Energy:
Renewable Energies
and Energy Efficiency

# Wind Power

# 1.3

2E a division of gunt HAMBURG

## Introduction



## Fundamentals and application engineering for using wind energy

In this section you will find suitable teaching systems for developing an understanding of all the principal aspects of wind energy use. The range provides the chance both to teach the fundamentals of aerodynamics and to deepen understanding of topical application issues from machinery monitoring for modern wind power plants.

## Fundamentals of Wind Energy Engineering



## Application Engineering in Wind Power Plants



Visit our website at:
www.gunt2e.de

## Subject Areas
# Wind Power

### 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 100 m 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.

| Subject Areas | 2E Products |
|---|---|
| **Fundamentals of Wind Energy Engineering** | |
| Investigations on flow around bodies | **HM 170** Open Wind Tunnel<br>**HM 170.05** Drag Body Square Plate<br>**HM 170.09** Drag Body Aerofoil NACA 0015<br>**HM 170.22** Pressure Distribution on an Aerofoil NACA 0015 |
| Generating electricity from wind energy | **ET 220** Energy Conversion in a Wind Power Plant |
| How the real wind supply and electricity demand affect the yield from wind power plants | **ET 220.01** Wind Power Plant |
| **Application Engineering in Wind Power Plants** | |
| Energy transmission in gears | **AT 200** Determination of Gear Efficiency<br>**GL 210** Dynamic Behaviour of Multi-Stage Spur Gears<br>**GL 212** Dynamic Behaviour of Multi-Stage Planetary Gears |
| Machine monitoring | **PT 500** Machinery Diagnostic System, Base Unit<br>**PT 500.11** Crack Detection in Rotating Shaft Kit<br>**PT 500.12** Roller Bearing Faults Kit<br>**PT 500.15** Damage to Gears Kit<br>**PT 500.19** Electromechanical Vibrations Kit |

# 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 conversion

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.

## Machine monitoring

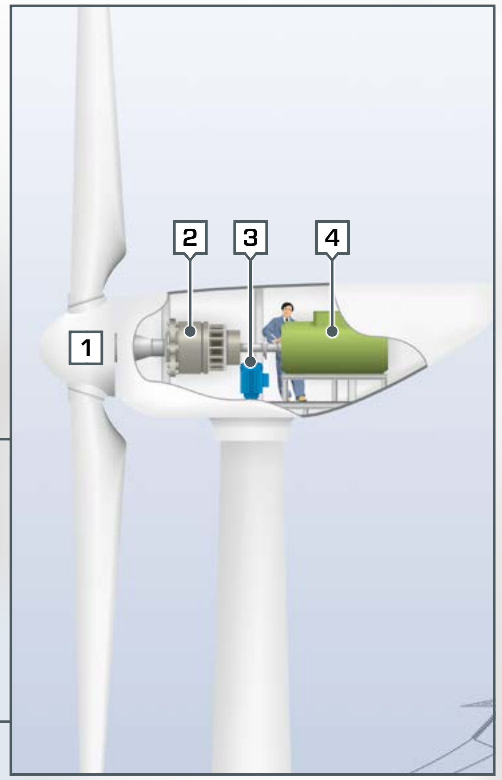
The construction and operation of a wind power plant go hand in hand with high investment costs. Failure of the rotor bearings, gears or rotor shaft leads to financial losses.

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:

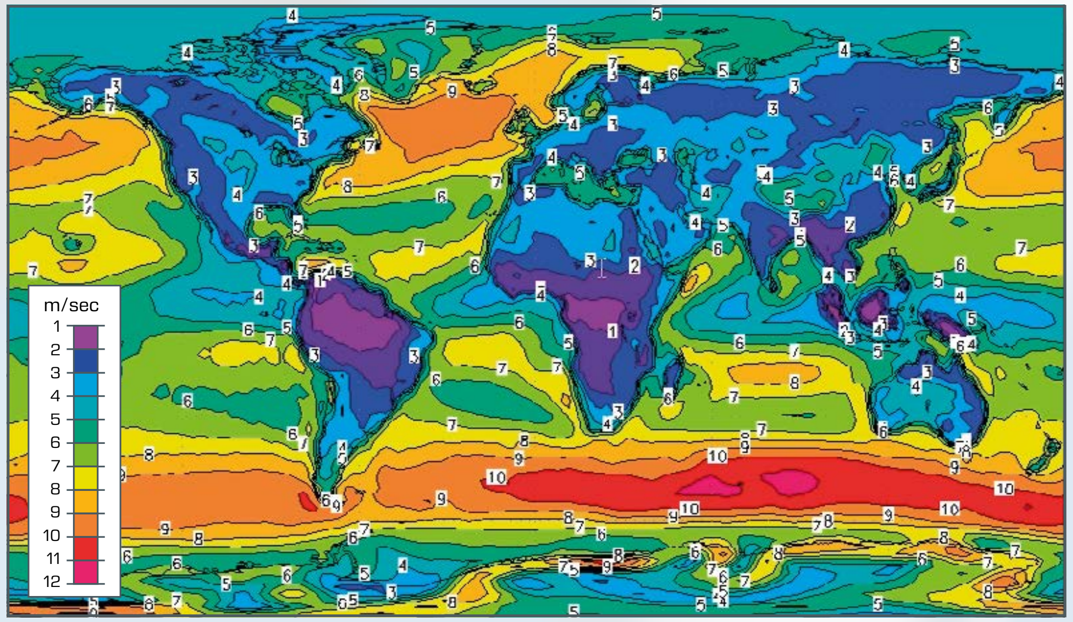
- functional principle and interaction of the individual components
- installation and operational monitoring




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 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.

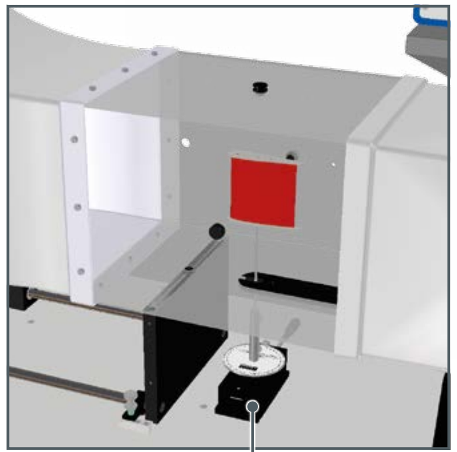
The HM 170 wind tunnel can be used to conduct experiments with different profile shapes and drag bodies. As a result it is possible to measure, for example, how the angle of incidence affects the pressure distribution on the profile. Lift and drag forces resulting from this determine the conversion of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

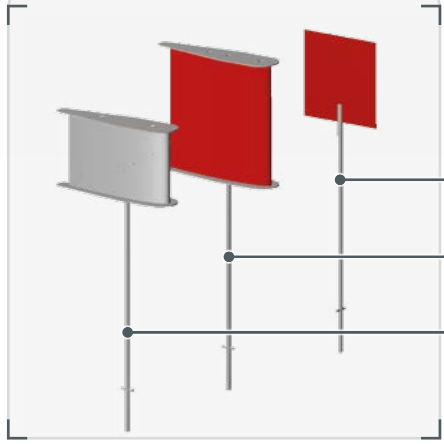
HM 170 is an “Eiffel” type open wind tunnel used to demonstrate and measure the aerodynamic properties of various models. For this purpose, air is drawn in from the environment through a flow straightener and accelerated. The air flows around a model, such as an aerofoil, in a measuring section. Then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

