gunt
HAMBURG

PT 500
Machinery diagnostic system

**Training in machine condition monitoring:
generating, measuring and evaluating mechanical vibrations**

**The system for an easy introduction to a demanding topic**

What is machine diagnosis?

The purpose of modern-day machine condition monitoring systems (CMS) is to carry out needs-based maintenance or repairs and thus to minimise the repair and other servicing downtimes of a machine. This increases the overall equipment effectiveness (OEE) and optimises the cost structure.

The aim ist to detect damage as it occurs, allowing scheduled repairs or maintenance to be carried out.

The mechanical condition of a machine or of machine components can be accurately diagnosed from the nature and extend of vibrations they generate. Accordingly, vibrations are measured, recorded and evaluated using sensors and recording equipment.

Convenient PC software makes it easy to display the measured values clearly.

Industrial plant

Vibrational analyser

Evaluation of vibrational signals

A (t)

t
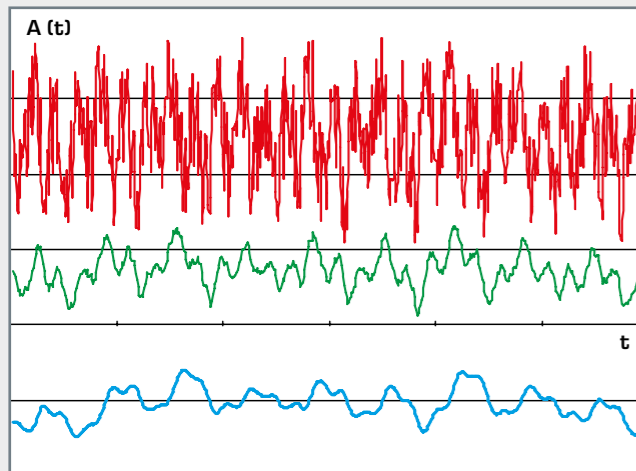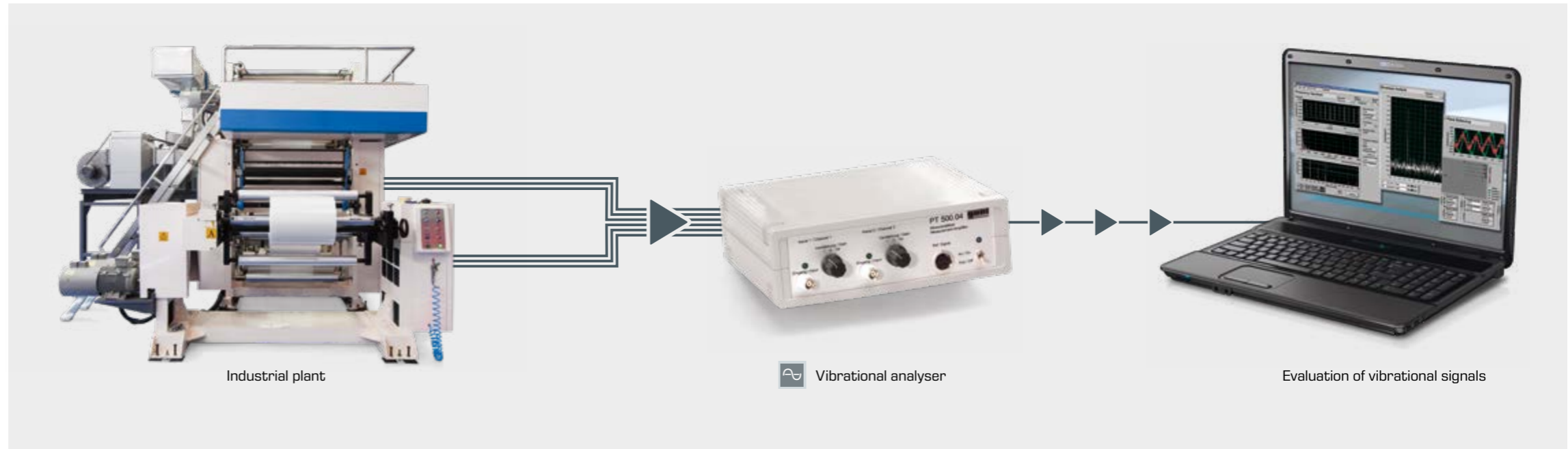
Typical vibration signals in the time domain

— acceleration
— velocity
— displacement

The internal forces and energies in the machine are of interest for fault identification and diagnosis. These variables cannot be measured directly, but their effects – vibrations – can.

Vibration measurement and analysis is therefore an attempt to obtain a picture of these forces. This can be used to identify their structure, the causes of them and their behaviour over time. Vibrations are normally frequency mixtures that result from superimposition of several vibrations. Some of these vibrations are part of the machine's normal operation, while others are intensified, or actually generated by defects. With sufficient experience, the condition of the machine can be assessed and a defect on the machine identified.

When it comes to machine condition monitoring, it is important to differentiate between parameter monitoring and frequency analysis.

Parameter monitoring
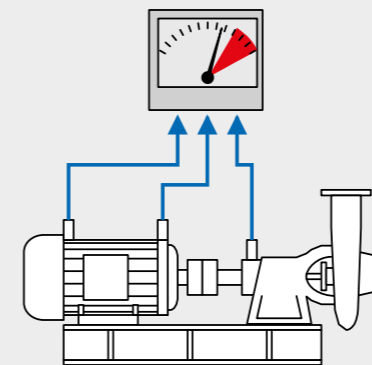
Parameter monitoring involves measurement of the vibration amplitude and comparison with a predefined limit value. Parameter monitoring can be carried out continuously and automatically. It is easy to implement and requires only little specialist knowledge. On simple standard equipment, parameter monitoring is often sufficient.

Frequency analysis
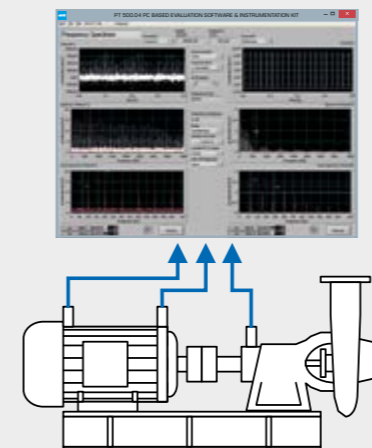
The use of **analysis in the frequency domain** is much more complex but also more powerful. This analysis enables the nature of a defect to be identified, which allows targeted repair measures to be initiated. However, performing frequency analysis requires a good understanding of the operating mechanisms and sufficient experience. Frequency analysis is mainly used as a supplementary method in conjunction with parameter monitoring.

Teaching concept and learning content

The PT 500 system provides you with a flexible and modular learning platform offering an introduction to the complex and demanding subject of machine diagnosis. The target group is students in mechanical engineering/machine dynamics, but it also includes other professional people as part of on-the-job training and development in maintenance and servicing.

The close links between practical work on the experimental unit and theoretical/analytical aspects of diagnosis foster integrated learning.

Successful work with the PT 500 requires knowledge of the basic principles from the fields of mathematics, machine dynamics, mechanical vibrations and measurement technology.

In contrast to the widespread practice of solely learning on-the-job, the effects to be investigated can be represented in isolation and are reproducible. This makes it easier to provide a step-by-step introduction to the topic and targeted development of relevant experience in diagnosis.

