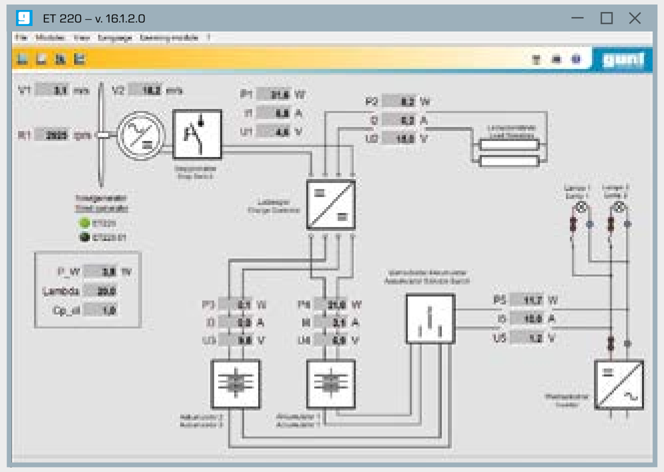
The ET 220 wind tunnel allows experiments under defined conditions. As a result, you can systematically study characteristic system variables regardless of the weather conditions, even with shorter experiment times.



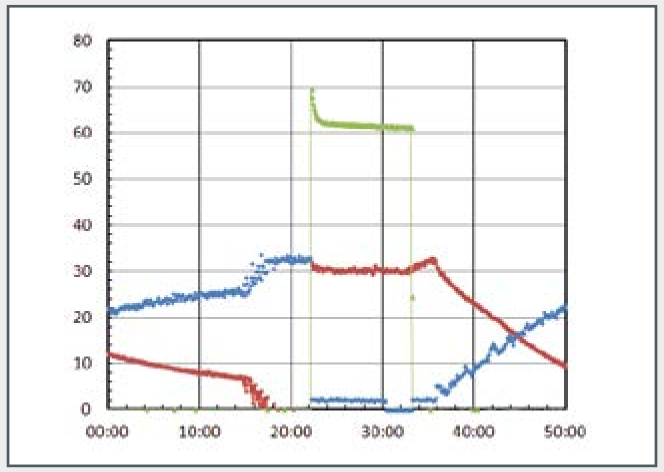
Software

With the software, current and voltage are measured at various points of the stand-alone system.

Energy balances are possible for the entire system and for separate components.



GUNT software for measurement data acquisition via PC

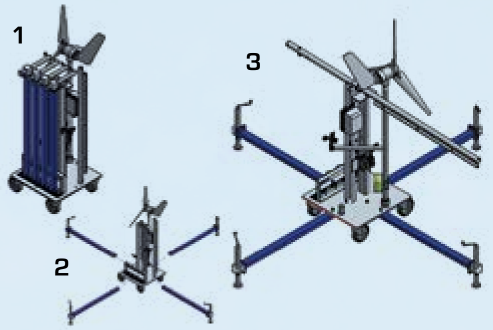


Measured time graphs of the electrical powers

ET 220.01 ET 220.10

Wind power plant
Control unit for wind power plant ET 220.01

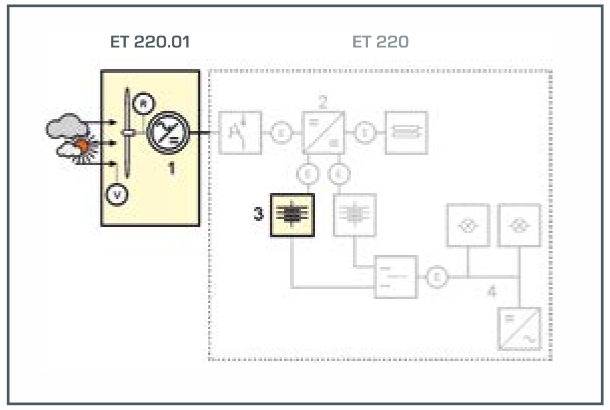
The yield of a wind power plant depends on the prevailing wind speeds and the usability of the electricity generated. The wind power plant ET 220.01 is either used together with ET 220 or together with ET 220.10.



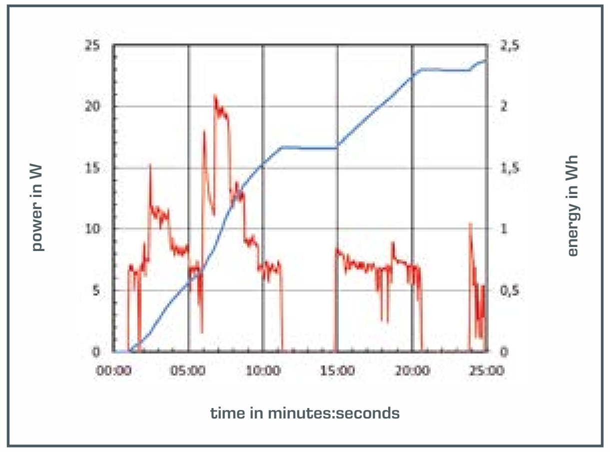
Commissioning ET 220.01

In its transport state **1**, the wind power plant can easily be brought to the experiment site. After the supports have been assembled **2**, the wind power plant is placed on the swivelling mast **3**.