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


### 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

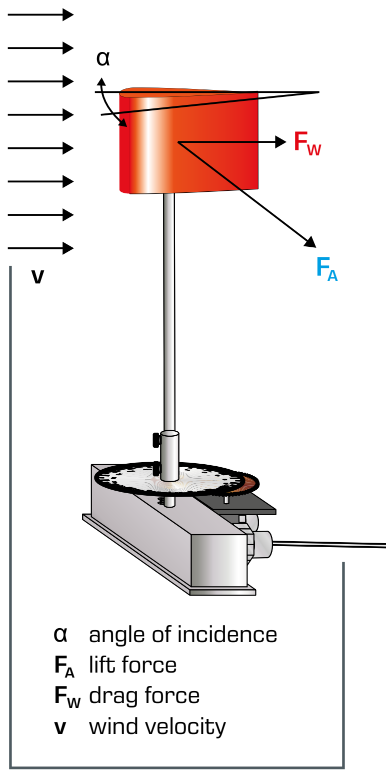
**HM 170.09**
Drag Body Aerofoil NACA 0015

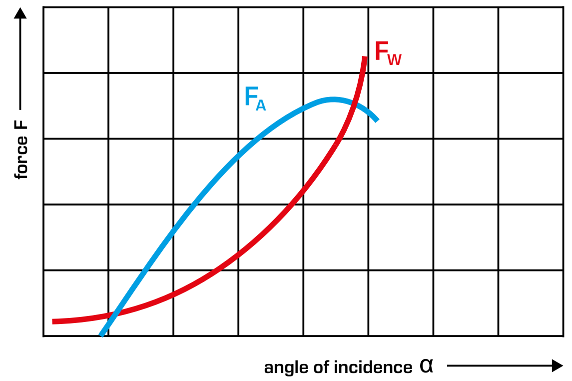
**HM 170.22**
Pressure Distribution on an Aerofoil NACA 0015

Product No.
070.17000
More details and technical data:
gunt.de/static/s3399_1.php

# HM 170 Open Wind Tunnel
## with Accessories

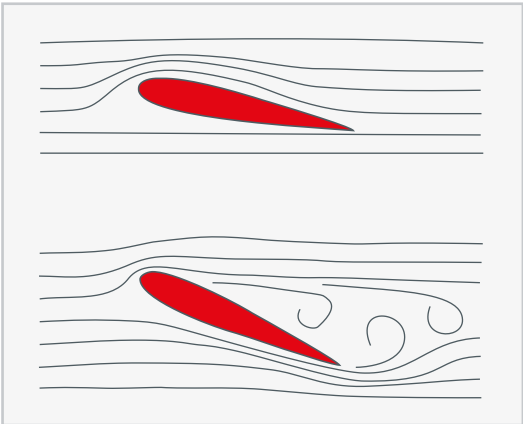
### HM 170.09
Drag Body Aerofoil NACA 0015




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.



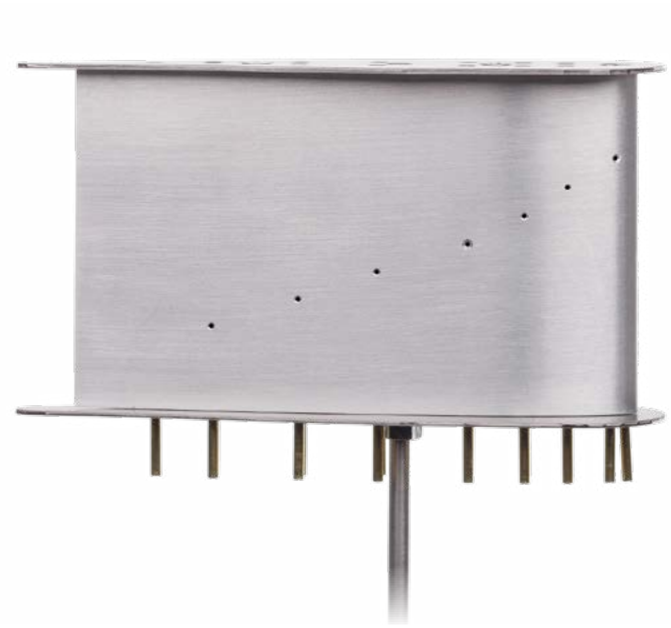
**"Pitch" and "stall" determine the operating behaviour of the wind power plant.**

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.

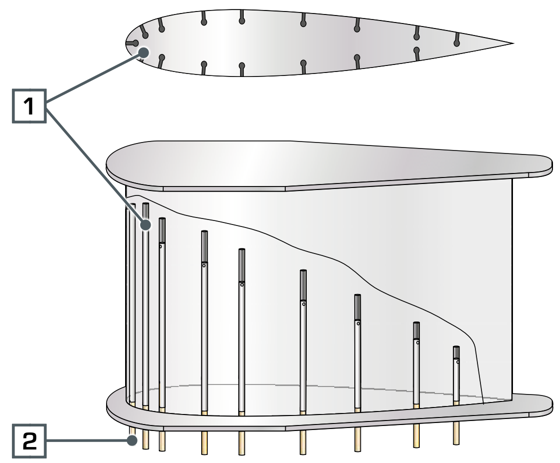
Product No.
070.17009
More details and technical data:
gunt.de/static/s3892_1.php

### HM 170.22
Pressure Distribution on an Aerofoil NACA 0015

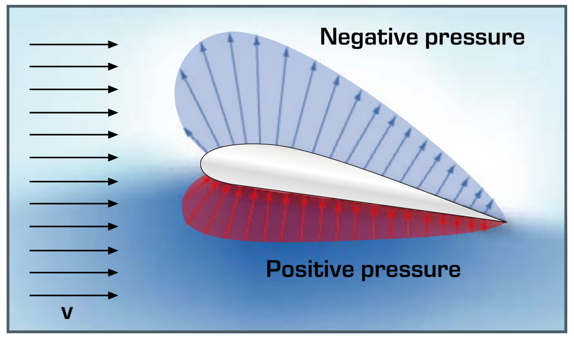


Measurement of the pressure distribution around an aerofoil profile under surrounding flow teaches students fundamental knowledge about the occurrence of lift force.

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




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.