Training using the PT 500 thus supplies a basis for effective and successful work in practical industrial situations.

When used in conjunction with on-the-job training and development, the intensive practice that is possible with the PT 500 significantly speeds up learning in the area of machine diagnosis.

Learning content

Mechanical vibrations	Causes, formation mechanisms, imbalance, Laval shaft, resonance, damping, impact
Vibration measuring technology	Measurement sensor, measuring amplifier, representation, oscilloscope, speed measurement
Vibration analysis	Acceleration, vibration speed, vibration displacement amplitude, parameters, representation in time and frequency domains, spectrum, FFT, orders, tracking analysis, envelope analysis, orbit, path curve
Machine diagnosis	Bearing and shaft vibrations, permissible vibration amplitude, roller bearing defects, electromagnetic vibrations, imbalance vibrations and balancing, gear defects, vibrations on belt drives, cavitation in pumps, blade vibrations, vibrations and impacts in crank drives, speed-dependent vibrations

In addition, practical skills and experience in handling and assembling machine components such as bearings, shafts and couplings are gained. The construction of mechanical machines can also be studied.

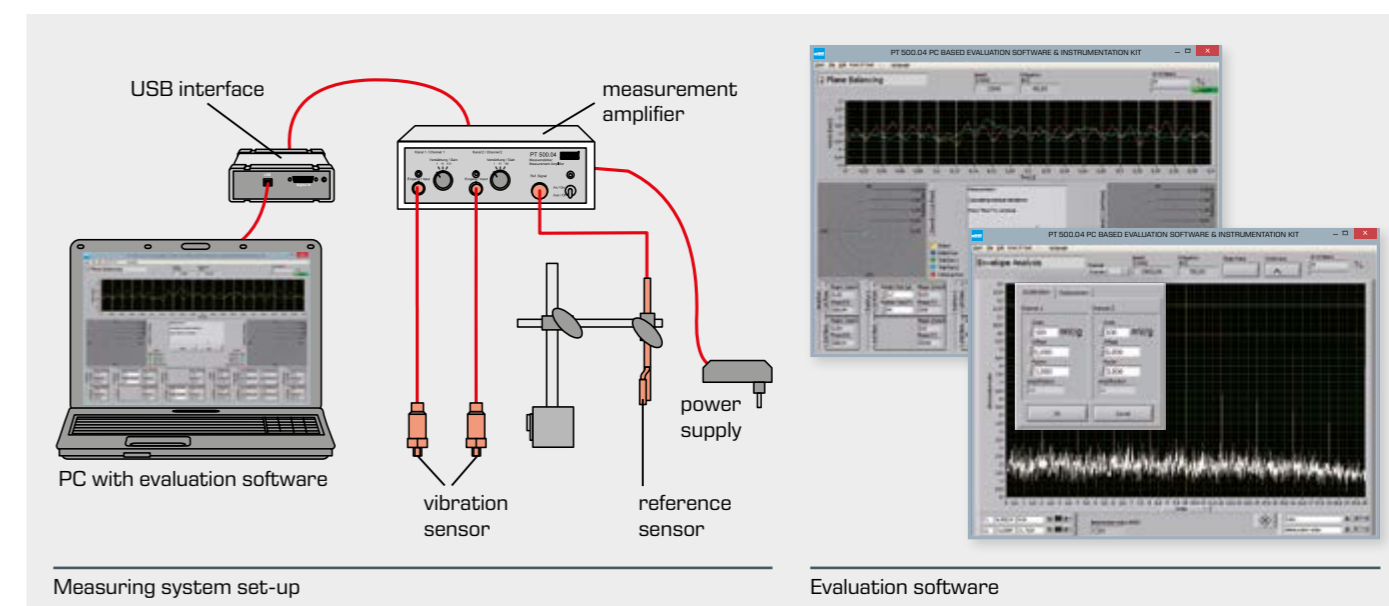Questions provide value experience for subsequent practical work in industry:

■ which measurement sensor do I use?

■ where can I expect a usable measuring signal?

■ how do I effectively mask interference signals?

Vibration analyser PT 500.04

The core of our machine diagnosis system is the PT 500.04 vibration analyser, which consists of the following components:

■ measurement amplifier

■ USB interface for data acquisition

■ analysis software

■ vibration sensor

■ reference sensor

USB interface · measurement amplifier · PC with evaluation software · vibration sensor · reference sensor · power supply

Measuring system set-up

Evaluation software

The measurement amplifier supplies the acceleration and displacement sensors with power and provides adjustable pre-amplification. Output sockets also allow the vibration signal to be output as a voltage signal. This allows you to integrate your own measuring instruments, e.g. an oscilloscope, into the measurement set-up.

The measurement amplifier also provides the opportunity to connect the displacement sensors PT 500.41, available as an accessory.

The analysis software runs on any standard PC under Windows. The USB interface provides an easy connection to the PC or laptop.

ICP acceleration sensors are used as vibration sensors. The advantage of ICP sensors is that they have an integral amplifier and thus guarantee that processing of the measured signal is insensitive to interference. The industrial quality sensors used are robust, have stable connecting cables and plugs and are therefore ideally suited for use in harsh training situations.

The reference sensor is used for speed measurement and phase information. A laser sensor with a large scanning range is used here, which delivers a reliable signal even in poor lighting conditions and with difficult access to the rotating shaft. A self-adhesive reflective strip acts as the reference mark.

# Example: identification of bearing defects

Bearing defects

Each rolling bearing has characteristic damage frequencies for the inner race, rolling bearing and outer race. These frequencies depend on the speed Ω, the geometric dimensions and the number of rolling elements. Thus, with a known impact frequency the type of damage and the defective bearing can be identified.
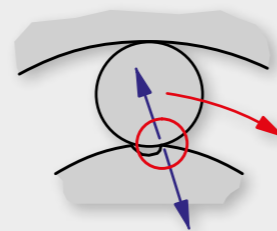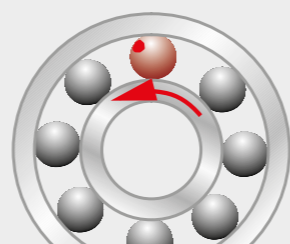
Impact force while running over bearing surface damage
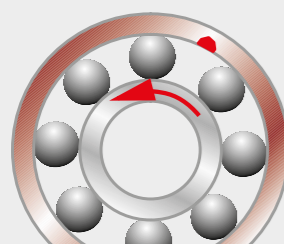
Bearing surface damage to the outer race, frequency 3,58 Ω
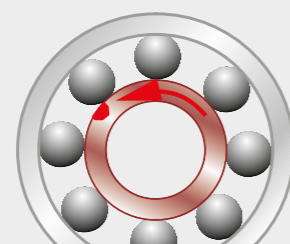
Bearing surface damage to the inner race, frequency 5,42 Ω