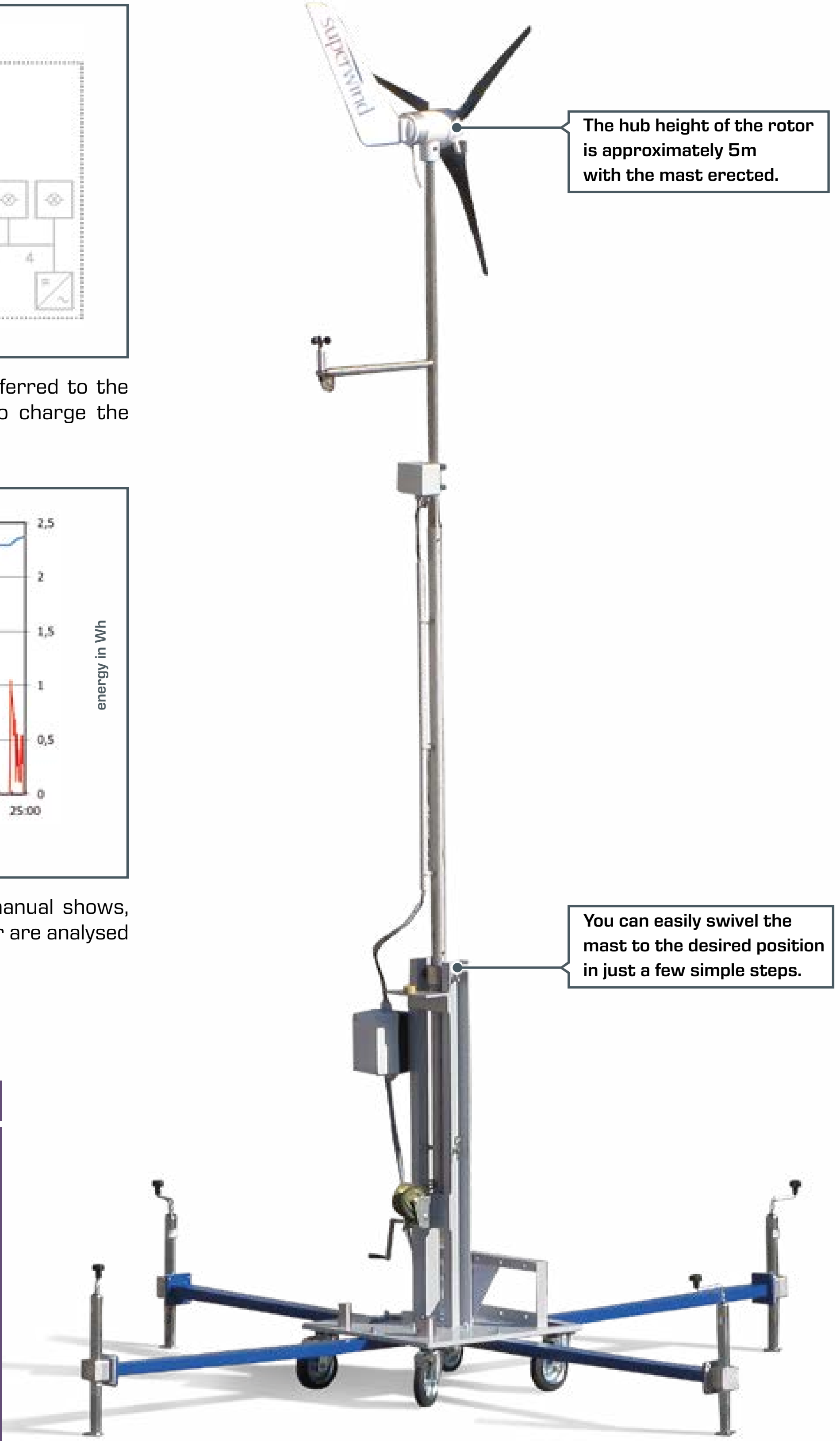
About the product:



The generated electrical energy is transferred to the ET 220 control unit and can be used to charge the accumulators or for direct consumption.



As a typical diagram from the ET 220 manual shows, power curves (red) caused by the weather are analysed to calculate the energy yields (blue).



ET 220.10
Control unit for wind power plant ET 220.01

The electrical energy from the wind power plant ET 220.01 is fed into the stand-alone system of ET 220.10, which is independent from the power grid.

Sensors record the wind velocity and the rotor speed of ET 220.01 as well as the current and voltage of the stand-alone system. The measured values are transmitted directly to a PC via USB, where they can be analysed using the software included. In addition, digital displays indicate the wind velocity and rotor speed.

About the product:

Learning objectives

- design and function of a wind power plant in stand-alone operation
- energy balance of a wind power plant under real wind conditions

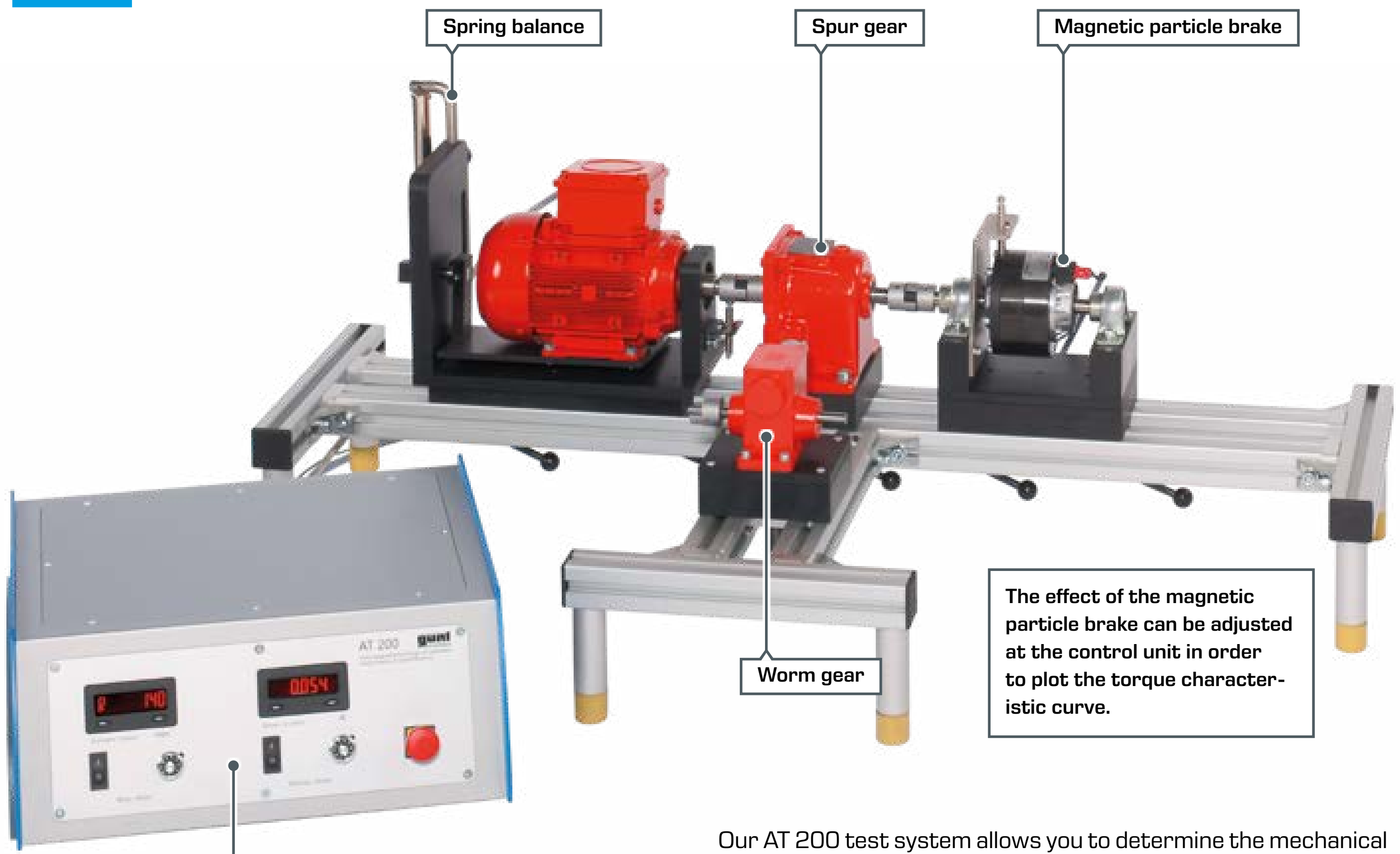
AT 200

Determination of gear efficiency

Gears play an essential role in energy conversion in wind power plants. The purpose of a gear is to transfer the kinetic energy of the rotor to the generator with as little loss as possible.

