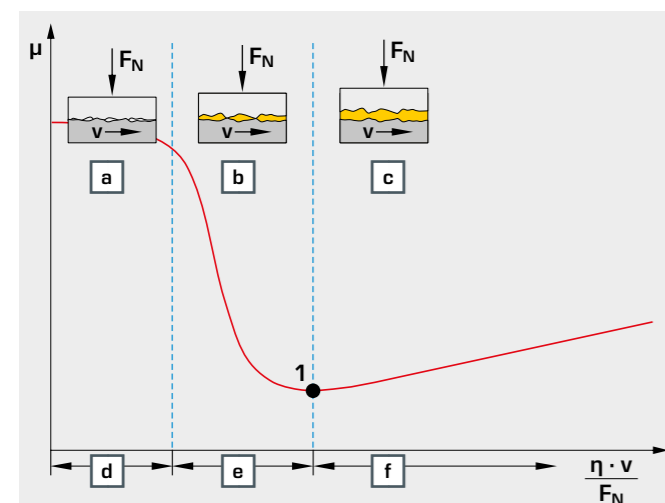
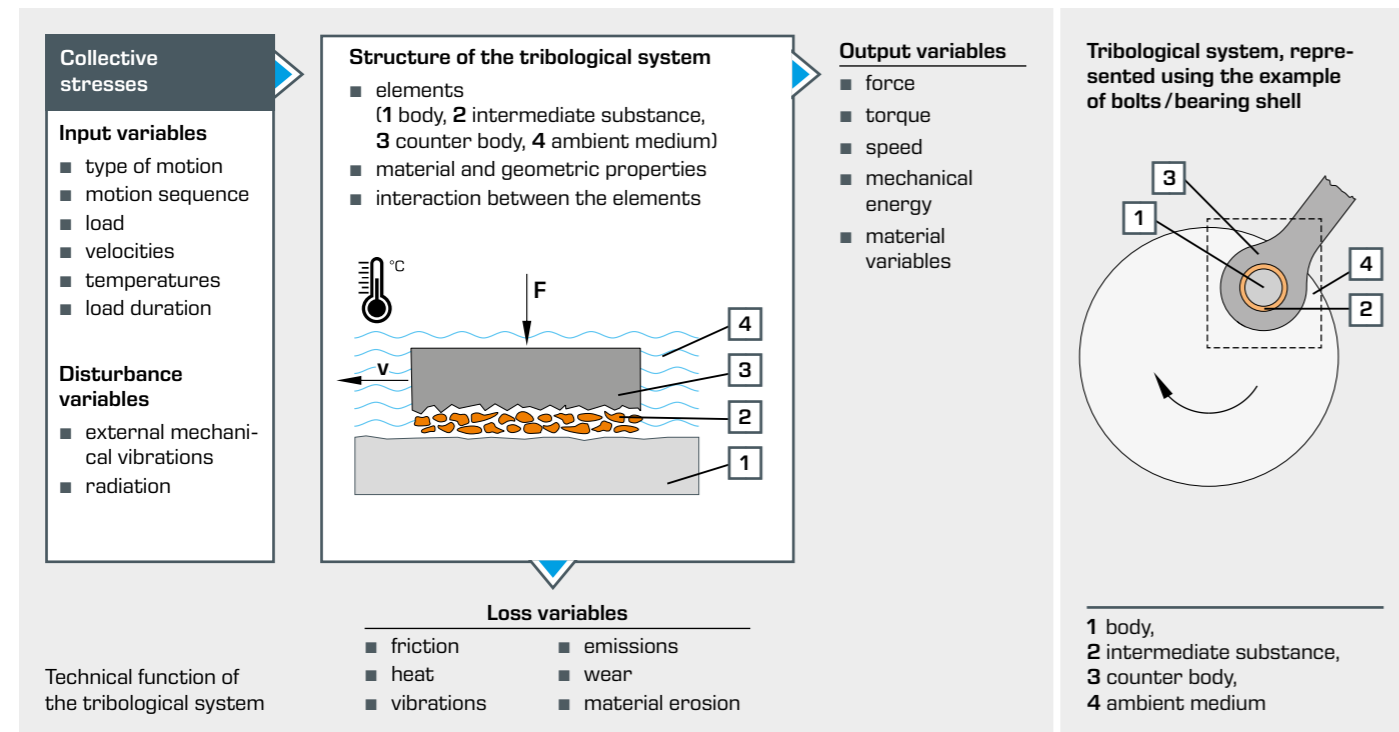


Tribology and corrosion

Tribology

Tribology is the science and technology of interacting surfaces in relative motion. The application of tribology in engineering is used to study friction, wear and lubrication. These studies extend to all areas of development, engineering design, production and maintenance of mechanical motion systems. Wear processes are analysed by means of a so-called tribological system and are described by "systemic" loss variables. A tribological system

contains all elements such as components and substances that are involved in a tribological load, as well as their properties. Material components such as body, counter body, intermediate substance and ambient medium form the system structure. The input variables and disturbance variables are summarised as collective stresses.



Stribeck curve for hydrodynamic friction

μ coefficient of friction, n speed, F_N load, v velocity, η viscosity, **a** dry friction, **b** mixed friction, **c** fluid friction, **d** boundary lubrication, **e** thin-film lubrication, **f** fluid lubrication, **1** release point

In the analysis of tribological systems, loss variables such as coefficient of friction, frictional forces and frictional vibrations are determined by suitable measuring methods. The change of an input variable or disturbance variable can change the friction and wear behaviour significantly. Experiments are required in order to investigate dependencies of loss variables.

The Stribeck curve gives a good overview of occurring friction states, such as in slide bearings. The relationships between coefficient of friction, friction pressure and bearing force are shown clearly. With increasing velocity, the lubricant film thickness increases and the regions of dry friction, mixed friction and fluid friction, in which the surfaces are completely separated by the lubricating film, are passed through in sequence.