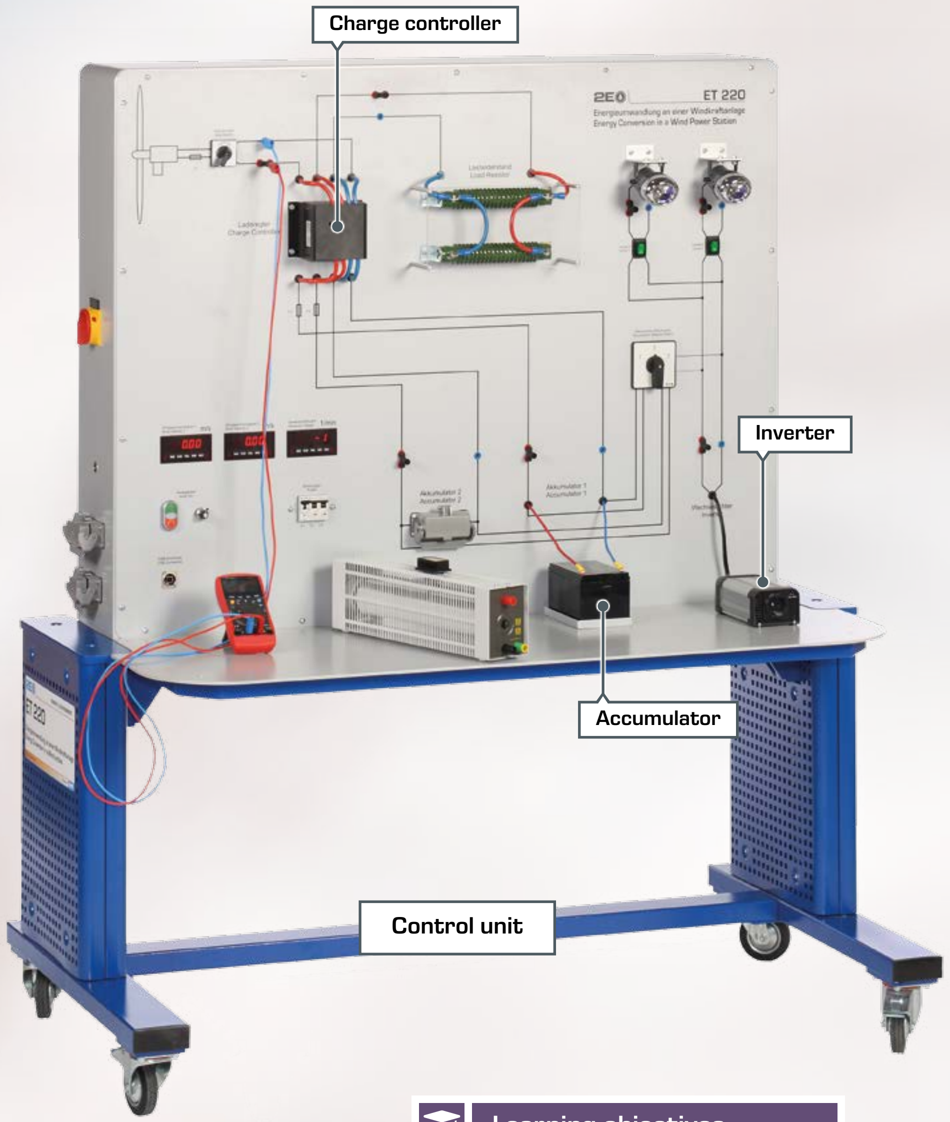

In order for lift to occur on a body under surrounding flow, there must be positive pressure on the underside of the body and negative pressure on the upper side.

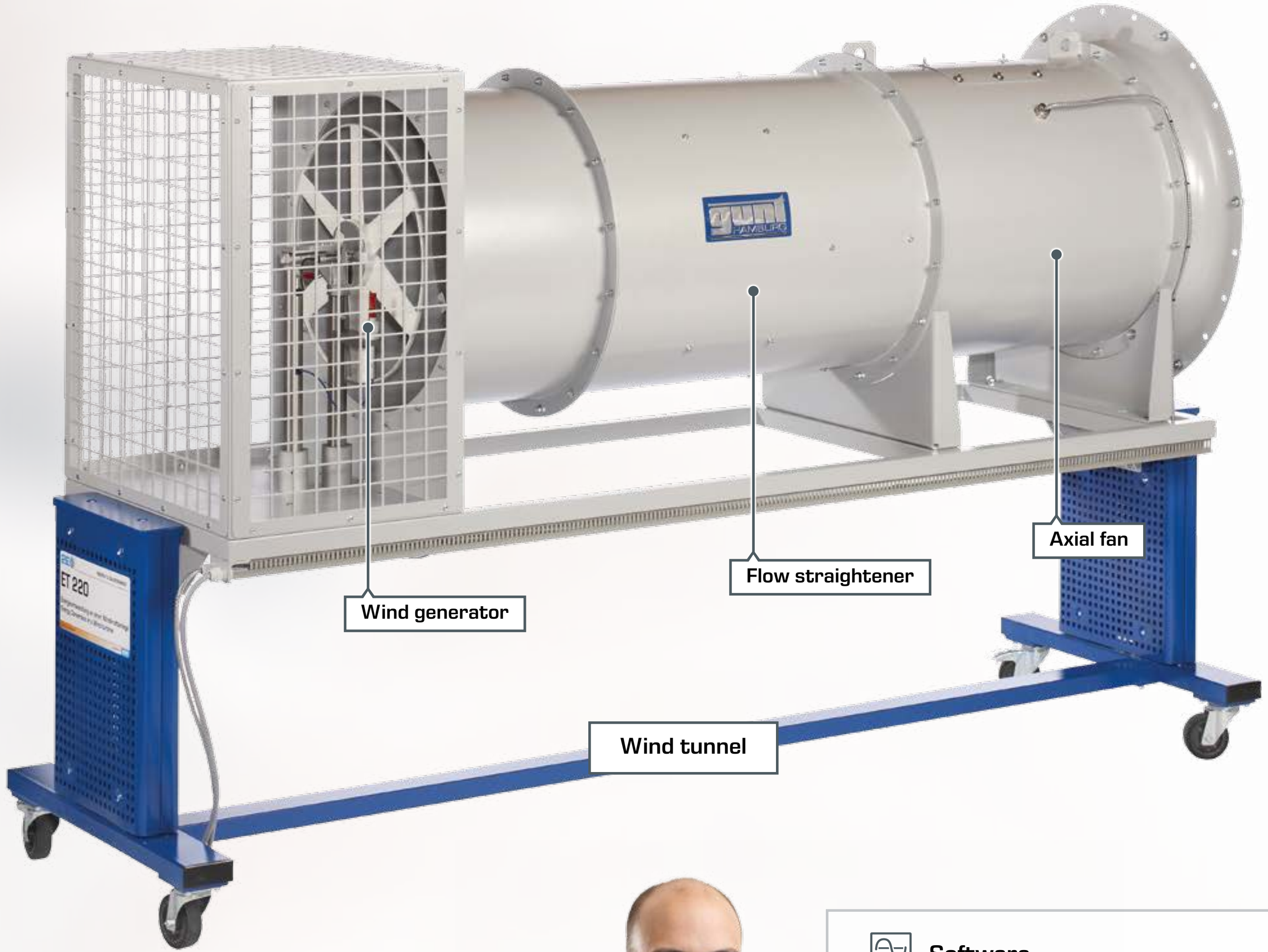
Product No.
070.17022
More details and technical data:
gunt.de/static/s3894_1.php

# 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.

The wind tunnel of ET 220 or the ET 220.01 Wind Power Plant can be connected to the control unit of ET 220 for installation outdoors.




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.

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.