In typical applications the comparatively low speed of the rotor has to be adjusted to the much higher speeds on the generator.

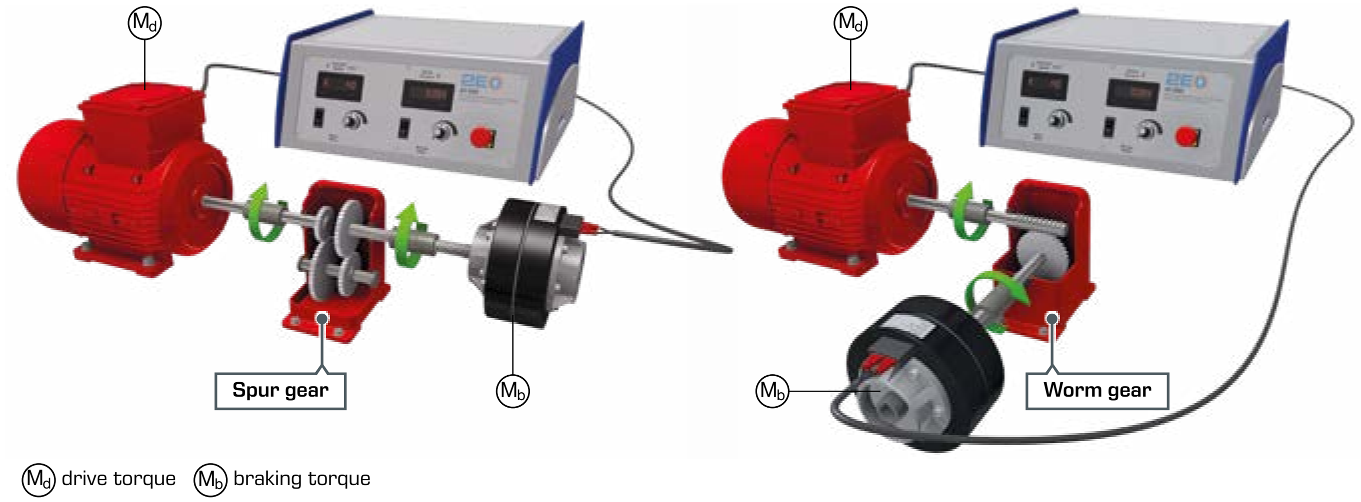
About the product:



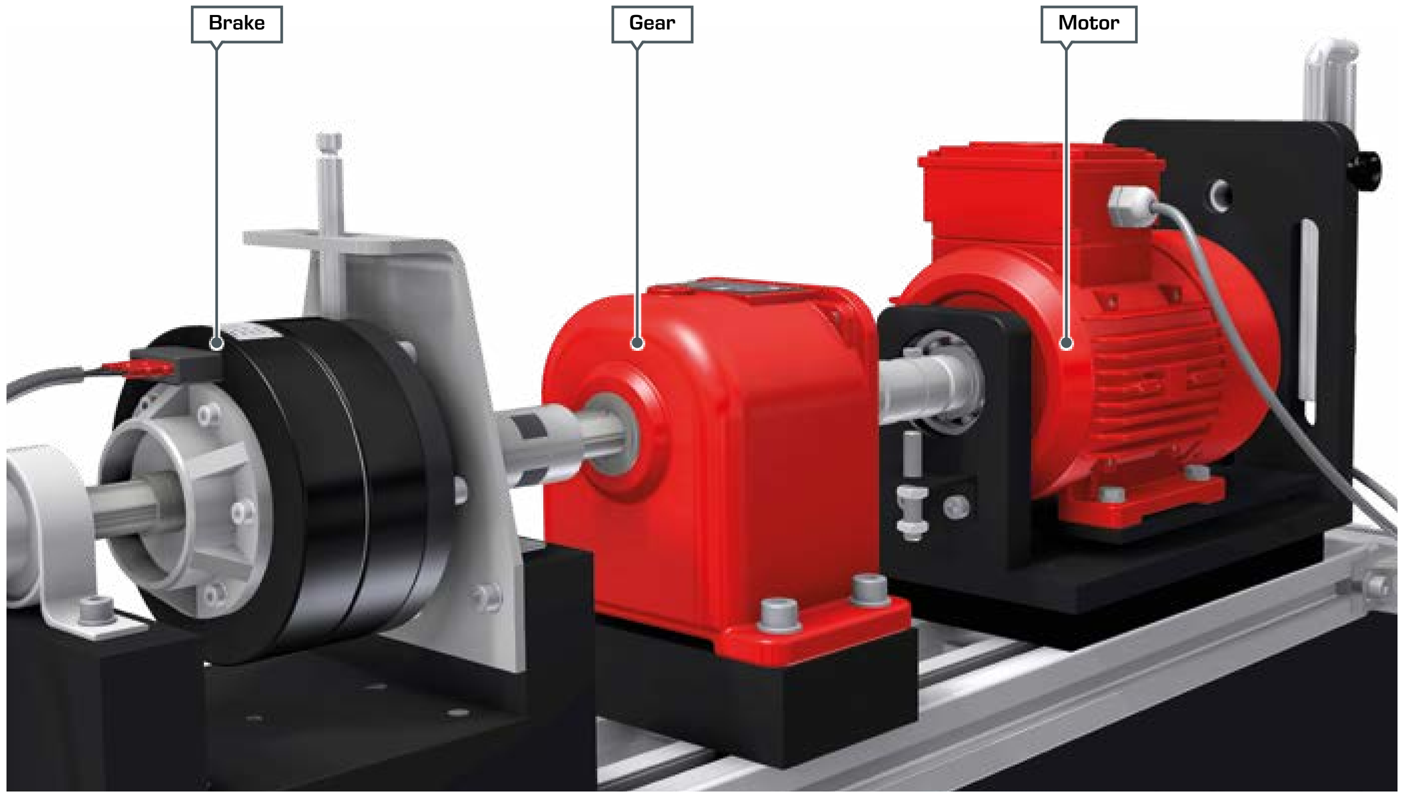
Our AT 200 test system allows you to determine the mechanical efficiency of gears and thus to teach the concept of energy loss in the classroom or in the laboratory.