A damaged rolling ball element, frequency 4,65 Ω

Envelope analysis process

Envelope analysis is used to identify defects, for example on rolling bearings and gears. The defects generate impacts with very high frequency vibration components. The low frequency impact frequency relevant for diagnosis of the damage is difficult or even impossible to identify in the normal spectrum. Envelope analysis demodulates the high frequency impact signal, thus allowing the impact frequency to be measured.
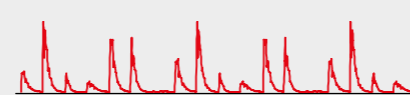
Measurement of the high frequency impact signal and high pass filtration to suppress low frequency interference signals (imbalance, alignment errors).
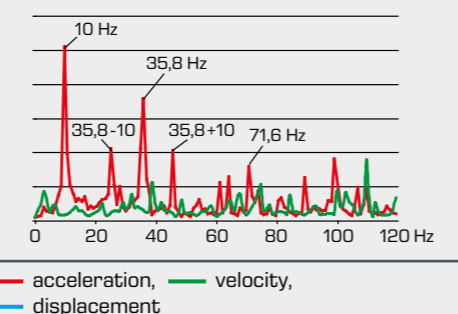
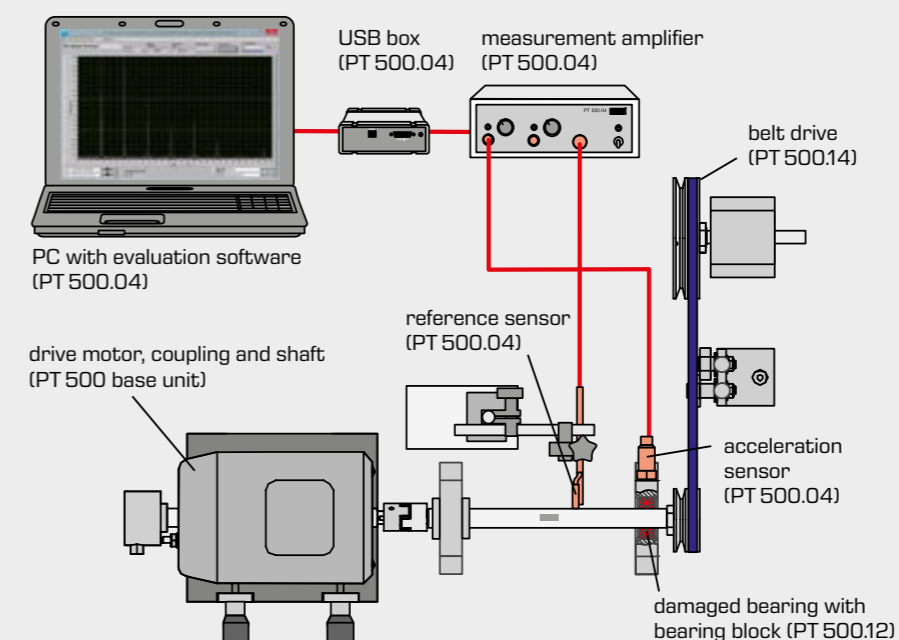Rectification of high frequency signal

Extracting the envelope of the rectified signal using a low pass filter

Performance of FFT to obtain the spectrum of the envelope. The speed (10 Hz) and the impact frequency (35,8 Hz) can be clearly identified. The side bands at the same spacing as the speed (35,8 -10, 35,8 +10) indicate an amplitude modulation. This represents an outer race defect with a rotating load.
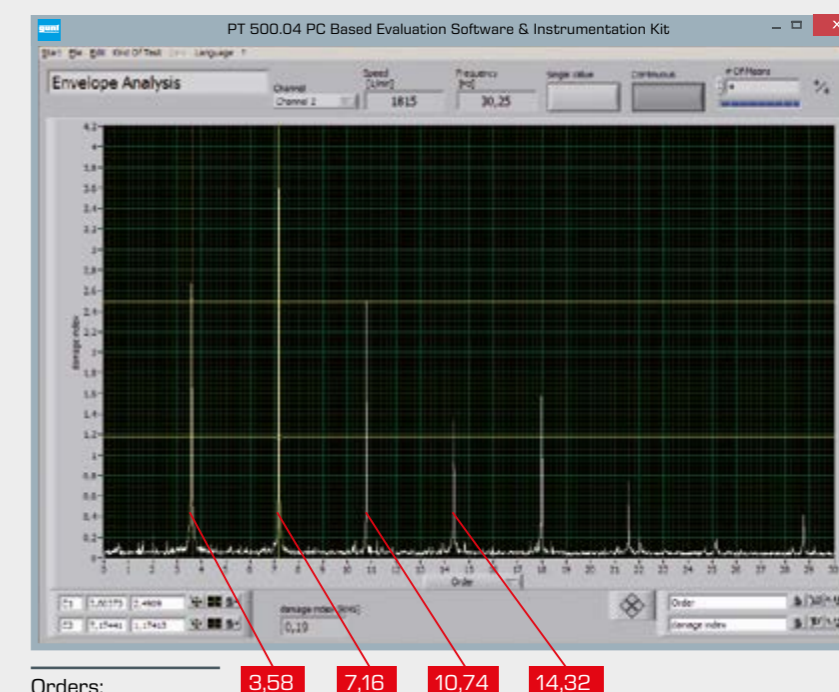
10 Hz
35,8 Hz
35,8 -10   35,8 +10   71,6 Hz

0   20   40   60   80   100   120 Hz

— acceleration,   — velocity,
— displacement

Experimental set-up for the identification of bearing defects

USB box (PT 500.04)   measurement amplifier (PT 500.04)

belt drive (PT 500.14)

PC with evaluation software (PT 500.04)

drive motor, coupling and shaft (PT 500 base unit)

reference sensor (PT 500.04)

acceleration sensor (PT 500.04)

damaged bearing with bearing block (PT 500.12)

The bearing to be investigated (PT 500.12) is fitted in a vice. Because bearing defects are only apparent under load, the belt force of the tensioned belt drive (PT 500.14) presents a radial load to the bearing. The shaft is powered by a variable speed motor. An acceleration sensor on the bearing block measures the impacts caused by the bearing defect. A reference sensor is used to measure the speed. The measurement amplifier (PT 500.04) transfers the measuring signals to the PC. The software performs the envelope analysis.

Typical experimental results

The illustration shows the envelope spectrum for a typical bearing defect. To obtain a representation independent of the rotary frequency, the order has been selected as the X coordinate. A rotary frequency signal has an order of 1. Frequency lines with an order of 3,58 are read when multiplying. This indicates an outer race defect in the bearing. The lack of side band lines with the same spacing as an order indicates a constant force direction – the belt tension in this case – and no rotating imbalance load.

PT 500.04 PC Based Evaluation Software & Instrumentation Kit

Envelope Analysis

Orders: 3,58   7,16   10,74   14,32

Screenshot of an envelope analysis showing outer race damage

Example: field balancing

If the centre of gravity of a rotating machine component does not correspond to the axis of rotation, i.e. it is not centred, the rotating mass of the machine component generates centrifugal or imbalance forces. These forces are transferred via the bearing to the entire machine and surroundings and stimulate vibrations, whose frequency corresponds to the speed. Because centrifugal forces depend on the square of the speed, they become much stronger as the speed increases.

Imbalance vibrations can be prevented or at least reduced by balancing. We differentiate between **balancing on special balancing machines**, which is carried out during production, and so-called **field balancing** on a machine that is already in operation. The PT 500 can be used to practice field balancing.