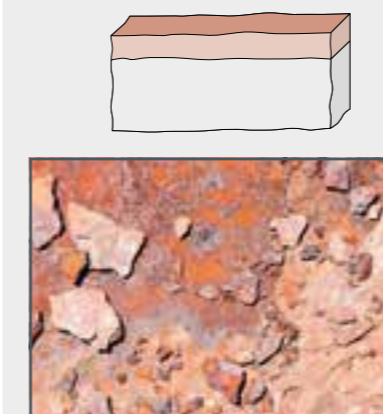
The transition from mixed friction to fluid friction is known as the release point. The lowest wear occurs in the region of fluid friction.

Corrosion

Corrosion refers to the reaction of a metallic material to its environment, which causes a measurable change in the material. This can lead to impairment of the function of a metal component or a whole system.

The form of the material changes due to corrosion

Surface erosion, uniform erosion of the workpiece surface



Pitting corrosion, crater-shaped or pinhole-like depressions that undermine the surface

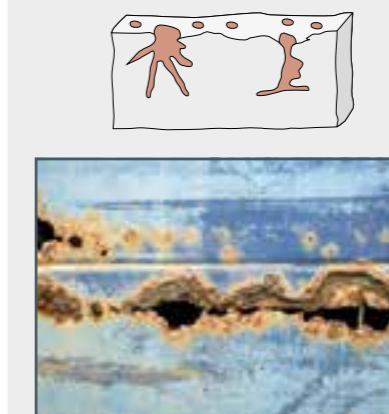
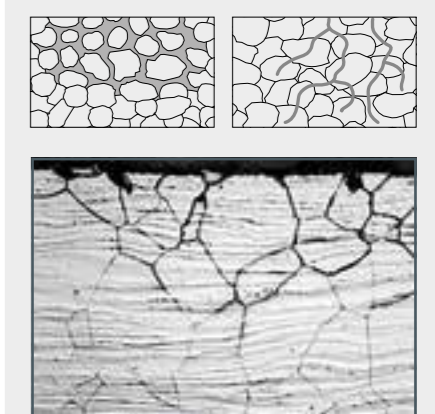


Figure left and below: intergranular corrosion along the grain boundaries.

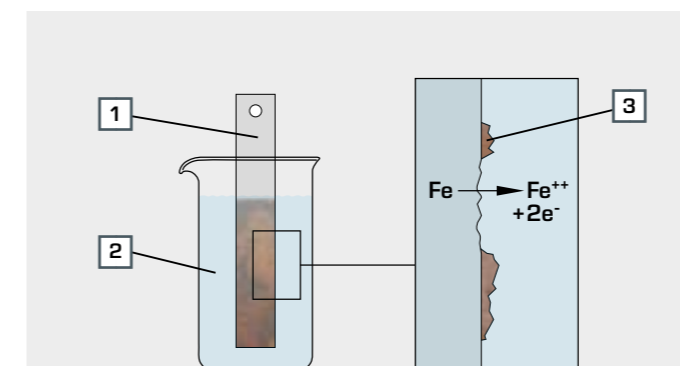
Figure right: transgranular corrosion, transverse through the grains



Processes during corrosion

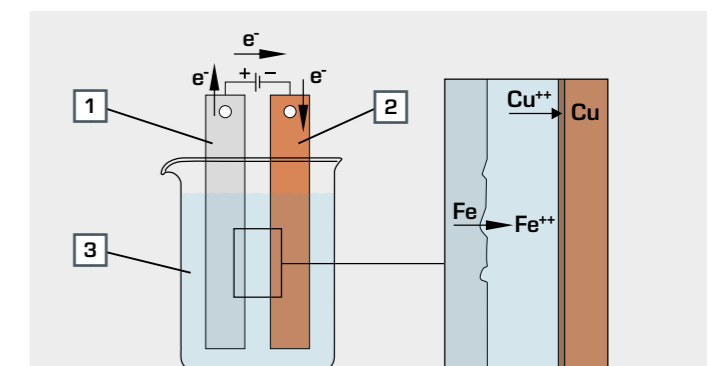
The environmental conditions of the material are significant for corrosion. Essentially, these are gases from the surrounding atmosphere and liquids. Solutions can be electrolytes

(ion-conducting liquids). In metals, corrosion is caused primarily by electrochemical or chemical processes.



Oxygen corrosion: a direct electron exchange takes place between iron and oxygen-enriched water. The iron bonds with the oxygen to form iron oxide.

1 electrode (iron Fe), 2 electrolyte enriched with oxygen (water), 3 iron oxide, Fe^{++} iron ion, e^- free electron



Electrochemical corrosion occurs through the formation of galvanic elements. If two different metals come into contact, an electrical current flows in the presence of an electrolyte. This dissolves base metal. More or less current flows depending on the metals present, and destruction takes place.

1 anode (iron Fe), 2 cathode (copper Cu), 3 electrolyte (copper sulphate $CuSO_4$), Cu^{++} copper ions, e^- electron, Fe^{++} iron ion

TM 260

Drive unit for tribological investigations



Description

- base module for studying various cases of sliding and rolling friction
- contact force by means of weights and lever
- electronic measurement of the frictional force between friction partners

Tribology studies friction, wear and lubrication. Friction occurs when two solids are in contact with each other and their movement is impeded. If material is lost progressively during this process, it is referred to as wear. Lubricants are used to minimise friction and wear.

The TM 260 drive unit, together with the experimental units TM 260.01 to TM 260.06, offer a complete course with a series of experiments to study tribological phenomena. Various rolling and sliding cases can be demonstrated in the classroom or studied in the laboratory. The parameters of a tribological system are recorded and analysed. A comprehensive range of friction pairings makes it possible, among other things, to represent how the frictional force is independent of the contact area.