Learning objectives

- determination of the mechanical efficiency of gears by comparing the mechanical driving and braking power for
  - spur gear, two-stage
  - worm gear
- plot the torque/current characteristic curve for a magnetic particle brake
- drive and control engineering



Energy losses in the gear mainly occur due to friction in the bearings and gear wheels. Friction converts kinetic energy into thermal energy. This energy is removed from the system and is therefore no longer available to produce electricity.



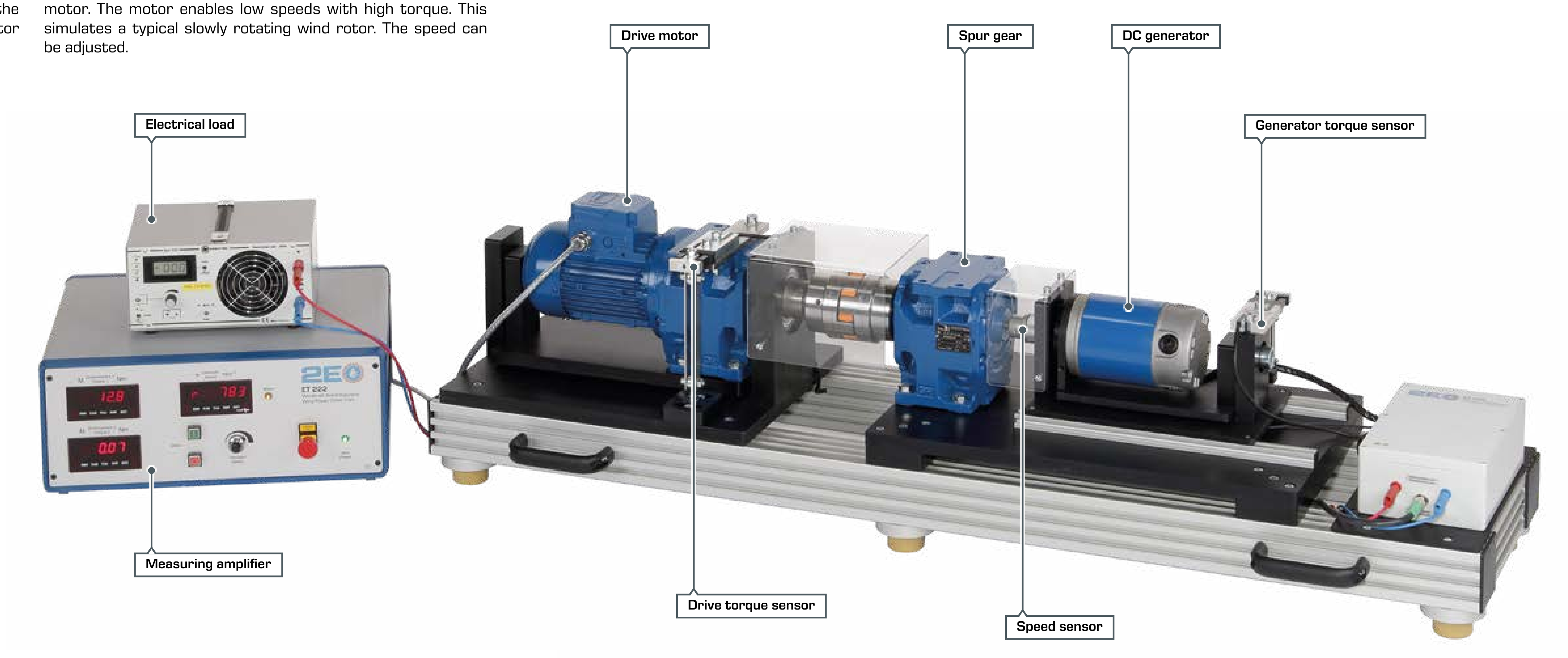
ET 222

Wind power drive train

Modern wind turbines should be optimally adapted to the wind available at their location and allow efficient operating conditions. In addition to the wind rotor itself, components of the drive train such as the transmission and the electric generator are crucial.

About the product:

The ET 222 experimental unit contains a typical wind power drive train at laboratory scale, which is driven by an electric motor. The motor enables low speeds with high torque. This simulates a typical slowly rotating wind rotor. The speed can be adjusted.

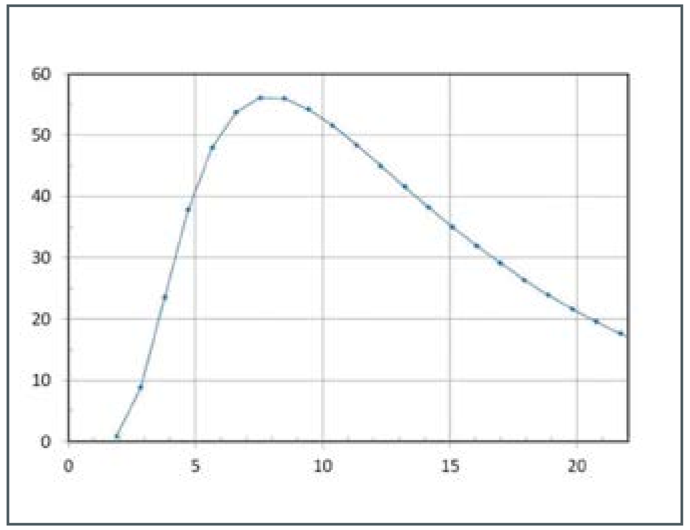


Features

- low-speed electric motor simulates wind rotor
- generator with adjustable electrical load
- torque measurements on drive and generator

Learning objectives

- conversion of rotational energy into electrical energy
- influence of torque and speed on the efficiency of the transmission
- influence of torque and speed on the efficiency of the generator
- influence of the typical torque characteristic of a wind rotor on the overall efficiency of the drive train



Simulated torque characteristic of a wind rotor:
x axis: shaft speed in min^{-1}
y axis: torque in Nm

The experiments with ET 222 simulate typical operating conditions of a drive train. To do this, the electrical load of the generator and the speed of the drive motor are varied. This makes it possible to approximate operating points of a typical torque characteristic. The calculated characteristic results from the mechanical power of a wind rotor for a given wind speed.

The generator speed and the torques of the drive side and generator are captured by sensors and displayed digitally on the measuring amplifier. The measured values are also available as analogue signals for optional external capture or processing.