Balancing involves an attempt to bring the centre of gravity of the rotor back into alignment with the axis of rotation. To do this, weights are added to or removed from the rotor. To determine the position and mass of the required balancing weights, the unknown imbalance must first be determined. Unfortunately, the imbalance cannot be directly measured but has to be determined indirectly from the measurable bearing vibrations. To do this, we use the bearing vibration to determine the amplitude and phasing (vector) of the component with a rotary frequency. All other vibration components are filtered out. The balancing process is carried out as follows:

- measurement of bearing vibrations on imbalanced machine (original out of balance run U)

- measurement of bearing vibrations after an additional, known imbalance has been applied to the machine (test imbalance T)

- comparison of the two measurements enables the original imbalance to be calculated

- calculation of the mass and position of the balancing weights to be added or removed

- control measurement (A) after weight correction

Depending on the success of the balancing, this procedure is repeated until the desired limits for the bearing vibration are achieved.

$F = e\, m\, \omega^2$

Development of the imbalance force
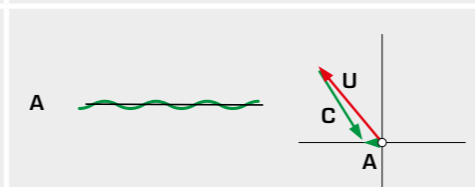

One-plane balancing

Two-plane balancing
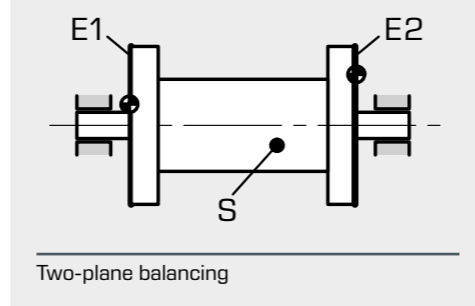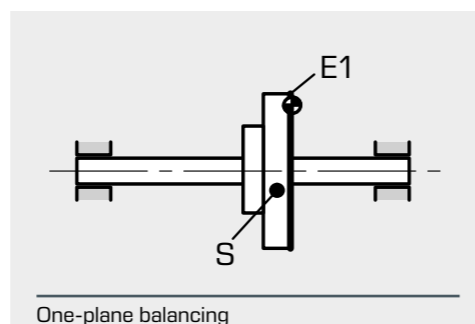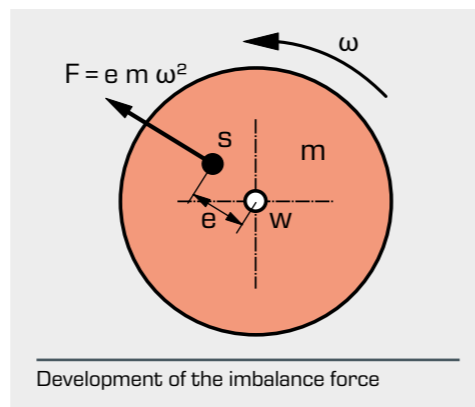
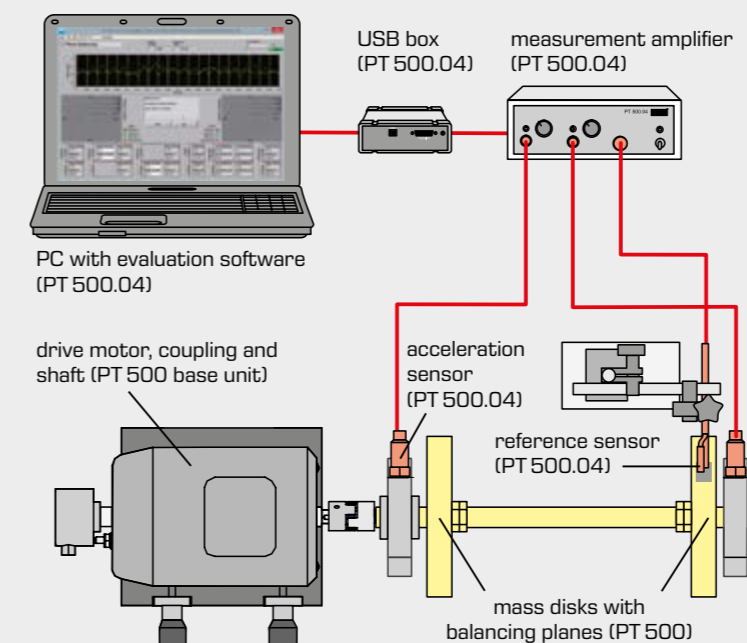Measurement of the bearing vibrations of the out-of-balance machine (original imbalance **U**).

Measurement of bearing vibrations according to which known imbalance was added to the machine (test imbalance **T**). It is possible to calculate the original imbalance by comparing of the two measurements.

Calculation of the size and position of the balancing masses **(C)** to be added or removed. Control measurement **(A)** after performing mass correction. Depending on the success of balancing, this procedure is repeated until the desired limit value of the bearing vibration is met.

Experimental set-up for the balancing in two planes

USB box (PT 500.04)
measurement amplifier (PT 500.04)
PC with evaluation software (PT 500.04)
drive motor, coupling and shaft (PT 500 base unit)
acceleration sensor (PT 500.04)
reference sensor (PT 500.04)
mass disks with balancing planes (PT 500)

The experimental set-up requires only the basic PT 500 unit and the PC-based PT 500.04 vibration analysis unit. The experimental set-up illustrated shows a rotor with two weights for carrying out two-plane balancing. The acceleration sensors measure the bearing vibrations directly adjacent to the weights. A reflective mark on one of the weights acts as a reference for the angle information. As balancing determines the transmission behaviour between the weight and the measuring point, the individual measurements are carried out at exactly the same speed. To simulate an original imbalance, small additional weights are screwed onto the disk. The same applies to the test and compensating weights.