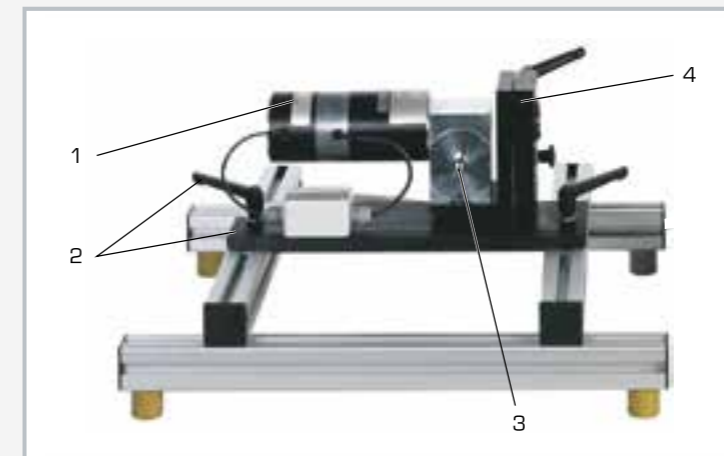
The TM 260 units comprise a frame on which the drive unit is mounted together with an experimental unit and a display and control unit. Quick-action chucks make it quick and easy to assemble. The drive unit has a pivotable motor block bearing. This allows the drive shaft to be installed horizontally or vertically. The speed of the DC motor is continuously adjustable and is detected by means of an incremental encoder. The frictional forces are measured by a force sensor in each experimental unit.

The display and control unit shows frictional force and speed, the latter of which can be adjusted continuously.

The following experiments can be conducted: Rolling friction in friction wheels (TM 260.01), Elasto-hydrodynamic behaviour (TM 260.02), Dynamic friction in a pin on a disk (TM 260.03), Frictional vibrations (TM 260.04), Dynamic friction in a cylindrical pin on a roller (TM 260.05), Pressure distribution in journal bearings (TM 260.06).

Learning objectives/experiments

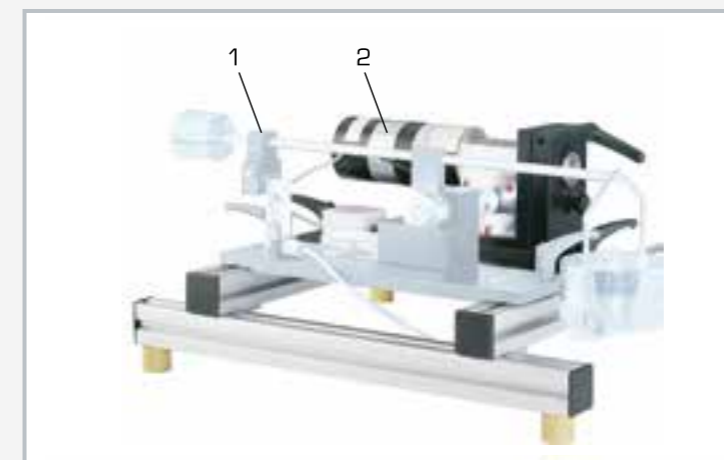
- together with the experimental units TM 260.01 to TM 260.06
 - ▶ rolling friction of two disks with slip
 - ▶ elasto-hydrodynamic behaviour (EHD theory) in rolling friction of a sphere against a flat surface
 - ▶ wear test: pin against disk
 - ▶ wear test: friction wheel experiment
 - ▶ frictional vibrations and slip-stick phenomenon
 - ▶ pressure distribution in the journal bearing



1 motor and gear, 2 quick-action chuck, 3 drive shaft, 4 pivotable drive



1 TM 260.03 experimental unit studies a tribological system, consisting of a pin and disk, which slide against each other, 2 TM 260 drive unit



1 TM 260.05 experimental unit studies a tribological system, consisting of a cylindrical pin and a roller, which slide against each other (point contact), 2 TM 260 drive unit

Specification

- [1] base module with drive unit and display and control unit for studying tribological phenomena
- [2] horizontal or vertical position of the drive shaft by means of pivotable motor block
- [3] various experimental units available as accessories
- [4] drive unit and experimental units secured by quick-action chucks
- [5] drive unit comprising DC motor with worm gear
- [6] speed of the DC motor is continuously adjustable
- [7] speed measured by incremental encoder
- [8] frictional force measured by force sensor
- [9] force and speed displayed on display and control unit

Technical data

DC motor

- rated speed: 3000min⁻¹
- torque: 18,5Nm

Worm gear: ratio 15:1

- operating speed: 0...200min⁻¹, electronically controlled

Measuring ranges

- force: 0...50N
- speed: 0...200min⁻¹

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 500x450x280mm (base module)

Weight: approx. 10kg

LxWxH: 360x330x170mm (display and control unit)

Weight: approx. 6kg

Scope of delivery

- 1 base module
- 1 display and control unit
- 1 set of cables
- 1 set of instructional material

TM 260.01

Rolling friction in friction wheels



The illustration shows TM 260.01 on the TM 260 frame.

Description

- frictional forces between two rolling friction wheels
- how slip affects the frictional force
- use of different lubricants possible

In bearing and drive technology, dynamic friction occurs at the sliding and rolling points, which leads to power losses in the technical systems. Dynamic friction is differentiated into sliding, rolling and spinning friction. In dynamic friction, there is relative translation between the two bodies. Rolling friction occurs when two bodies roll on each other without sliding. In rolling friction, the rolling motion is superposed with a smaller sliding friction, known as slip. Rolling friction is therefore a combination of rolling and dynamic friction.

The tribological system in TM 260.01 allows a clear representation of the rolling friction and an analysis of the frictional forces. The experimental unit comprises two friction wheels, pairing the materials aluminium and rubber at the contact points.

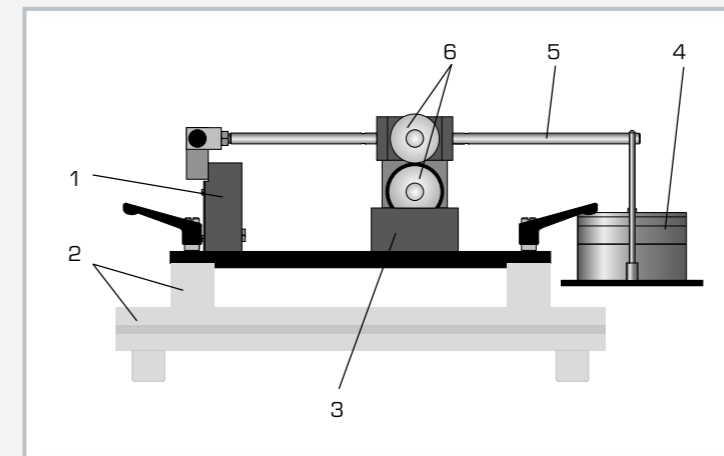
The slip between the friction wheels is kept constant at 4% by a gear unit. The contact force can be adjusted gradually up to a maximum of 80 N by means of a lever. The experimental unit includes a tank that supplies lubricant. Different lubrication conditions can be studied, such as dry friction, water or oil lubrication.