NOTTINGHAM TRENT UNIVERSITY

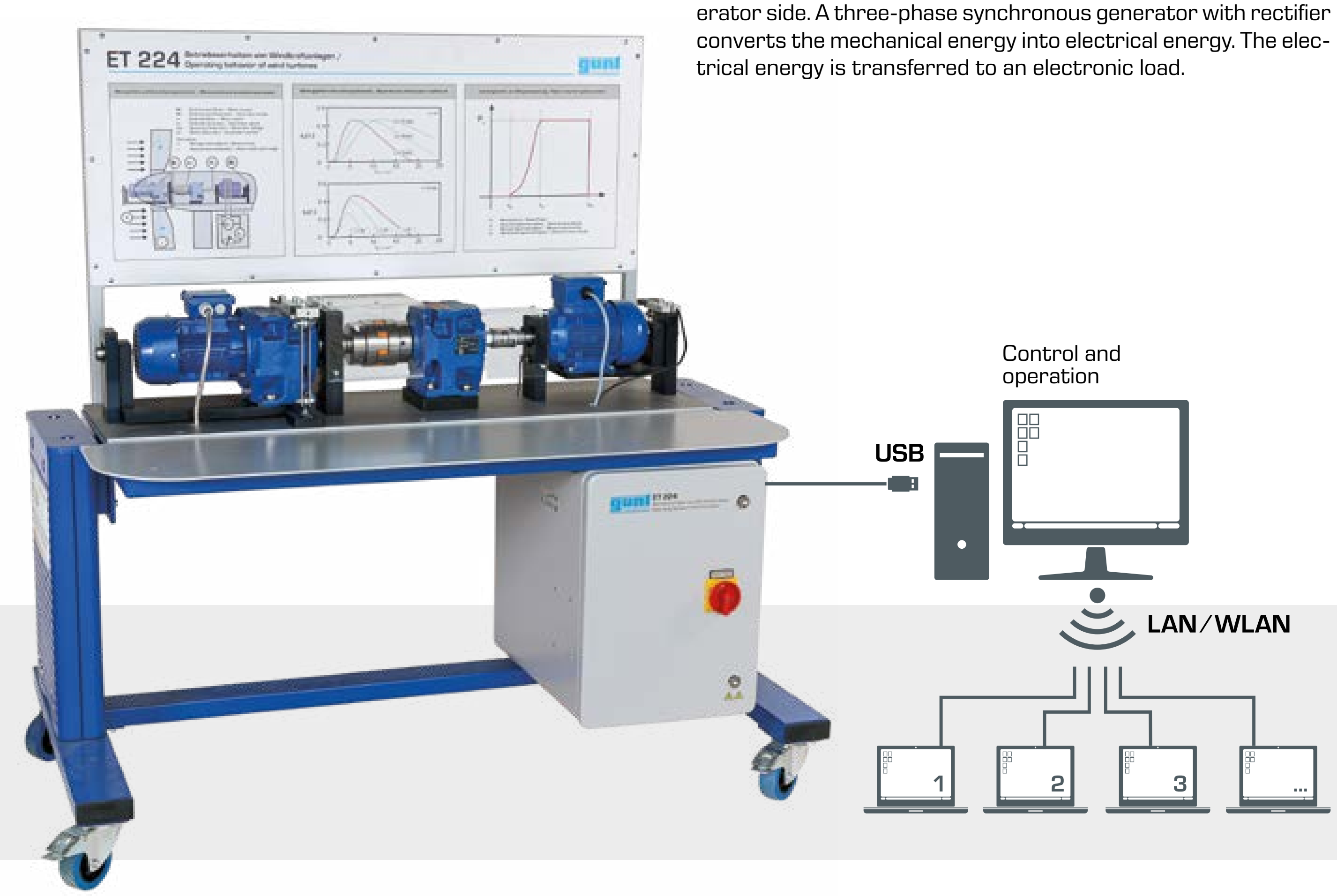
ET 222 was developed specifically for wind energy training at NOTTINGHAM TRENT UNIVERSITY (UK).

ET 224

Operating behaviour of wind turbines

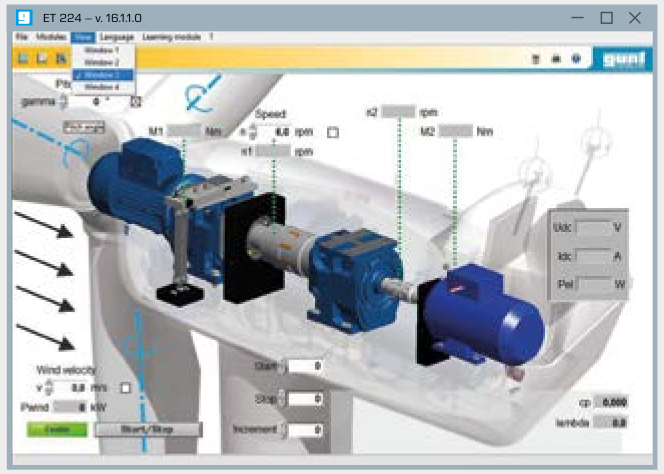
The performance of wind power plants depends on mechanical and electrical components, and on an efficient turbine control system. Therefore, it is essential that the influence of the effective parameters under all relevant operating conditions be known.

ET 224 looks at the components of a wind power drive train. To aid understanding, the main turbine parameters are studied in experiments with simulated characteristic diagrams. An adjustable speed gear motor simulates the typical slowly rotating wind rotor with high torque. A three-stage spur gear is located between the slow-rotating drive side and the fast-rotating generator side. A three-phase synchronous generator with rectifier converts the mechanical energy into electrical energy. The electrical energy is transferred to an electronic load.

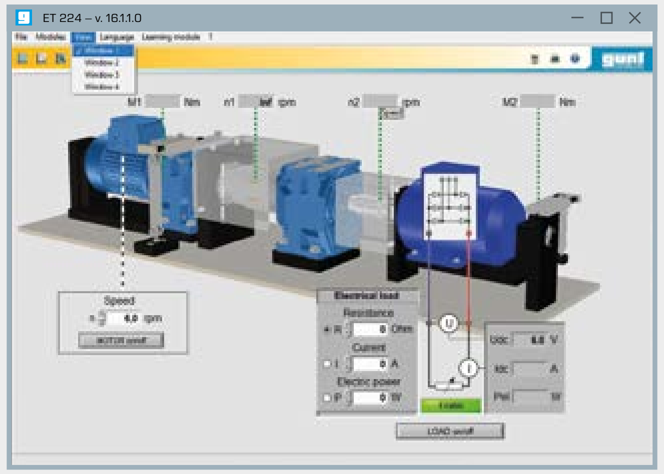


Software

The electronic load can be controlled directly or via the simulation module in the supplied GUNT software. It is possible to perform single measurements, automated capture of characteristic curves and characteristic diagrams, as well as measurements in autonomous wind-guided turbine mode.