## Learning objectives

- conversion of kinetic wind energy into electrical energy
- function and design of an 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

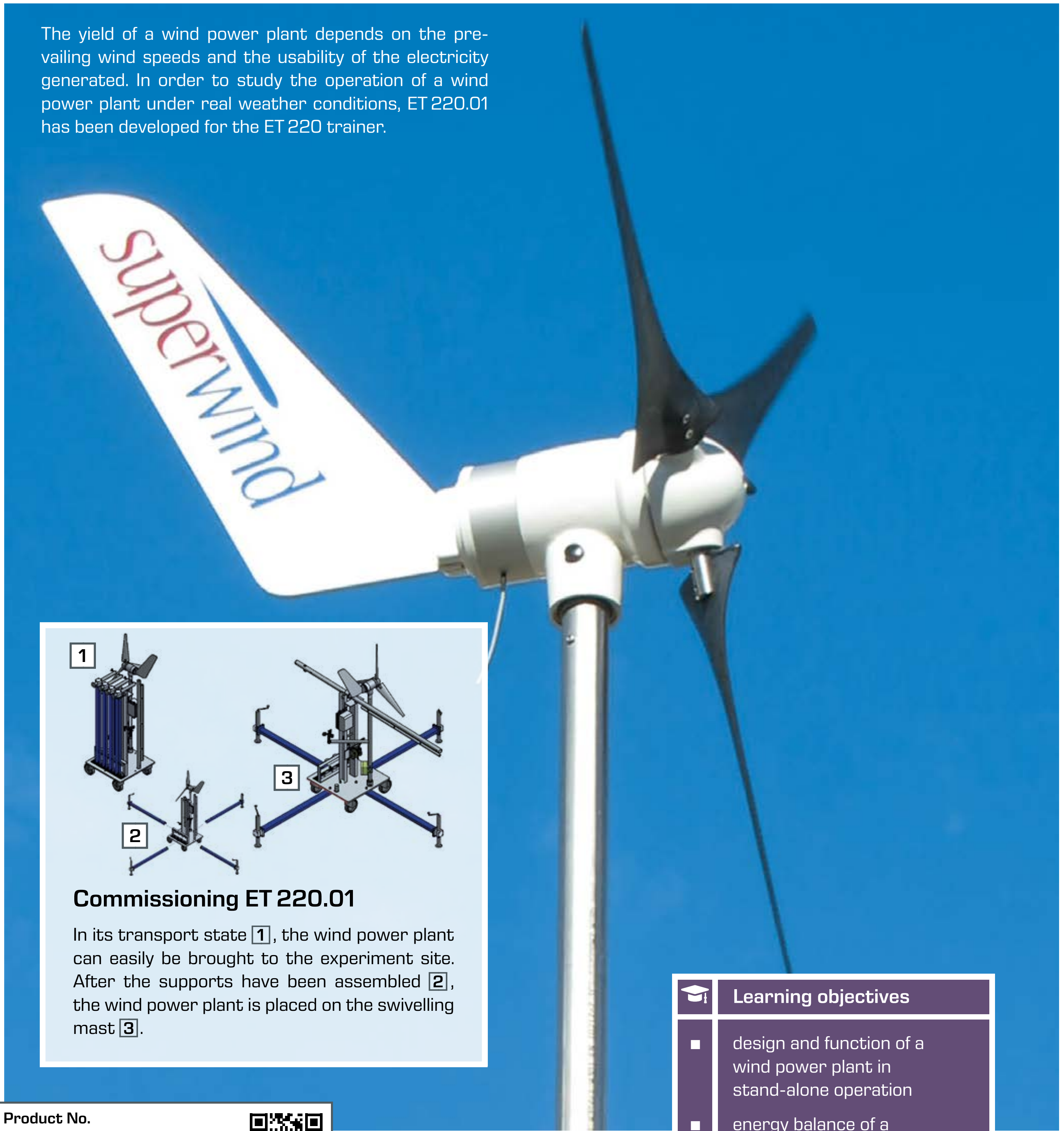
## Software

The software for ET 220 enables the acquisition, representation and analysis of the measured values. Consequently, 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.

**Product No.**
**061.22000**
More details and technical data:
gunt.de/static/s5226_1.php

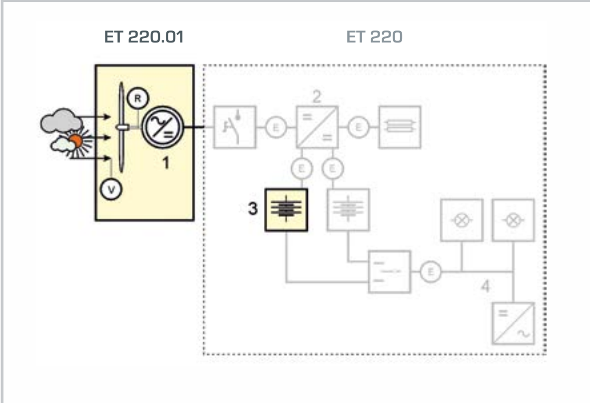
# ET 220.01 Wind Power Plant

The yield of a wind power plant depends on the prevailing wind speeds and the usability of the electricity generated. In order to study the operation of a wind power plant under real weather conditions, ET 220.01 has been developed for the ET 220 trainer.

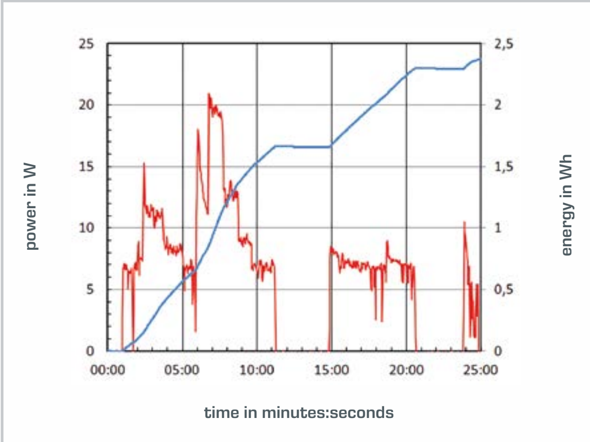



## Commissioning ET 220.01

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].




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).


The hub height of the rotor is approximately 5 m with the mast erected.

You can easily swivel the mast to the desired position in just a few simple steps.

### Learning objectives

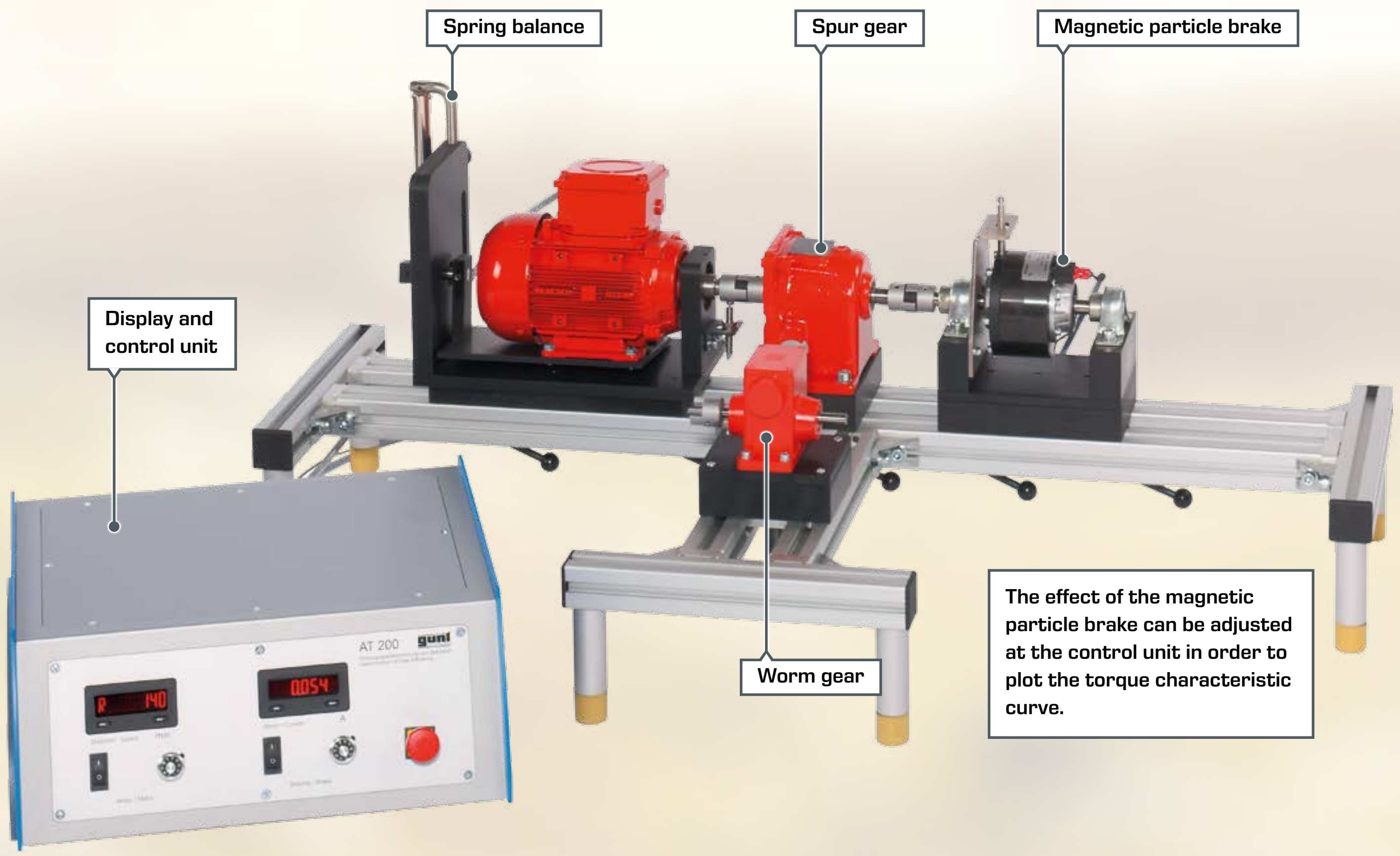
- design and function of a wind power plant in stand-alone operation
- energy balance of a wind power plant under real wind conditions