Typical experimental results

The illustration shows the software user interface after a complete balancing process. In the upper window, the vibration signal is displayed directly for monitoring purposes. The two diagrams on the left and right show the imbalance signals from the individual measurements as vectors. Between them, a dialog box indicates the next step to be performed. The lower section of the screen shows the results of the measurements, the position and mass of the test weights and the position and mass of the calculated compensating weights.
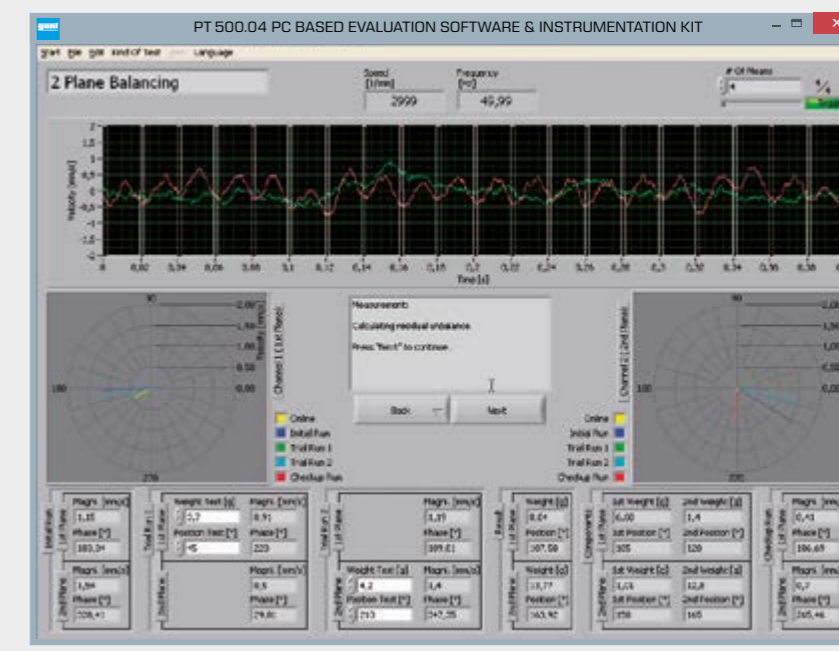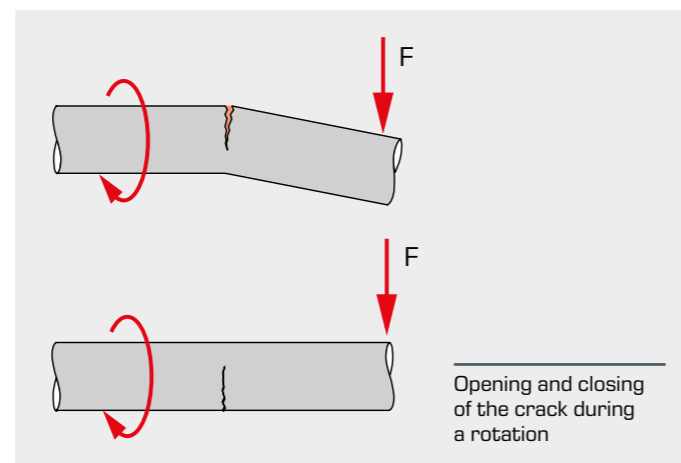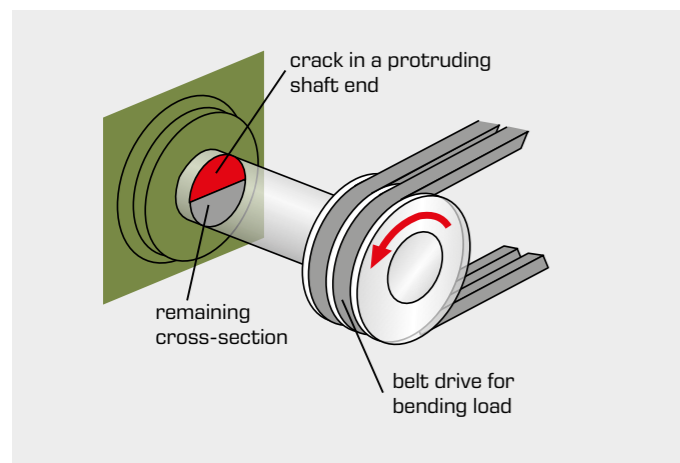

Screenshot: balancing in two planes

Example: identification of cracks in shafts

Cracks in shafts are amongst the most dangerous of defects. If a crack is not detected in good time, the shaft can break. As this usually happens at high speeds and loads, the consequences are disastrous and often result in the total destruction of the machine. In the past, machines were totally dismantled at fixed intervals and the rotor was subjected to an extensive crack test. The costs of this kind of inspection are huge. Modern machine condition monitoring methods enable cracks to be identified while the machine is still in place.

- crack in a protruding shaft end
- remaining cross-section
- belt drive for bending load

- F
- F

Opening and closing of the crack during a rotation

Cracks are caused by material faults, material fatigue and the concentration of stress at surface faults. The continuous flexural fatigue stress when the shaft is rotating then causes the crack to develop constantly until the remaining healthy cross-section finally yields to a forced fracture.

The crack reduces the rigidity of the shaft. This reduction in rigidity is modulated by the rotation of the shaft, which means that the rigidity is slightly higher if the crack runs parallel to the load direction than perpendicular to it. In addition, the crack can continuously open and close while rotating.
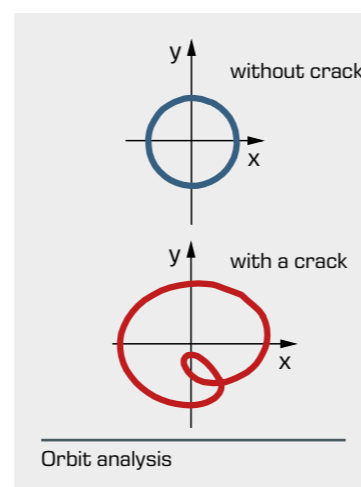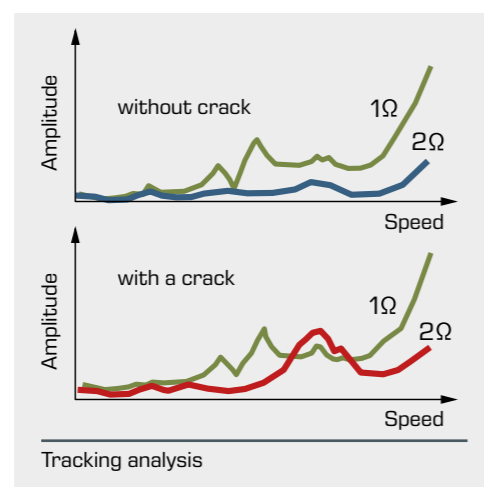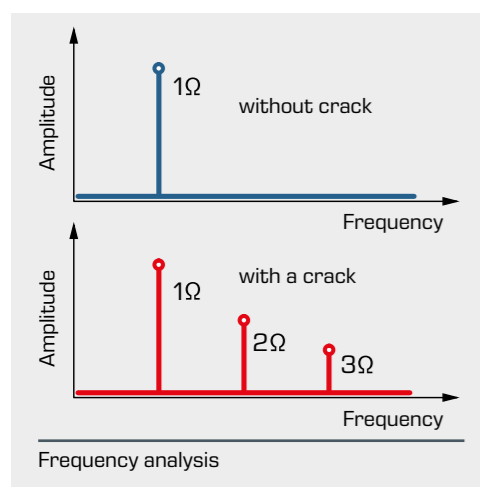
Analysis methods

The phenomena mentioned generate a characteristic vibration signal, which can be used to identify the existence of the crack. In particular the second order harmonic rises sharply compared to that for an undamaged shaft. Frequency analysis, tracking analysis and orbit analysis are all appropriate analysis methods.
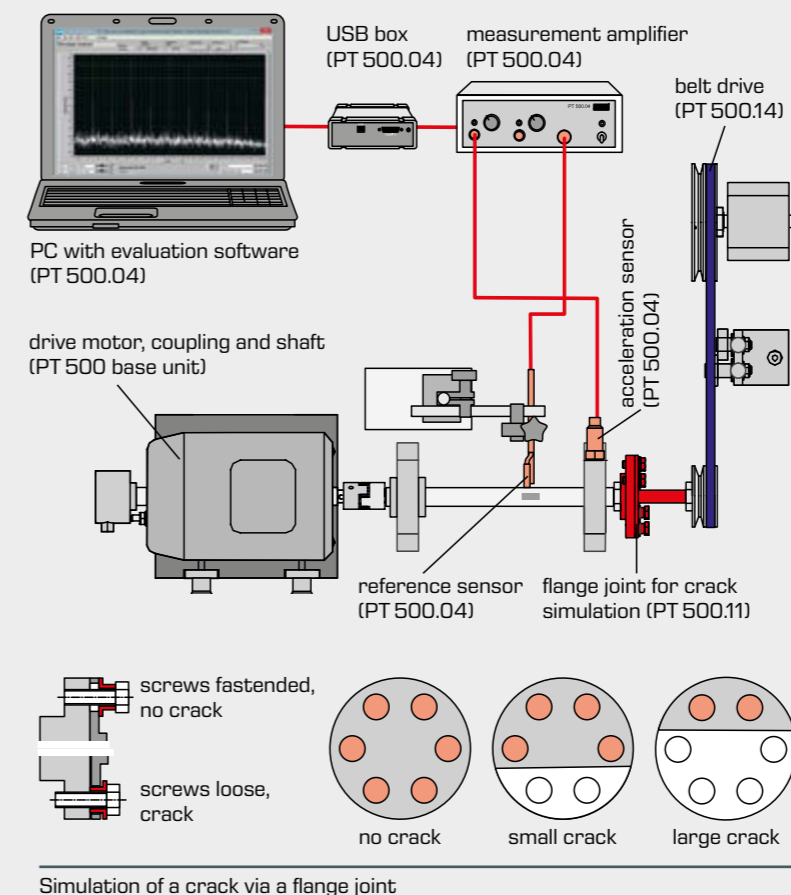
Frequency analysis involves looking at the frequency spectrum of the signal at a fixed speed. If there is a crack, additional frequency lines occur in the spectrum.