Automated measurements in simulation mode



Plant control without simulation

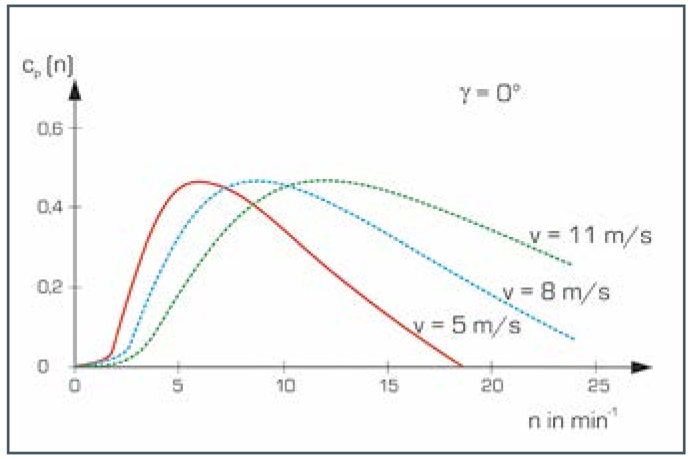
About the product:

Learning objectives

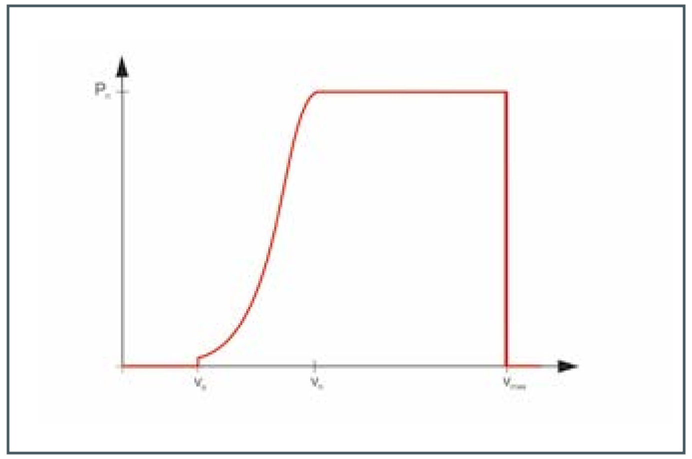
- conversion of kinetic energy into electrical energy
- power coefficient and tip-speed ratio
- study how torque and speed affect the efficiency of the gearbox and generator
- study how wind speed and rotor blade angle affect the typical torque characteristic of a wind rotor
- power limitation by controlling speed and rotor blade angle
- familiarisation with wind-guided turbine control in autonomous mode

Features

- low speed drive unit simulates wind rotor
- GUNT measurement and simulation software with control function for electronic load
- automated capture of characteristic diagrams as a function of wind speed, rotor blade angle and rotor speed
- network capability: observe, acquire, analyse experiments via customer's own network



Power coefficient as a function of rotor speed: simulation of typical characteristic diagrams at different wind velocities and rotor blade angles



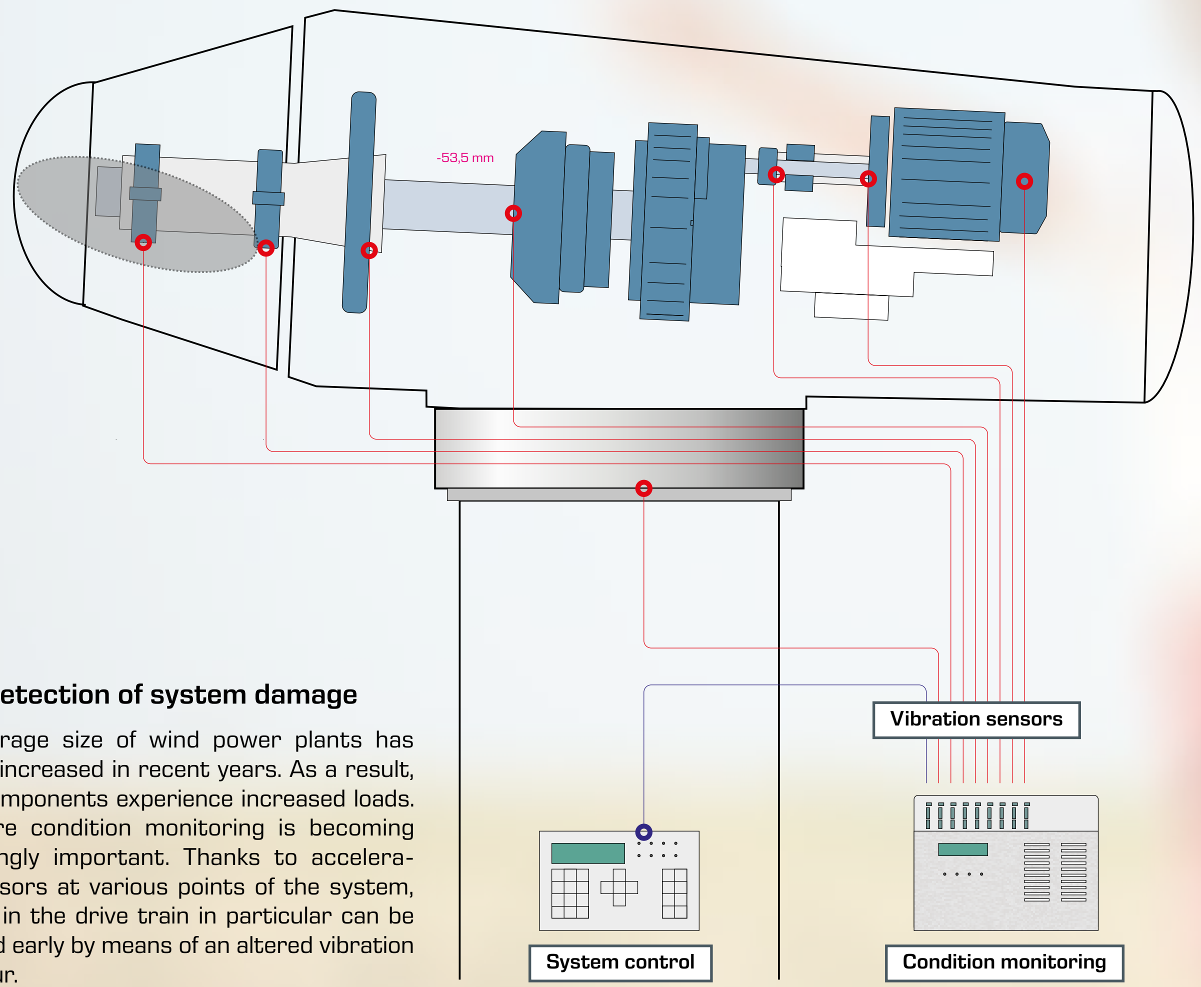
Power curve for autonomous mode with increasing wind velocity: power output is limited by the turbine control system by adjusting rotor speed and rotor blade angle

Basic knowledge
Condition monitoring in wind power plants

In order to reduce technical and economic risks, systems for monitoring the status of the equipment (CMS, Condition Monitoring Systems) are now used in all large-scale wind power plants.