Product No.
061.22001
More details and technical data:
gunt.de/static/s5247_1.php

A video showing the setup and commissioning of **ET 220.01** is available at: www.gunt2e.de

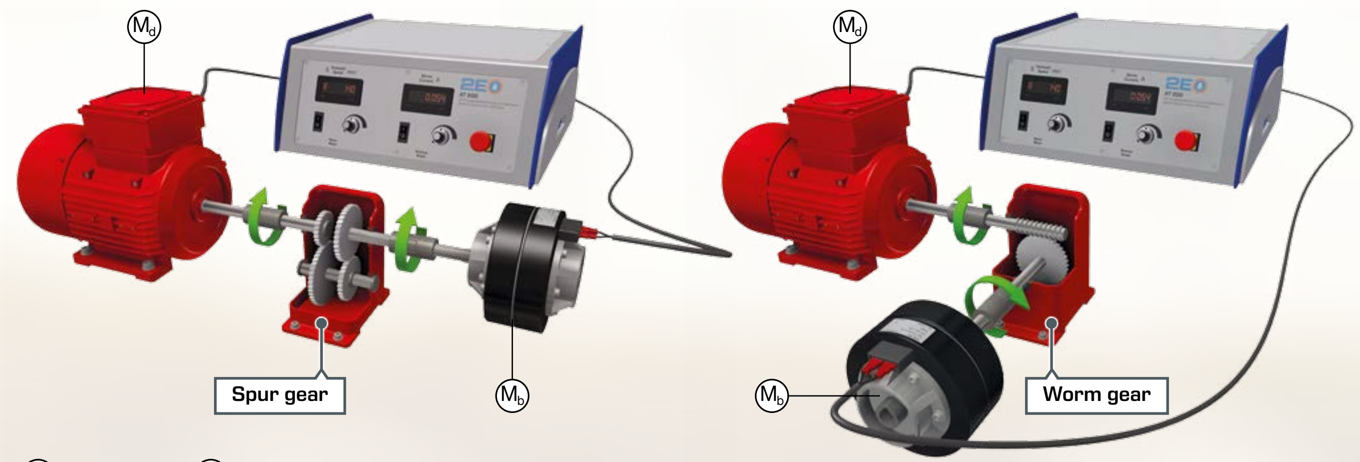
# AT 200 Determination of Gear Efficiency

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.




The effect of the magnetic particle brake can be adjusted at the control unit in order to plot the torque characteristic curve.

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.

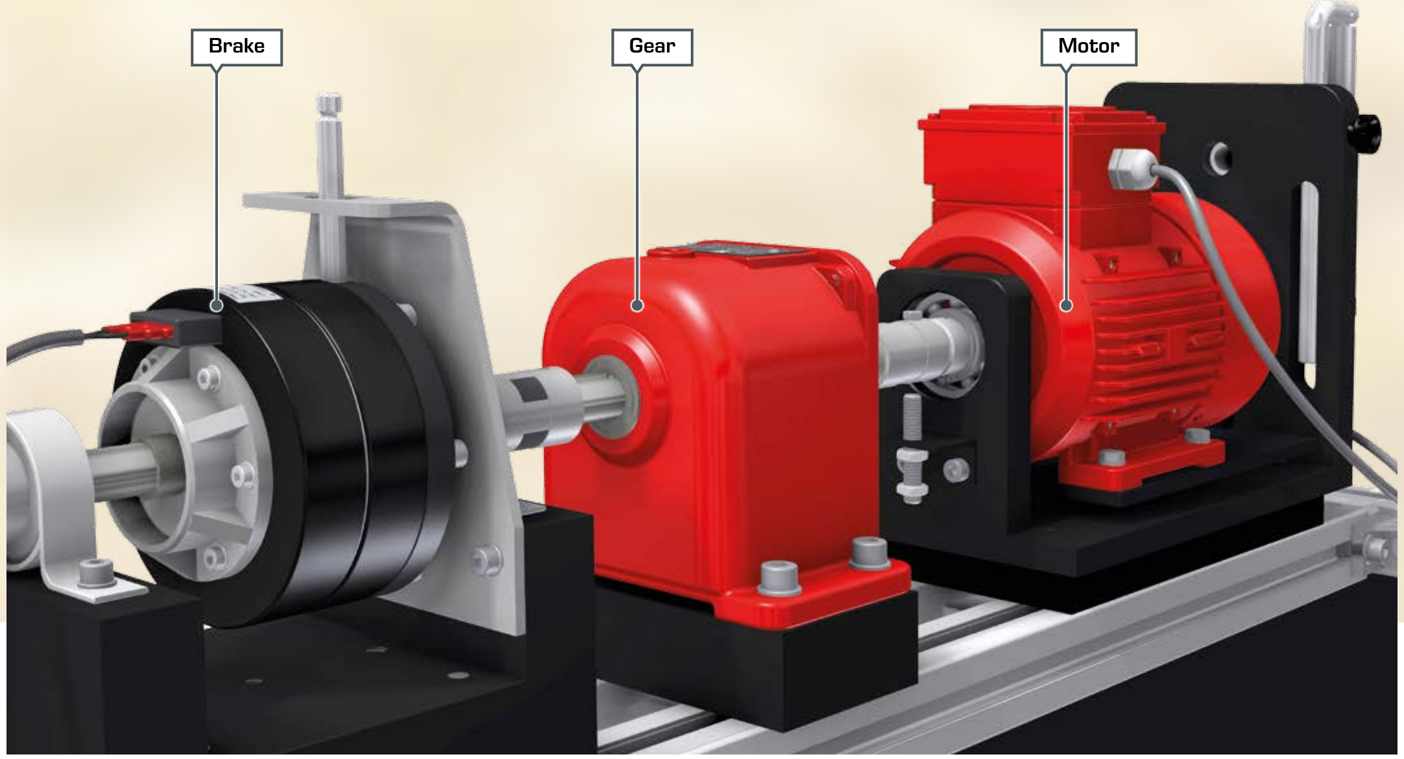



$M_g$ drive torque $M_b$ braking torque

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.