Tracking analysis involves recording the vibration signal over a wider speed range and investigating it for the different orders of rotary frequency using a special filter.

Orbit analysis involves investigating the path of the shaft measured using two displacement sensors. Second order components can be discerned here by the formation of loops in the path.

Frequency analysis

Tracking analysis

Orbit analysis

Experimental set-up for the identification of cracks in shafts

- USB box (PT 500.04)
- measurement amplifier (PT 500.04)
- belt drive (PT 500.14)
- PC with evaluation software (PT 500.04)
- drive motor, coupling and shaft (PT 500 base unit)
- acceleration sensor (PT 500.04)
- reference sensor (PT 500.04)
- flange joint for crack simulation (PT 500.11)
- screws fastended, no crack
- screws loose, crack
- no crack
- small crack
- large crack

Simulation of a crack via a flange joint

The PT 500.11 Crack detection in rotating shaft accessory kit can be used to create two different experimental set-ups:

- crack in a projecting shaft under external load
- crack in a Laval shaft under own weigh load

The experimental set-up with a projecting shaft is shown here. The external load is simulated by the pretensioning of the V belt. To simulate a crack with a variable depth, a special flange coupling is inserted into the shaft. Depending on the installation position of the specially designed gaps, either fixed clamping or a loose connection with clearance is created at the connecting screws. The number of loose screws can thus be used to simulate a crack of different depths.

Typical experimental results

The two figures show the result of a tracking analysis. The measurements were carried out on the experimental set-up shown, with the projecting shaft. Graph A shows the first order bearing vibration component **(1Ω),** graph B the second order component **(2Ω).**

In the top figure, all screws at the flange connection were tight, corresponding to the condition with no crack. The first order bearing vibrations increase quite normally as the speed rises due to the imbalance. The second order bearing vibrations are minimal.

In the lower figure, a deep crack is simulated. Here, only two of the six screws were fully tightened. While the first order bearing vibrations demonstrate similar behaviour to a shaft without a crack, there is a very sharp rise in the second order in the middle speed range, clearly indicating the presence of a crack.
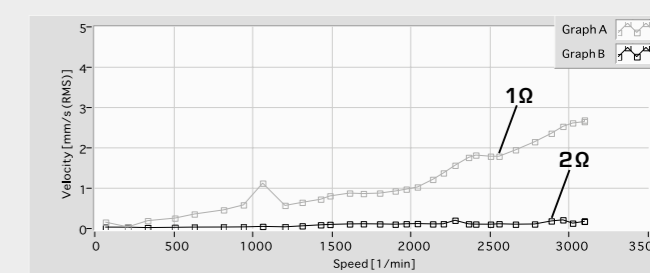
Tracking analysis shaft without crack
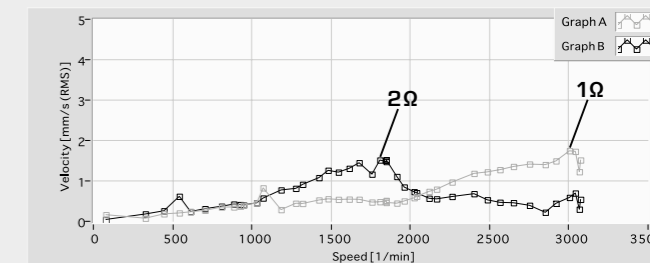
Tracking analysis shaft with crack

Modular system

Base unit

A range of training exercises relating to machinery diagnosis and monitoring can be carried out using just the PT 500 base unit together with the computerized vibration analyser PT 500.04.

As well as the exercises in the measurement of the vibration (vibration displacement, velocity and acceleration in the time or frequency domains), field balancing of rigid rotors and shaft alignment exercises can also be carried out.

The base unit includes a vibration-damped workholder plate, a speed-controlled drive motor with a tachometer, a shaft with two mass discs and two bearing units, a coupling and balancing weights.

A wide range of accessories enables almost any subject area relating to machinery diagnosis to be covered.
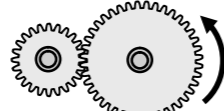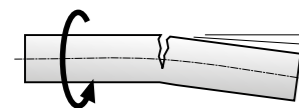
Accessory kits

PT 500.10 Elastic shaft
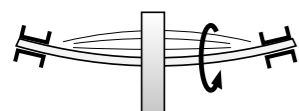
Unbalanced mass vibration of a flexurally elastic shaft; resonance, critical rotation speed, balancing
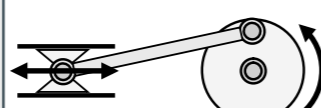
PT 500.11 Crack detection in rotating shaft

Vibration behaviour of a cracked shaft, identification of the crack from the vibration signal

PT 500.12 Roller bearing faults
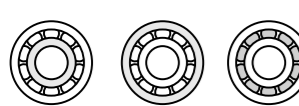
Identification of bearing damage from running noise. Various pre-damaged roller bearings

PT 500.13 Couplings

Properties of different coupling types, influence of eccentricity, wobble and pitch fault on vibration behaviour

PT 500.14 Belt drive

Vibration in belt drives, resonance and critical rotation speeds, influence of belt tension, eccentricity and misalignment

PT 500.15 Damage to gears

Identification of gear damage from the vibration signal, influence of toothing type and lubrication

### PT 500.16 Crank mechanism

Vibration in crank drives, free inertia forces, bumps and jolts resulting from bearing play and wear
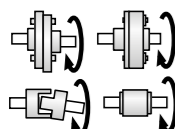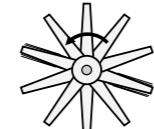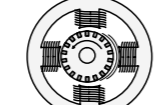
PT 500.17 Cavitation in pumps

Noise and damage resulting from cavitation, conditions for cavitation inception

PT 500.18 Vibrations in fans

Vibration in fans, demonstration of vibration excitation by blade passage, influence of centrifugal force

PT 500.19 Electromechanical vibrations

Interaction of electromagnetic/mechanical elements of system, influence of load, gap geometry and electrical asymmetry


The overview below shows how you can flexibly combine the accessories outlined for different experiments.