In addition to typical data such as wind velocity, speed, electrical power and temperature, these systems also detect vibrations at all relevant points of a turbine. By analysing the vibration data and comparing it with set values, it is possible to detect and replace damaged components in good time before the components fail.

From the perspective of operational management, both the adaptation of suitable maintenance intervals and the early detection of damage are important. Taking into account CM systems, downtimes of much less than 10% are now agreed in contracts between wind power plant manufacturers, operators and insurance companies.



Early detection of system damage

The average size of wind power plants has steadily increased in recent years. As a result, many components experience increased loads. Therefore condition monitoring is becoming increasingly important. Thanks to acceleration sensors at various points of the system, damage in the drive train in particular can be detected early by means of an altered vibration behaviour.

Preventing hazards

Faults may occur in sensitive components of a wind power plant, such as bearings and gear wheels, due to a number of causes. These include regular wear and tear, extreme environmental conditions, overloads as well as installation and manufacturing faults. If resulting defects remain undiscovered for too long and are not rectified in good time, this can lead to significant damage up to destruction of a wind power plant.

Therefore continuous monitoring of the turbine condition is essential for larger wind power plants in particular, not least because of risks to the environment.

Expert knowledge ensures reliable system monitoring

Condition monitoring includes vibration measurements on various system components in a suitable frequency range. By analysing the structure-borne sound, it is possible to draw conclusions about the condition of the components. Other important measured variables for example are speed and the temperature of the oil and the bearings.

In many cases, experienced experts are also required to safely distinguish between measurements caused by the condition of the component and those simply caused by operation. We are pleased to present to you important experiments with our equipment in the field of wind energy in order to teach the necessary expert knowledge.

PT 500

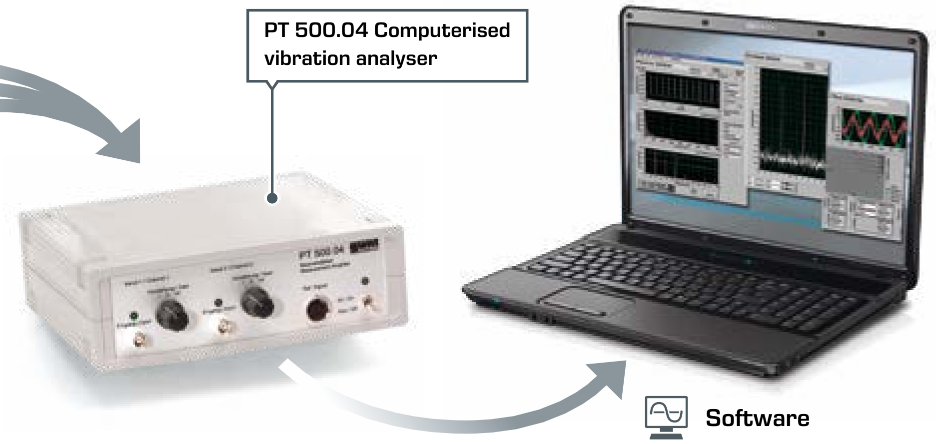
Machinery diagnostic system, base unit

Using the teaching system PT 500 Machinery diagnostic, you can simulate, measure and evaluate vibration signals from various typical malfunctions and damage. The interpretation of measurement signals can be practised extensively.

Professional measurement technology supports the transfer of experience gained in the day-to-day operation of modern wind power plants.

About the product:

www



The PT 500 base unit, together with the PC-based PT 500.04 vibration analyser, allows a series of experiments on the topic of machinery diagnostics and machinery monitoring. The GUNT software offers a variety of analysis options for the evaluation. These include, for example:

- oscilloscope
- frequency spectrum
- vibration intensity
- envelope analysis
- damage analysis on roller bearings and gears using envelope spectra

Learning objectives

- introduction to vibration measurement methods on rotating machinery systems
  - fundamentals of measurement of shaft and bearing vibrations
  - basic variables and parameters
  - sensors and measuring devices
  - influences of speed and shaft layout
  - influence of transducer positioning
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser

Detailed information about the PT 500 system

A complete summary of all options of the modular system can be found in our PT 500 brochure, which is available for download at **www.gunt.de.**

References

Many customers around the world are already successfully working with our PT 500 teaching system.

Below are a few selected references:

- Hamburg University of Applied Sciences, Germany
- Dresden University of Applied Sciences, Germany
- Reinhold-Würth University, Künzelsau, Germany
- Warsaw University, Poland
- RFPC Training Center, Bandar Iman, Iran
- INTECAP Instituto Technica de Capacitatión y Productividad, Guatemala

Accessories for PT 500 system

PT 500.01 Laboratory trolley
PT 500.04 Computerised vibration analyser
PT 500.05 Brake & load unit
PT 500.10 Elastic shaft kit
PT 500.11 Crack detection in rotating shaft kit
PT 500.12 Roller bearing faults kit
PT 500.13 Couplings kit
PT 500.14 Belt drive kit
PT 500.15 Damage to gears kit
PT 500.16 Crank mechanism kit
PT 500.17 Cavitation in pumps kit
PT 500.18 Vibrations in fans kit
PT 500.19 Electromechanical vibrations kit
PT 500.41 Two displacement sensors

The base unit contains a vibration-damped fixing plate, a speed-controlled drive motor with tachometer, a shaft with two mass discs and two bearing units, a coupling and balancing weight. Almost any topic of machinery diagnostics can be covered thanks to a wide range of accessories.

PT 500.11 Crack detection in rotating shaft kit

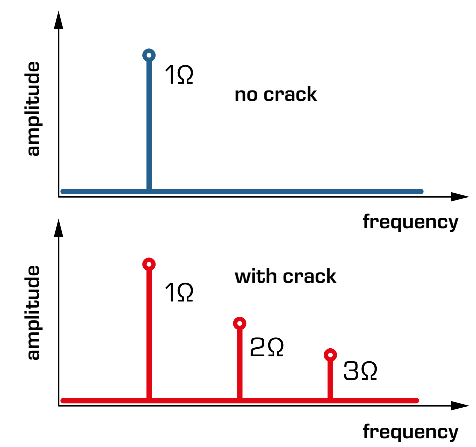
The rotor shaft of a wind power plant transfers the mechanical energy from the rotor to the gear. By detecting cracks in the shaft early, the risk of a costly failure and/or the danger of destruction of the turbine can be minimised.

Our PT 500.11 accessory allows you to conduct vibration analyses on faulty shafts. Different shafts are available, with which different sized cracks can be simulated.