The TM 260 drive unit is required in order to conduct experiments. The experimental unit is mounted quickly and easily on the frame of the drive unit with quick-action chucks. The driving wheel is driven by a clampable coupling between drive unit and gear unit. The display and control unit of the drive unit shows frictional force and speed and allows the continuous adjustment of the speed.

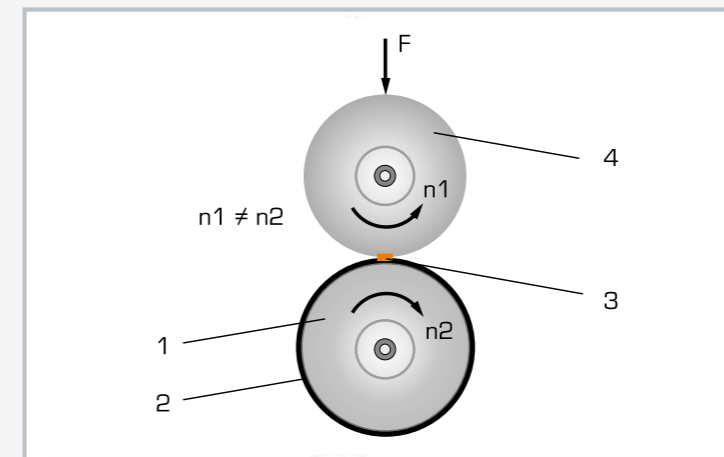
The frictional force and the coefficient of friction can be determined in experiments. The frictional forces are measured by a force sensor.

Learning objectives/experiments

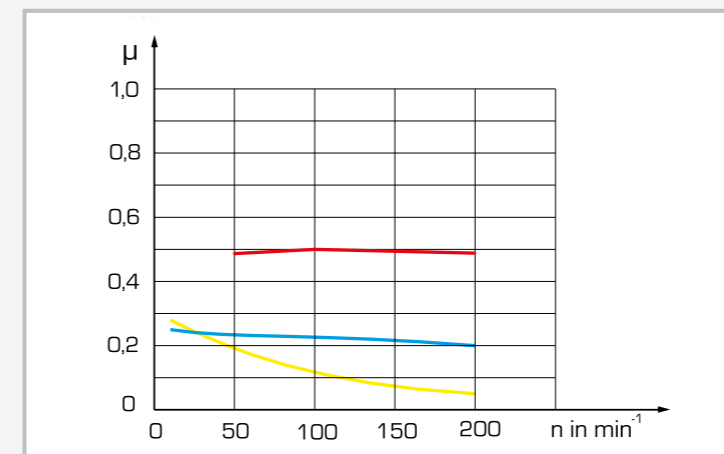
- together with the drive unit
 - ▶ determine the frictional forces as a function of load, lubrication and operating speed
 - ▶ how slip affects the frictional force
 - ▶ determine the coefficients of friction



1 force sensor, 2 frame of TM 260, 3 tank for lubricant, 4 weight, 5 load application device lever, 6 friction wheels



Tribological system using the example of friction wheels pairing aluminium and rubber: 1 driving friction wheel as main body, 2 rubber ring, 3 lubricant as intermediate substance, 4 driven wheel as counter body, F force, n speed



Coefficients of friction for different lubrication at constant load; μ coefficient of friction, n speed, red: dry friction, blue: water lubrication, yellow: oil lubrication

Specification

- [1] frictional forces in two rolling friction wheels
- [2] quick and easy assembly of the experimental unit on the frame of the drive unit
- [3] driving wheel is driven by a clampable coupling between drive unit and gear unit
- [4] slip between friction wheels kept constant at 4% by means of gear unit
- [5] load on the friction wheels via lever arm and stepped weights
- [6] friction wheels materials pair: aluminium/rubber
- [7] use of different lubricants
- [8] frictional force measured by force sensor
- [9] displays of force and speed and speed adjustment on the drive unit

Technical data

Load application device

- max. load: 80N
- lever arm ratio: 2:1

Friction wheels

- $\varnothing=49\text{mm}$
- $\varnothing=45\text{mm}$, incl. rubber ring

Gear ratio

- i: 0,96, slip approx. 23%

Force sensor for frictional force

- 0...50N

Weights

- 1x 5N (hanger)
- 1x 5N
- 1x 10N
- 1x 20N

LxWxH: 480x250x150mm

Weight: approx. 7kg

Scope of delivery

- 1 experimental unit
- 2 friction wheels
- 1 set of weights
- 1 set of instructional material

TM 260.02

Elasto-hydrodynamic behaviour



Learning objectives/experiments

- together with the drive unit
 - ▶ determine the thickness of the lubricating film at the contact point of a sphere with a plane surface – compare with theoretical value
 - ▶ study the effect of load and speed on the thickness of the lubricating film

Description

- elasto-hydrodynamic behaviour between the sphere and rotating-glass-plate friction pair
- investigation of the thickness and shape of the lubricating film

Elasto-hydrodynamic lubrication occurs in roller bearings, gear wheels and cam followers, whose contact surfaces are subjected to high loads. These surfaces are elastically deformed because of high contact pressures. The theory of elasto-hydrodynamics (EHD theory) takes into consideration the elastic deformation of the bodies in contact with each other and provides a basis for calculating the influence of lubrication on damage to gears and roller bearings.