## 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

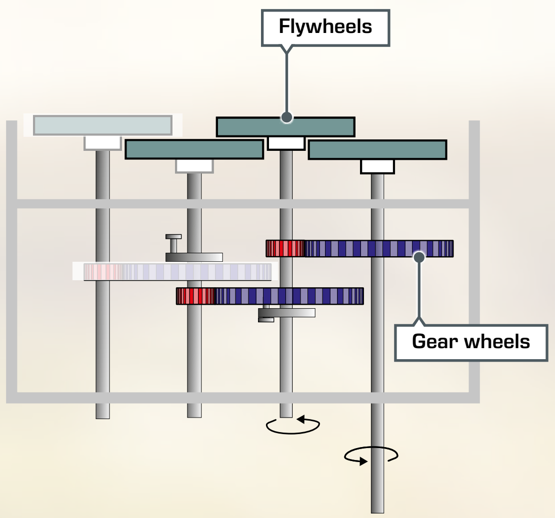



Product No.
031.20000
More details and technical data:
gunt.de/static/s3639_1.php

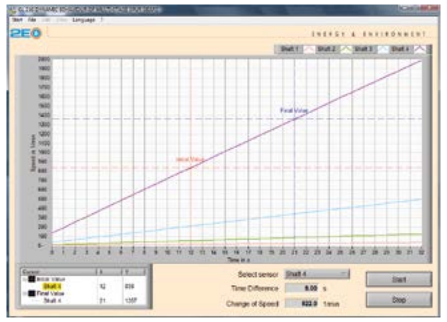
# GL 210 Dynamic Behaviour of Multi-Stage Spur Gears

# GL 212 Dynamic Behaviour of Multi-Stage Planetary Gears

With our GL 210 and GL 212 trainers, you can clearly demonstrate the structure and function of commonly used types of gears in wind power plants and investigate their rotational dynamics.







### Software

For GL 210 and GL 212, the speeds of the various rotational axes are recorded via the measurement data acquisition using the GUNT software. The speed-time diagrams can be used to read off the acceleration for various gear configurations.

### Learning objectives

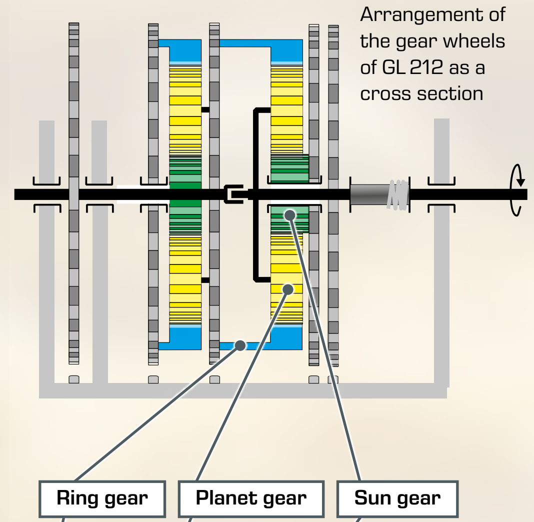
The following variables have to be determined in order to study the dynamics of multi-stage gears:

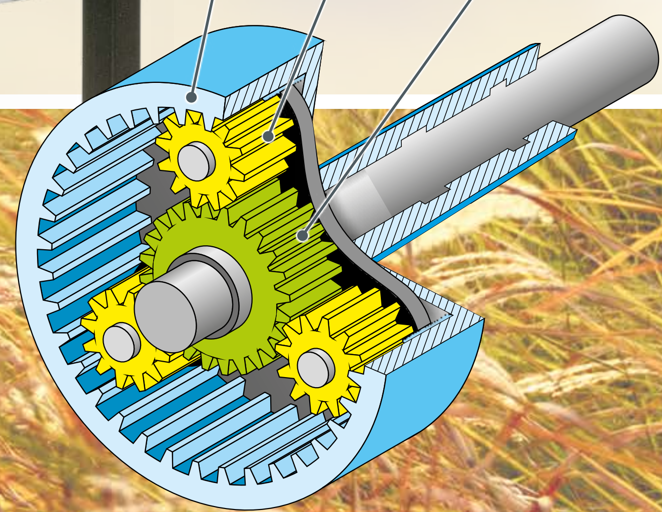
- angular acceleration
- mass moment of inertia
- friction
- gear efficiency

Product No.
030.21000
More details and technical data:
gunt.de/static/s3640_1.php

In large wind power plants, a combination of spur gears and planetary gears is often used.

GL 212 enables experiments on a two-stage planetary gear. Using adjustable locking mechanisms, a total of four different transmission ratios can be created.

The planetary gear is a special type of gear mechanism, in which multiple planet gears revolve around a centrally arranged sun gear.

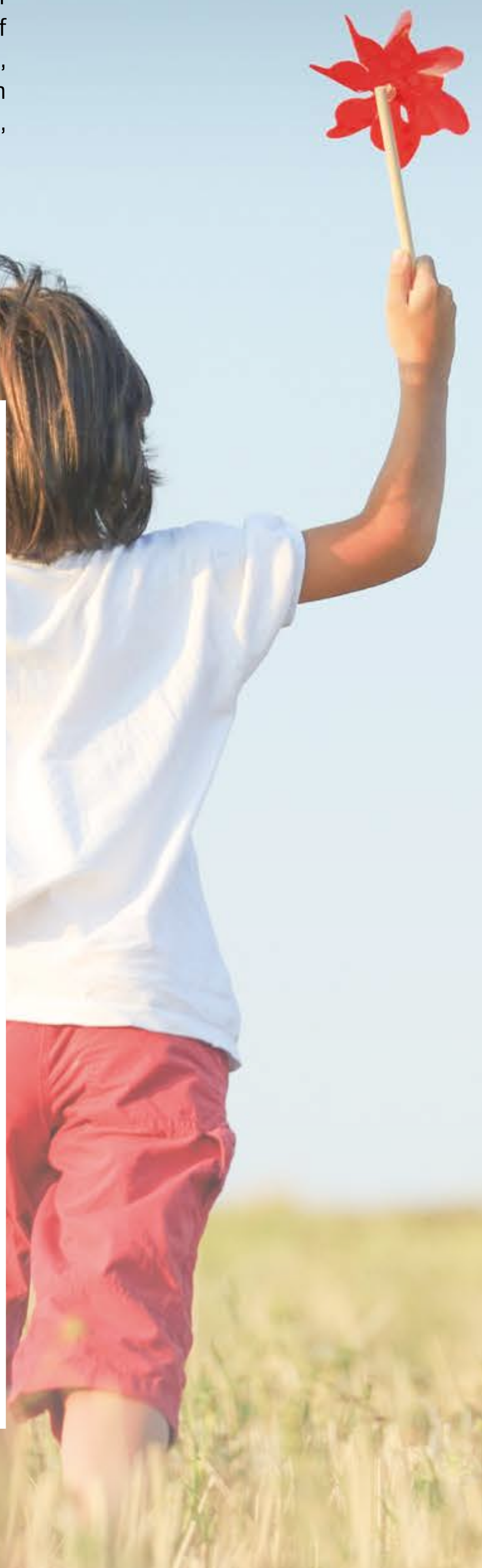
Product No.
030.21200
More details and technical data:
gunt.de/static/s3402_1.php