About the product:

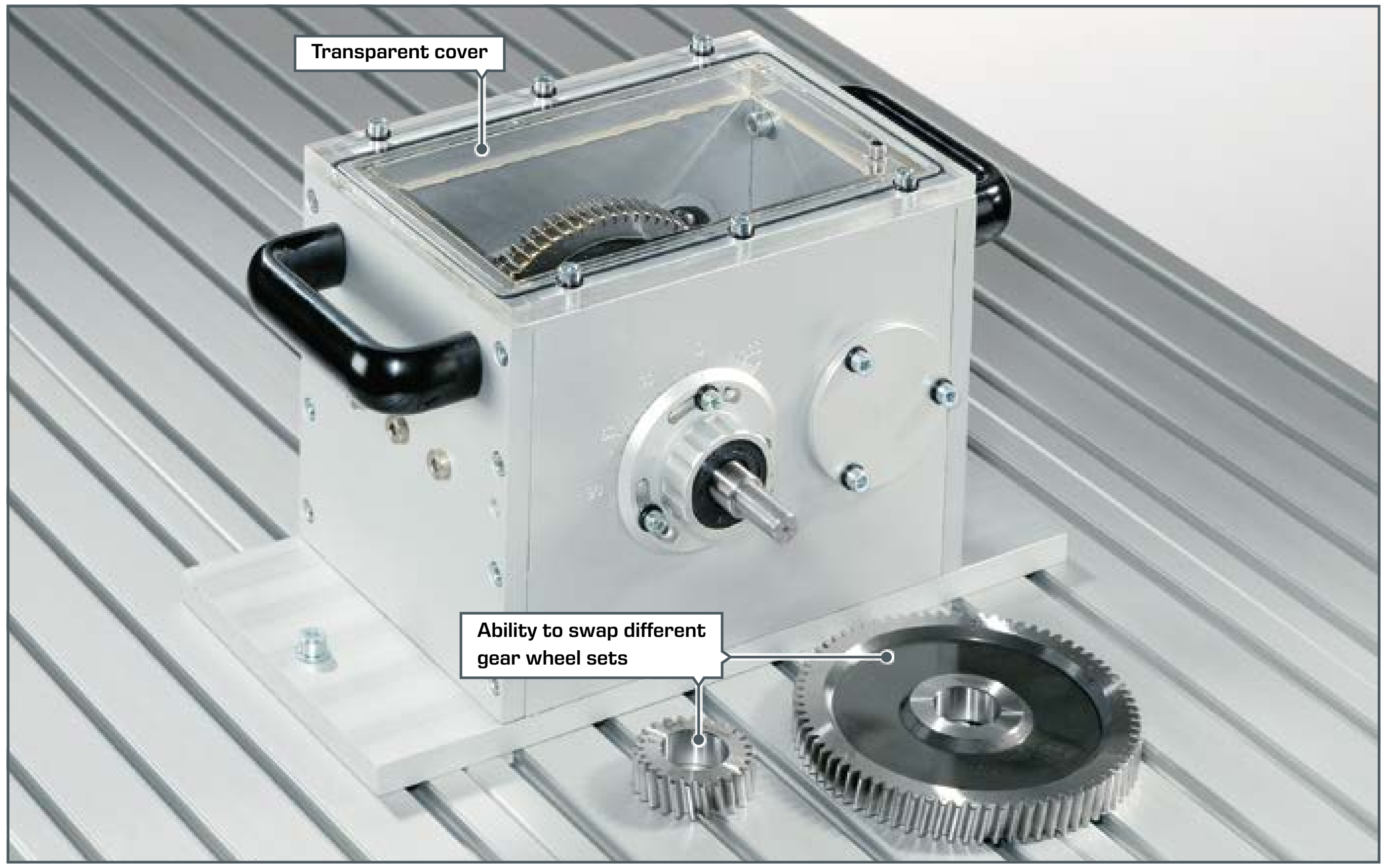
Learning objectives

- change in characteristic vibration behaviour (natural frequency, resonance speed, amplitude and phase of vibrations) due to a crack
- crack identification from the change in vibration spectrum
- detection of cracks in rotating shafts at the protruding shaft end
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser



The opening and closing of a crack during one revolution of the damaged shaft leads to additional frequency components. The second order harmonic in particular increases rapidly compared to the undamaged shaft.

PT 500.15 Damage to gears kit

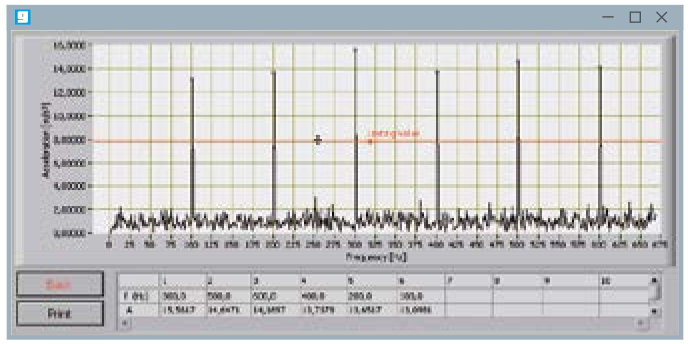


The PT 500.15 accessory set provides you with a variety of gear wheel sets with damaged teeth. Undamaged wheels are also included for comparative measurements. PT 500.15 enables you to conduct targeted experiments on the vibration analysis of toothing damage and on locating damage in gears.

About the product:

Learning objectives

- identification of gear damage from vibration behavior
- influence of gearing type
- localisation of damage
- influence of lubrication
- influence of centre distance and of backlash
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser



Spectrum of a straight-toothed gear at 1800min^{-1} and tooth engagement frequency of 752 Hz

The complete GUNT programme

Engineering mechanics and engineering design

- statics
- strength of materials
- dynamics
- machine dynamics
- engineering design
- materials testing

Mechatronics

- engineering drawing
- cutaway models
- dimensional metrology
- fasteners and machine parts
- manufacturing engineering
- assembly projects
- maintenance
- machinery diagnosis
- automation and process control engineering

Thermal engineering

- fundamentals of thermodynamics
- heat exchangers
- thermal fluid energy machines
- internal combustion engines
- refrigeration
- HVAC

Fluid mechanics

- steady flow
- transient flow
- flow around bodies
- components in piping systems and plant design
- turbomachines
- positive displacement machines
- hydraulic engineering

Process engineering

- mechanical process engineering
- thermal process engineering
- chemical process engineering
- biological process engineering
- water treatment

2E Energy & Environment

Energy

- solar energy
- hydropower and ocean energy
- wind power
- biomass
- geothermal energy
- energy systems
- energy efficiency in buildings

Environment

- water
- air
- soil
- waste

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