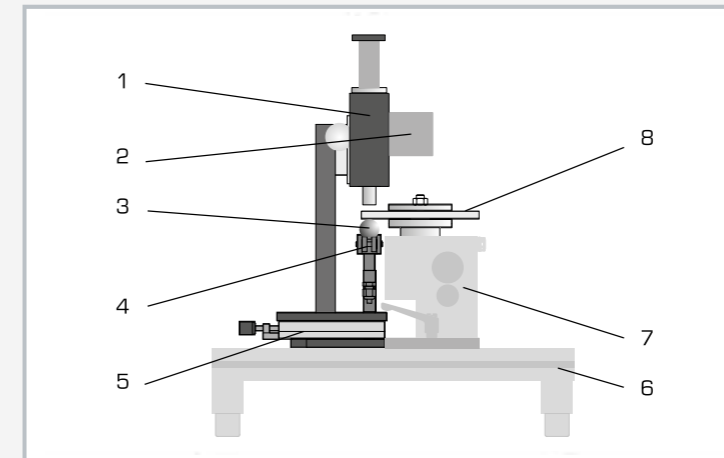
The tribological system in TM 260.02 allows a clear representation of the elasto-hydrodynamic behaviour of lubricating film layers.

To do this, the lubricating film between a sphere and a glass plate is determined and studied using a reflected-light microscope. The experimental unit contains a rotating glass plate and a steel sphere as the friction pair. The steel sphere is pressed against the glass plate from underneath. The contact force between the friction partners can be adjusted continuously by means of a lever. A lubricating film is located between the sphere and glass plate at the contact point. The glass plate is plane-parallel and dielectric coated. The surface of the hardened steel ball is polished. The reflected-light microscope stands on an adjustable xy cross table and has a focus drive.

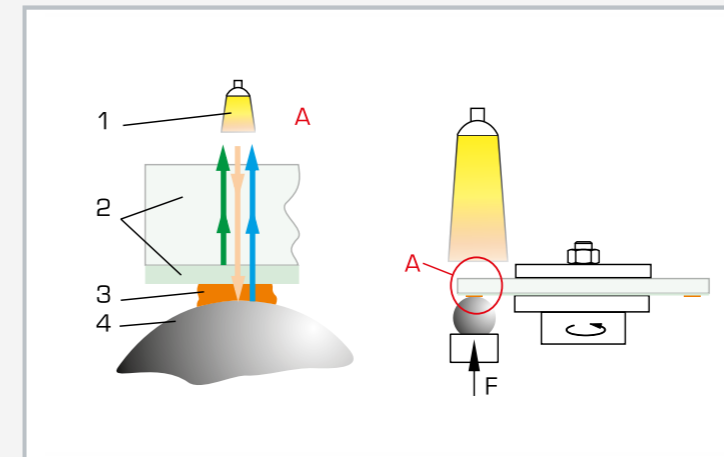
The TM 260 drive unit is required in order to conduct experiments. The experimental unit is mounted quickly and easily on the frame of the drive unit with quick-action chucks.

The glass plate is driven by a clampable coupling between drive unit and gear unit. The display and control unit of the drive unit shows contact force and speed and allows the continuous adjustment of the speed.

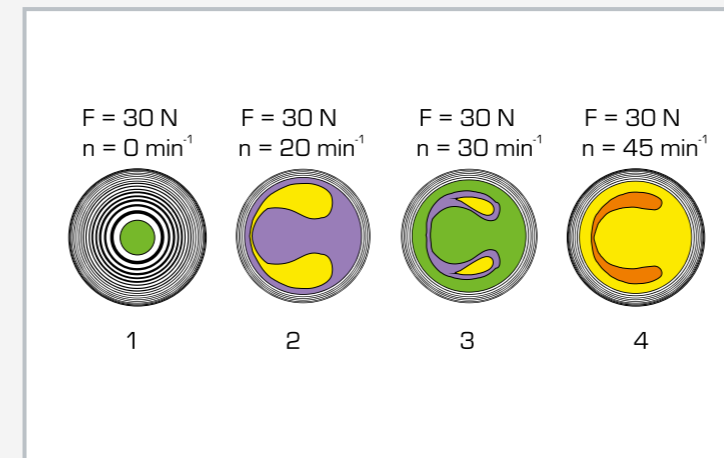
In the experiment, light waves from the reflected-light microscope pass through the glass plate and the lubricating film and are reflected by the surface of the steel sphere. The light waves are refracted in the lubricating film, making colour interference fringes visible. The wavelength of light increases or decreases with the variable thickness of the lubricating film. The thickness of the lubricating film is determined visually by means of the colour of the interference fringes created. The contact force is measured by a force sensor.



1 reflected light microscope, 2 halogen lamp, 3 steel sphere, 4 load application device, 5 cross table, 6 frame of TM 260, 7 drive unit from TM 260, 8 glass plate



Determine the thickness of the lubricating film by optical interference: 1 halogen lamp, 2 glass plate with dielectric coating, 3 lubricating film, 4 steel sphere; arrows orange: incident light, green: dielectric coating reflects 30% of the light, blue: steel sphere reflects the remaining light



Effect of lubricating film thickness on speed: 1 static case, 2 to 4 increase in lubricating film width (lubricating oil ISO VG 100)

Specification

- [1] elasto-hydrodynamic behaviour of a lubricating film layer between sphere and rotating glass plate
- [2] quick and easy assembly of the experimental unit on the frame of the drive unit
- [3] determine the thickness of the lubricating film by optical interference
- [4] glass plate is driven by a clampable coupling between drive unit and gear unit
- [5] hardened steel sphere, polished
- [6] rotating plane-parallel glass plate with dielectric coating
- [7] continuous load on the sphere via lever arm
- [8] load measured by force sensor
- [9] displays of force and speed and speed adjustment on the drive unit

Technical data

Load application device

- max. load: 150N
- lever arm ratio: 3:1

Sphere

- diameter: 25,4mm
- hardened steel, polished

Glass plate

- diameter: 150mm, plane-parallel
- coating: BK 7, dielectric, R=30%

Microscope

- magnification: x50
- halogen lamp: 10W

Force sensor: 0..50N

LxWxH: 350x250x550mm

Weight: approx. 8kg

Scope of delivery

- 1 experimental unit
- 1 sphere
- 1 glass plate
- 1 set of instructional material

TM 260.03

Dynamic friction in pin - disk



Description

- frictional forces between two sliding friction pairs
- investigation of wear
- use of different lubricants possible

In bearing and drive technology, dynamic friction occurs at the sliding and rolling points, which leads to power losses in the technical systems. Dynamic friction is differentiated into sliding, rolling and spinning friction. In dynamic friction, there is relative translation between the two bodies.