- basic accessories are used repeatedly.
- the modular system enables you to easily create your own experiment configurations.
- if a special measuring technique is already in use, this can be integrated into the system with no problems.
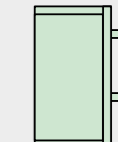
Basic accessories are required for numerous applications
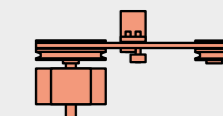
The computerised vibration analyser PT 500.04 is required for every application.
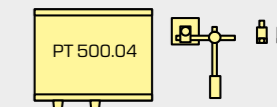
Because many defects only become apparent under load, the brake and load unit PT 500.05 is useful in many of the experiments.

The belt drive PT 500.14 is also used to generate static loads or to allow the speed to be reduced in many experiments.

PT 500.04 / PT 500

Experimental set-up bearing vibrations and balancing

PT 500.04 / PT 500.14 / PT 500.11 / PT 500

Experimental set-up shaft with crack

PT 500.04 / PT 500.14 / PT 500 / PT 500.12

Experimental set-up bearing damages

PT 500.04 / PT 500 / PT 500.41 / PT 500.10

Experimental set-up elastic shaft

PT 500.04 / PT 500.05 / PT 500.14 / PT 500

Experimental set-up belt drive

PT 500.04 / PT 500.15 / PT 500.05 / PT 500 / PT 500.04

Experimental set-up gears

PT 500.04 / PT 500 / PT 500.05 / PT 500.13

Experimental set-up coupling

PT 500.04 / PT 500.17 / PT 500

Experimental set-up cavitation

PT 500.04 / PT 500 / PT 500.18

Experimental set-up vibrations in fans

PT 500.04 / PT 500.14 / PT 500 / PT 500.16

Experimental set-up crank mechanism

PT 500.04 / PT 500.05 / PT 500.19

Experimental set-up electromechanic vibrations

Analysis software

An analysis software has been specially developed for the machine diagnostic system to fully include the required teaching demands of a training system.

Standard systems for industrial use focus on the collection of data, statistical functions and comprehensive adaptation to a variety of tasks. In contrast to these industrial systems, our software features clearly laid out and easy operation and quick changes between different analysis methods. This enables the advantages and disadvantages of the various methods to be highlighted during a measurement process.

For example, a signal can be represented using different methods (time lapse, spectrum, orbit, order analysis). Likewise, the characteristics of acceleration, speed and displacement signals can be clearly represented. The influence of the scanning rate, recording time, sensitivity and time base can also be demonstrated. This enables the trainee to develop a feel for the processes involved in vibration analysis.

Complicated adjustments and configurations, such as those on industrial systems, are not required.
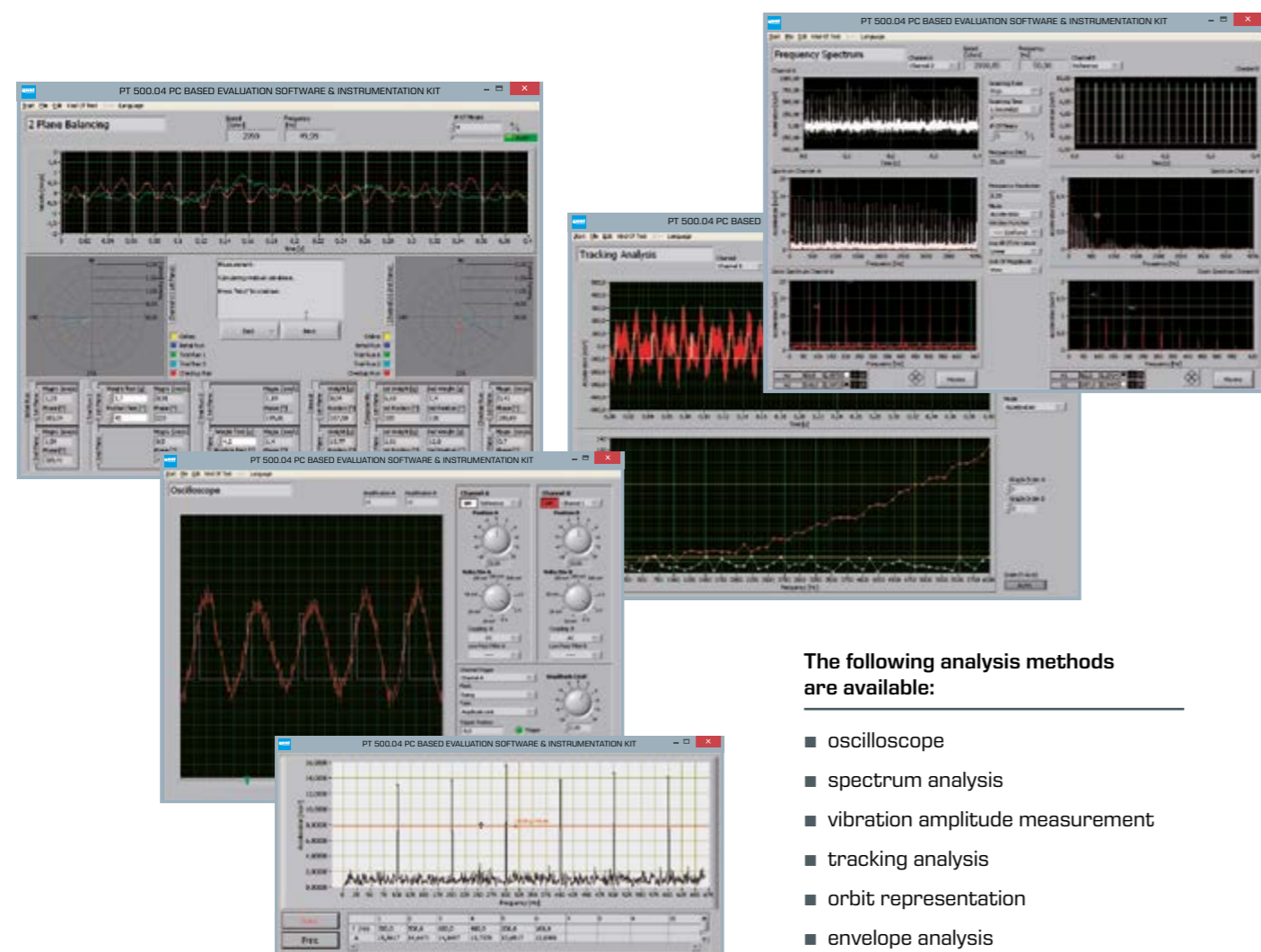
The following analysis methods are available:

- oscilloscope
- spectrum analysis
- vibration amplitude measurement
- tracking analysis
- orbit representation
- envelope analysis
- field balancing in one plane
- field balancing in two planes

Of course, the software is in four languages and has an integrated help function.

The basic hardware is a measurement amplifier for connection of two ICP acceleration sensors, two inductive displacement sensors and an optical reference sensor. A USB data acquisition system allows a PC to be connected directly without making any adjustments on the computer.

Instructional material

We have developed extensive instructional material for the PT 500 series. This provides you with an easy introduction to the demanding area of machine diagnosis.

- A representation of the vibration measurement method shows the different vibration signals and gives an introduction to the measuring technique. The capabilities of the different analysis methods are explained in detail, with their advantages and disadvantages.

- Detailed, illustrated recommended set-ups for practical experiments in each of the areas of the topic are included. Example measured results make it easier to correctly evaluate independent experiments and to identify mistakes.