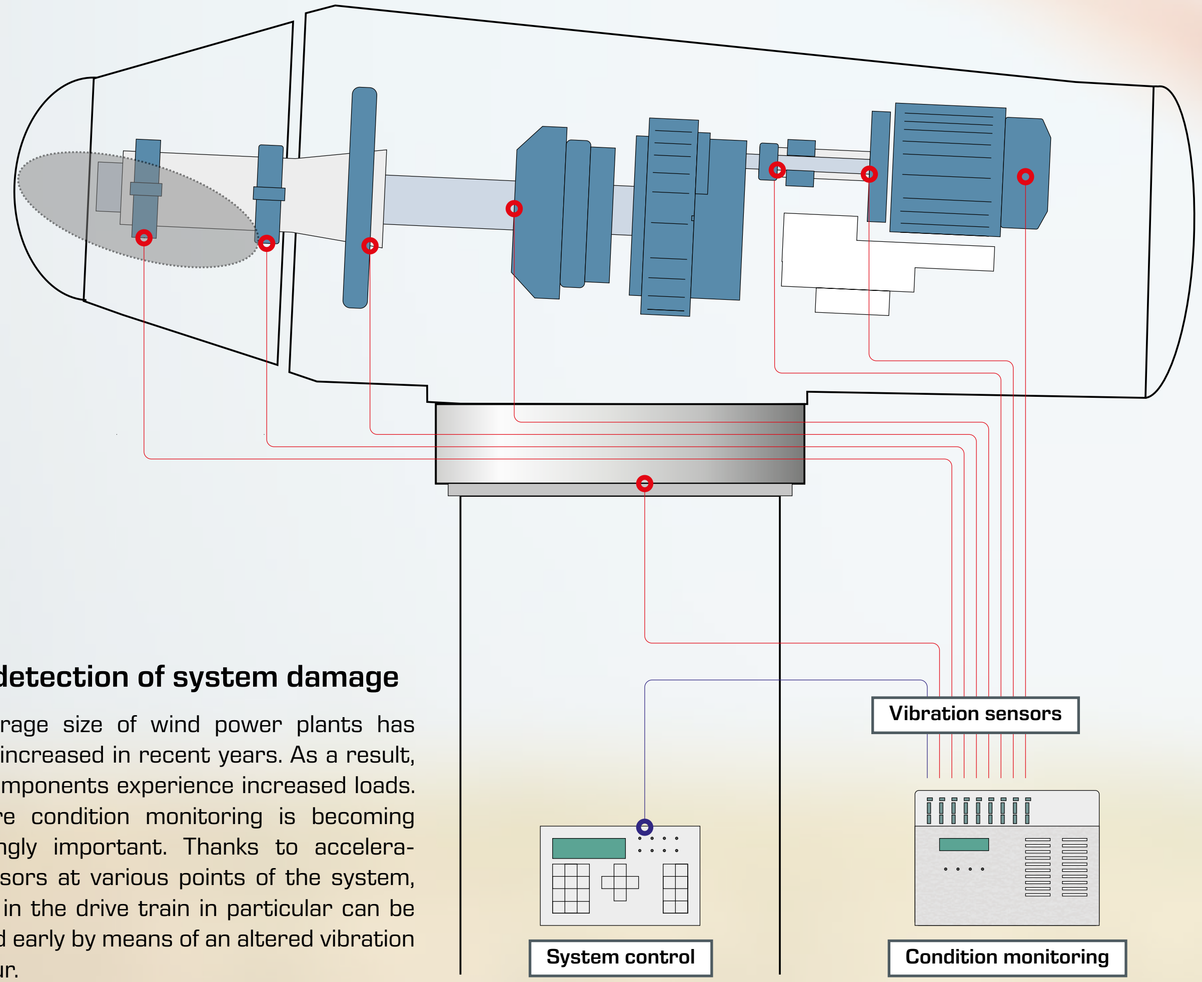
## Basic Knowledge

# Condition Monitoring in Wind Power Plants

In order to reduce technical and economic risks, systems for monitoring the status of the equipment (CMS, **C**ondition **M**onitoring **S**ystems) 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

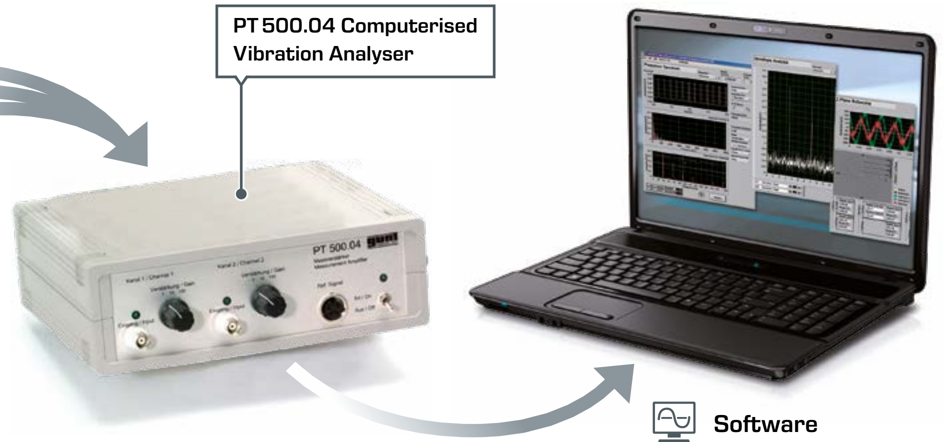
Condition monitoring includes vibration measurements on various system components in a suitable frequency range. By analysing the structure-borne sound, it is possible to draw conclusions about the condition of the components. Other important measured variables for example are speed and the temperature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



PT 500.04 Computerised Vibration Analyser

Software

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


**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.

## 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

Product No.
052.50000
More details and technical data:
gunt.de/static/s3680_1.php

## 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

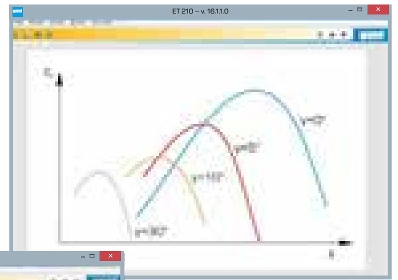
The base unit contains a vibration-damped fixing plate, a speed-controlled drive motor with tachometer, a shaft with two mass discs and two bearing units, a coupling and balancing weight. Almost any topic of machinery diagnostics can be covered thanks to a wide range of accessories.