The tribological system in TM 260.03 allows a clear representation of the dynamic friction and an analysis of the frictional forces. The experimental unit contains a fixed pin that is pressed axially against a rotating disk as the friction pair. The contact force between the friction partners can be adjusted gradually up to a maximum of 80 N by means of a lever. The rotating disk is enclosed by an open cup that can be filled with different lubricants for the experiments.

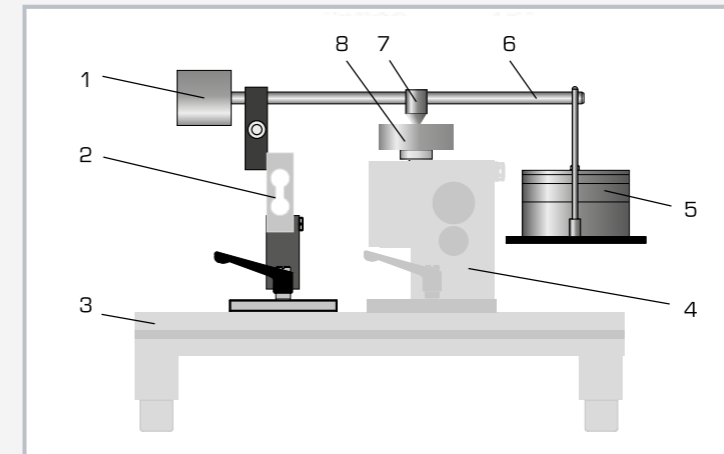
Different lubrication conditions can be studied, such as dry friction, water or oil lubrication. Pins made of different materials are included in the scope of delivery to study different friction pairings.

The TM 260 drive unit is required in order to conduct experiments. The experimental unit is mounted quickly and easily on the frame of the drive unit with quick-action chucks. The disk is driven by a clampable coupling between drive unit and gear unit. The display and control unit of the drive unit shows frictional force and speed and allows the continuous adjustment of the speed.

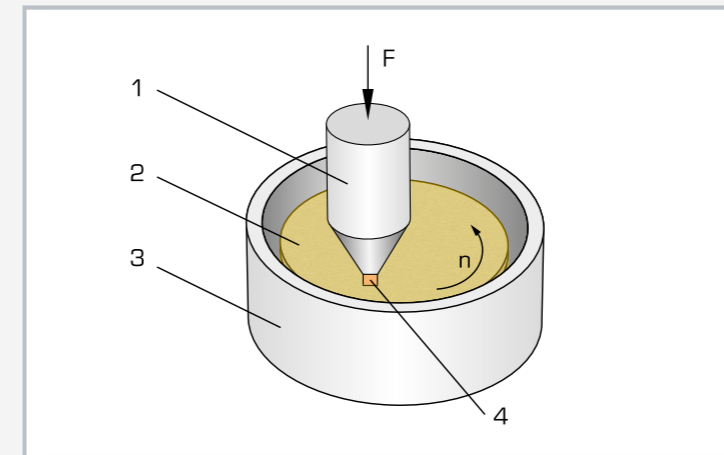
The frictional force and the coefficient of friction can be determined in experiments. The frictional forces are measured by a force sensor. The wear can be determined precisely by measuring the change (reduction) in length of the pin.

Learning objectives/experiments

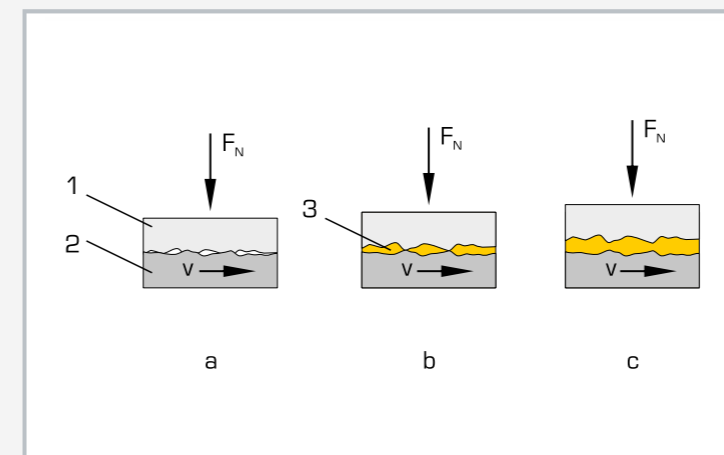
- together with the drive unit
 - ▶ frictional forces in different friction pairs and loads
 - ▶ frictional forces with different lubrication
 - ▶ frictional forces at different relative speeds of the friction partners
 - ▶ wear under different friction parameters and lubrication conditions



1 counterweight, 2 force sensor, 3 frame of TM 260, 4 drive unit from TM 260, 5 weight, 6 load application device lever, 7 pin, 8 disk



Tribological system pin and disk: 1 pin as counter body, 2 rotating disk as main body, 3 cup with lubricant as intermediate substance, 4 contact area; F force, n speed



Effect of the lubricating film on friction: 1 pin, 2 disk, 3 lubricant; a dry friction, b mixed friction, c fluid friction; F_N force, v velocity

Specification

- [1] frictional forces in pin and disk, which slide against each other, disk subjected to axial load
- [2] quick and easy assembly of the experimental unit on the frame of the drive unit
- [3] disk is driven by a clampable coupling between drive unit and gear unit
- [4] fixed pin made of different materials: aluminium, brass or steel
- [5] rotating disk made of hardened and ground stainless steel
- [6] load on the pin via lever arm and stepped weights
- [7] use of different lubricants, e.g. water or oil
- [8] frictional force measured by force sensor
- [9] displays of force and speed and speed adjustment on the drive unit

Technical data

Load application device

- max. load: 80N
- lever arm ratio: 2:1

Disk

- $\varnothing=50\text{mm}$
- hardened stainless steel, ground

Pin, $\varnothing \times H$: 4x25mm

- 3x aluminium
- 6x brass
- 6x steel

Force sensor for frictional force

- 0...50N

Weights

- 1x 5N (hanger)
- 1x 20N
- 1x 10N
- 1x 5N

LxWxH: 350x430x230mm

Weight: approx. 8kg

Scope of delivery

- 1 experimental unit
- 1 disk
- 1 set of pins
- 1 set of weights
- 1 set of instructional material

TM 260.04

Frictional vibrations



Description

- slip-stick phenomenon at the transition from static to dynamic friction
- friction rings of different materials for the study of different friction pairings

Friction is the resistance of a body against movement on a base. Static friction means that a body remains at rest under the action of a force. If a limit value is exceeded, the body begins to move on the base, resulting in dynamic friction. Self-excited friction oscillations, also known as slip-stick phenomenon, occur if the static friction is significantly higher than the dynamic friction.