- A comprehensive presentation (slides, CD) outlining the basic principles of machine diagnosis provides an excellent teaching resource.

The instructional material is professionally designed using clear graphics, and easily understandable text. The principles of vibration measurement can be printed for student handouts.

However, for sustained learning success in this complex and demanding area, we recommend a solid engineering grounding in machine dynamics, vibration and mathematics.

Manuals with example results

Fundamentals vibration measurement methods
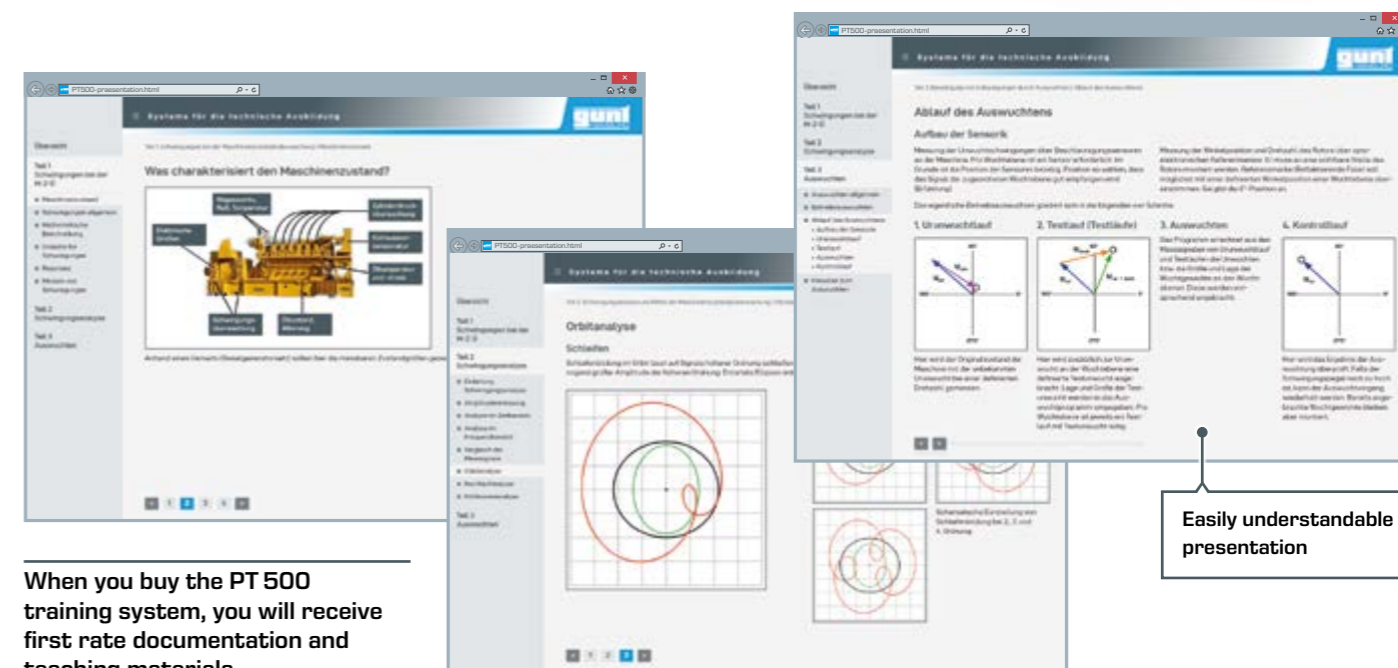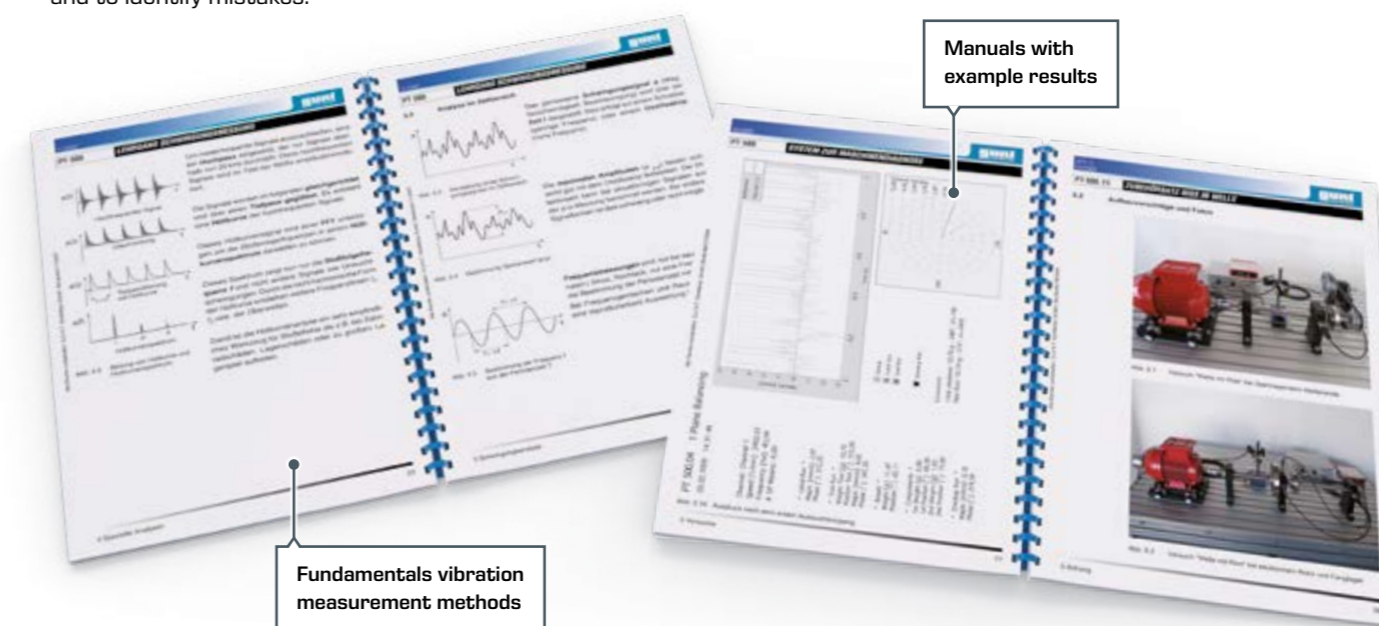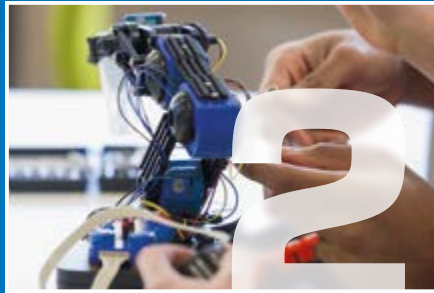

Easily understandable presentation

When you buy the PT 500 training system, you will receive first rate documentation and teaching materials.

The complete GUNT programme

1 Engineering mechanics and engineering design

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

2 Mechatronics

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

3 Thermal engineering

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

4 Fluid mechanics

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

5 Process engineering

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

6 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

Contact

G.U.N.T. Gerätebau GmbH
Hanskampring 15 - 17
22885 Barsbuettel
Germany

+49 40 670 854 - 0
sales@gunt.de
www.gunt.de

Visit our website
www.gunt.de