# Wind power

## ET 210
### Fundamentals of wind power plants


Wind power plant with rotor blade adjustment and yaw angle adjustment

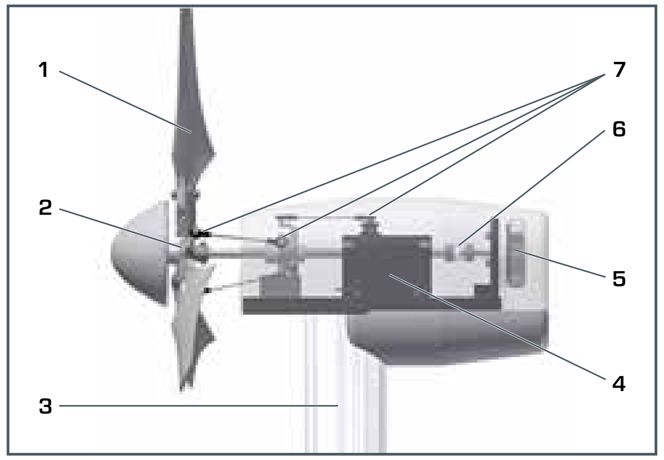
- conversion of kinetic energy into electrical energy
- power adjustment by means of speed adjustment
- power adjustment by means of rotor blade adjustment
- behaviour in the case of oblique flow
- comparison of different rotor blade shapes
- recording of characteristic diagrams
  - determination of the power coefficient as a function of the tip-speed ratio and rotor blade adjustment angle
  - determination of the power coefficient as a function of the tip-speed ratio and yaw angle



Analysis of measurement data with GUNT software: Power coefficient vs. tip speed ratio at different rotor blade pitch angles

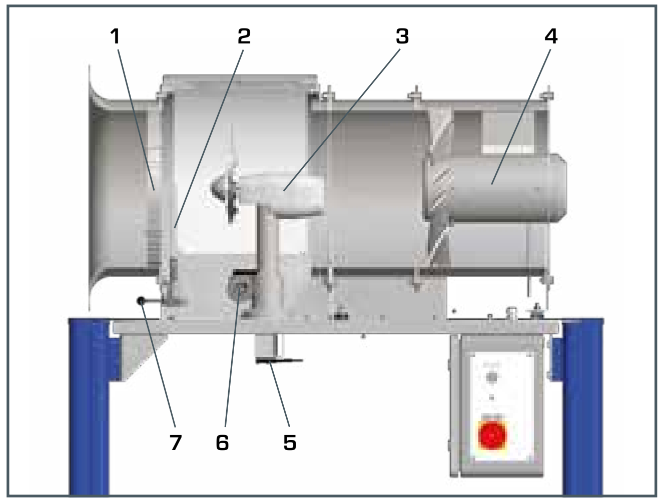
Replaceable rotor blades:
Measurement on different blade profiles (production by means of 3D printing)

GUNT software for device control and measurement data acquisition via PC




Setup of the wind power plant

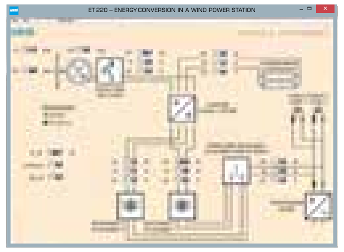
**1** rotor blade, **2** hub, **3** tower, **4** servomotor, **5** generator, **6** coupling, **7** rotor blade adjustment




**1** flow straightener, **2** wind velocity sensor, **3** wind power plant, **4** fan, **5** yaw angle sensor, **6** handwheel, **7** lever

## ET 220
### Energy conversion in a wind power plant


- conversion of kinetic wind energy into electrical energy
- function and design of an 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



## ET 220.01
### Wind power plant

Connection to ET 220 or ET 200.10; outdoor installation allows practically relevant investigations

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

## Energy

### Geothermal energy: shallow geothermal energy

**ET 101**
**Simple compression refrigeration circuit**

Demonstration of a heat pump: cooling and heating of the heat exchangers directly tangible

Order No.: 061.10100

**ET 262**
**Geothermal probe with heat pipe principle**

Transparent components allow observing how the state of the heat transfer medium changes

Order No.: 061.26200

**ET 264**
**Geothermal energy with two-well system**

Use of geothermal energy in an open system without thermal repercussion

Order No.: 061.26400

**HL 320.01**
**Heat pump**

Heat pump for operation with different sources

Order No.: 065.32001

**HL 320.07**
**Underfloor heating / geothermal energy absorber**

Can be used as heat sink or heat source

Order No.: 065.32007

**HL 320.08**
**Fan heater / air heat exchanger**

Can be used as heat sink or heat source

Order No.: 065.32008

## Energy

### Geothermal energy: deep geothermal energy

**ET 851**
**Axial steam turbine**

Single-stage steam turbine with power output measurement; steam supply from ET 850

Order No.: 061.85100

**ET 850**
**Steam generator**

Laboratory scale gas-fired steam generator for wet or superheated steam; integrated condenser

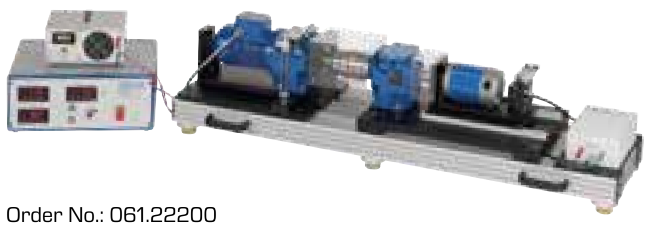
Order No.: 061.85000

## Energy

### Wind power: fundamentals of wind energy technology

**ET 222**
**Wind power drive train**

Experiments on conversion of rotational energy into electrical energy



Order No.: 061.22200

**ET 210**
**Fundamentals of wind power plants**

Wind power plant with rotor blade adjustment and yaw angle adjustment

Order No.: 061.21000

## Energy

### Wind power: fundamentals of wind energy technology

**ET 220**
**Energy conversion in a wind power plant**

Conversion of kinetic wind energy into electrical energy

Order No.: 061.22000

**ET 220.01**
**Wind power plant**

Connection to ET 220 or ET 220.10; outdoor installation allows practically relevant investigations

Order No.: 061.22001

**ET 220.10**
**Control unit for wind power plant ET 220.01**

Use of wind energy in stand-alone operation under real weather conditions

Order No.: 061.22010

**HM 170**
**Open wind tunnel**

Experiments from the field of aerodynamics and fluid mechanics with an "Eiffel" type wind tunnel

Order No.: 070.17000

**HM 170.22**
**Pressure distribution on an aerofoil NACA 0015**

Experiments with different aerofoil angles of attack

Order No.: 070.17022

**HM 170.05**
**Drag body square plate**

Order No.: 070.17005

**HM 170.09**
**Drag body aerofoil NACA 0015**

Order No.: 070.17009

## Energy

### Wind power: application technology for wind power plants

**GL 210**
**Dynamic behaviour of multistage spur gears**

Investigation of the dynamics of rotation of one-, two- and three-stage spur gear units

Order No.: 030.21000

**GL 212**
**Dynamic behaviour of multistage planetary gears**

Investigation of rotational dynamics of a two-stage epicyclic gear with three planetary gears each

Order No.: 030.21200

**PT 500.11**
**Crack detection in rotating shaft kit**

Vibrational behaviour of a shaft with a radial crack

Order No.: 052.50011

**PT 500.12**
**Roller bearing faults kit**

Assessment of bearing condition by vibration analysis

Order No.: 052.50012

**PT 500.15**
**Damage to gears kit**

Vibration analysis of gearing damage

Order No.: 052.50015

**PT 500.19**
**Electromechanical vibrations kit**

Investigation of vibrational behaviour of an electric motor

Order No.: 052.50019

**PT 500**
**Machinery diagnostic system, base unit**

Base unit for setting up wide ranging experiments in machinery diagnostics using modular accessory sets

Order No.: 052.50000

**AT 200**
**Determination of gear efficiency**

Test system for determining mechanical drive and braking efficiency for spur and worm gears

Order No.: 031.20000