The tribological system in TM 260.04 allows a clear demonstration of the transition from static to dynamic friction and the occurrence of friction oscillations. The experimental unit contains a rotating stainless-steel disk and a loosely fitting friction ring as the friction pair. The contact force between the friction partners can be adjusted gradually up to a maximum of 40 N by means of weights.

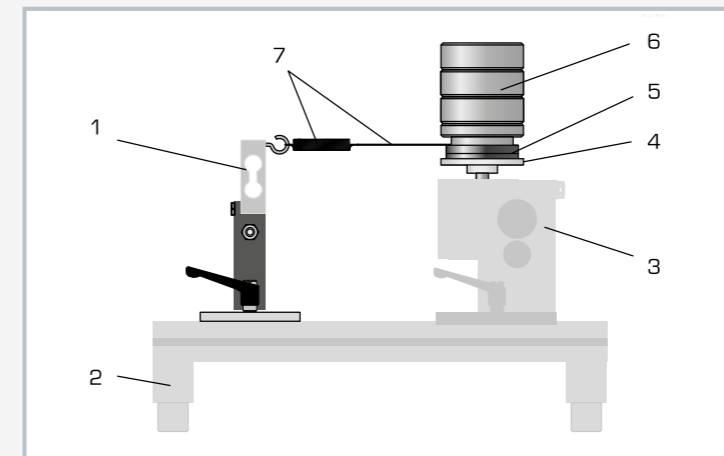
A tension spring prevents the friction ring from rotating. The necessary holding force is measured by a force sensor.

The TM 260 drive unit is required in order to conduct experiments. The experimental unit is mounted quickly and easily on the frame of the drive unit with quick-action chucks. The disk is driven by a clampable coupling between drive unit and gear unit. The display and control unit of the drive unit shows frictional force and speed and allows the continuous adjustment of the speed.

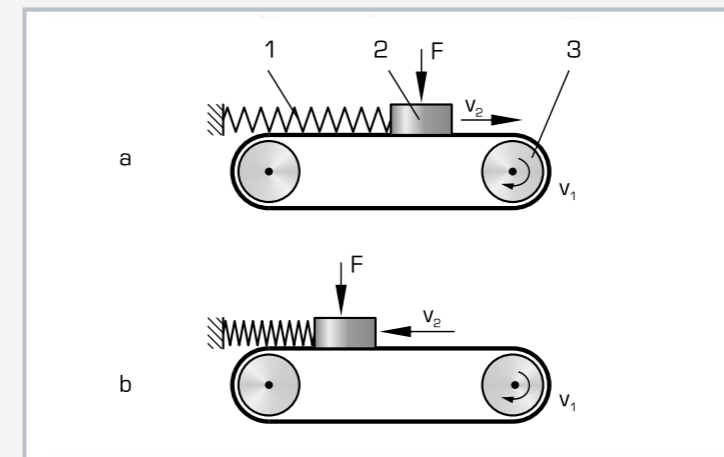
The frictional force and the coefficient of friction can be determined in experiments. The frictional forces are measured by a force sensor. Friction rings made of different materials are included in the scope of delivery to study different friction pairings.

Learning objectives/experiments

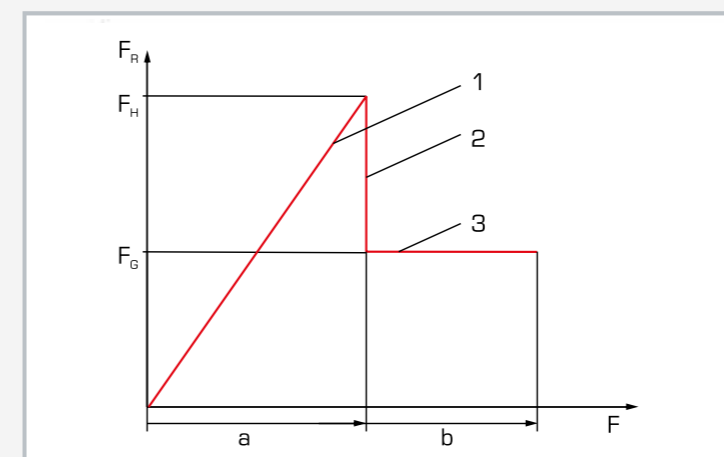
- together with the drive unit
 - ▶ observation of the transition from static to dynamic friction
 - ▶ influence of lubrication on slip-stick phenomenon
 - ▶ influence of the force between the friction partners on the slip-stick phenomenon
 - ▶ influence of the relative velocity of the friction partners on the slip-stick phenomenon



1 force sensor, 2 frame of TM 260, 3 drive unit from TM 260, 4 rotating disk, 5 friction ring, 6 weight, 7 spring and cable



Friction oscillations (Slip-stick phenomenon): 1 spring, 2 body, 3 drive; F force, v velocity, a static, b dynamic



Frictional force at static and dynamic friction: 1 static friction, 2 slide limit, 3 dynamic friction, F_R frictional force, F traction, F_H static frictional force, F_G dynamic frictional force, a rest state, b motion

Specification

- [1] friction oscillations at static and dynamic friction
- [2] quick and easy assembly of the experimental unit on the frame of the drive unit
- [3] rotating stainless steel disk
- [4] disk is driven by a clampable coupling between drive unit and gear unit
- [5] friction ring of different materials: stainless steel, brass or plastic (PA)
- [6] friction pair subject to load by stepped weights
- [7] frictional force measured by force sensor
- [8] displays of force and speed and speed adjustment on the drive unit

Technical data

Disk

- Ø: 60mm
- stainless steel

Friction ring

- outer diameter: 80mm
- inner diameter: 50mm
- 1x stainless steel
- 1x brass
- 1x plastic (PA)

Force sensor for frictional force

- 0...50N

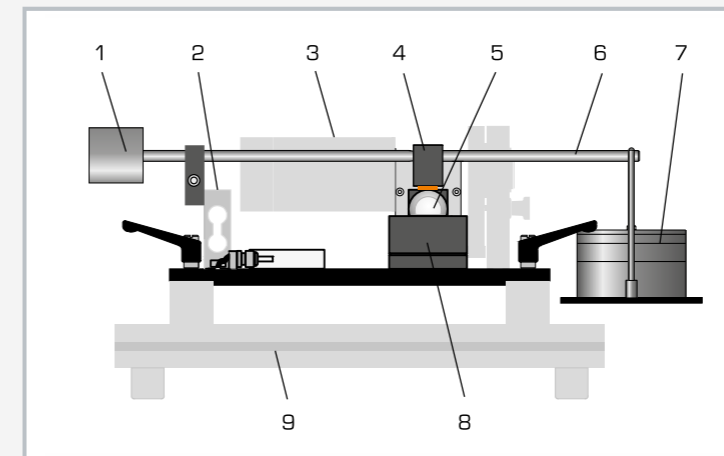
Weights

- 1x 5N
- 3x 10N

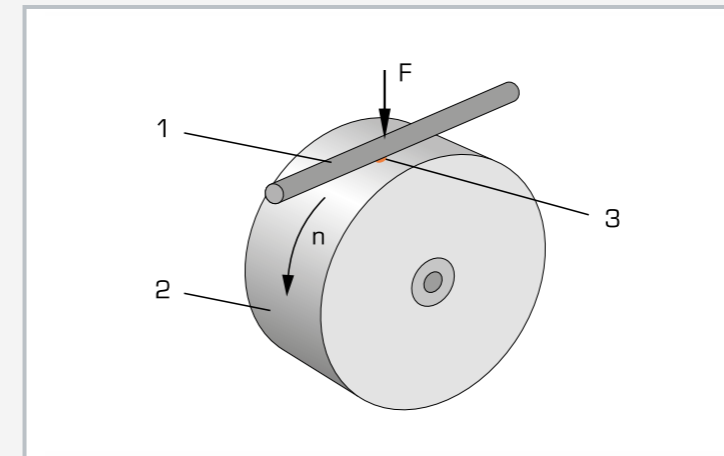
Weight: approx. 7kg

Scope of delivery

- 1 experimental unit
- 1 disk
- 1 friction ring
- 1 spring
- 1 set of weights
- 1 set of instructional material

TM 260.05**Dynamic friction in cylindrical pin - roller**

1 counterweight, 2 force sensor, 3 drive unit from TM 260, 4 sliding holder with cylindrical pin, 5 roller, 6 load application device lever, 7 weight, 8 tank for lubricant, 9 frame from base module TM 260



Tribological system of cylindrical pin and roller (point contact): 1 fixed cylindrical pin as counter body, 2 rotating roller as main body, 3 lubricant as intermediate substance; F force, n speed

Specification

- [1] frictional forces in cylindrical pin and roller that slide on each other (point contact)
- [2] quick and easy assembly of the experimental unit on the frame of the drive unit
- [3] rotating roller made of hardened and ground stainless steel
- [4] roller is driven by a clampable coupling between drive unit and gear unit
- [5] fixed cylindrical pin made of different materials: aluminium, brass or steel
- [6] load on the cylindrical pin via lever arm and stepped weights
- [7] use of different lubricants, e.g. oil or water
- [8] frictional force measured by force sensor
- [9] displays of force and speed and speed adjustment on the drive unit

Technical data**Load application device**

- max. load: 80N
- lever arm ratio: 2:1

Roller

- $\varnothing=40\text{mm}$
- hardened stainless steel, ground

Cylindrical pin, $\varnothing \times H$: 10x20mm

- 3x aluminium
- 6x brass
- 6x steel

Force sensor for frictional force

- 0...50N

Weights

- 1x 5N (hanger)
- 1x 20N
- 1x 10N
- 1x 5N

LxWxH: 570x100x120mm

Weight: approx. 8kg

Scope of delivery

- 1 experimental unit
- 1 roller
- 1 set of cylindrical pins
- 1 set of weights
- 1 set of instructional material

Description

- frictional forces between two sliding friction pairs
- investigation of wear
- use of different lubricants possible

In bearing and drive technology, dynamic friction occurs at the sliding and rolling points, which leads to power losses in the technical systems. Dynamic friction is differentiated into sliding, rolling and spinning friction. In dynamic friction, there is relative translation between the two bodies.

The tribological system in TM 260.05 allows a clear representation of the dynamic friction and an analysis of the frictional forces. The experimental unit contains a fixed cylindrical pin that is pressed radially against a rotating roller as the friction pair. There is point contact between the friction partners. The contact force between the friction partners can be adjusted gradually up to a maximum of 80 N by means of a lever. The experimental unit includes a tank that supplies lubricant.

Different lubrication conditions can be studied, such as dry friction, water or oil lubrication. Cylindrical pins made of different materials are included in the scope of delivery to study different friction pairings.

The TM 260 drive unit is required in order to conduct experiments. The experimental unit is mounted quickly and easily on the frame of the drive unit with quick-action chucks. The roller is driven by a clampable coupling between drive unit and gear unit. The display and control unit of the drive unit shows frictional force and speed and allows the continuous adjustment of the speed.

The frictional force and the coefficient of friction can be determined in experiments. The frictional forces are measured by a force sensor.

Learning objectives/experiments

- together with the drive unit
 - ▶ frictional forces in different friction pairs and loads
 - ▶ frictional forces with different lubrication
 - ▶ frictional forces at different relative speeds of the friction partners
 - ▶ wear under different friction parameters

TM 260.06**Pressure distribution in journal bearings****Learning objectives/experiments**

- together with the drive unit
 - ▶ pressure distribution in the journal bearing depending on speed
 - ▶ pressure distribution in the journal bearing depending on load or bearing gap width
 - ▶ stability limit as a function of the gap width

Description

- depiction of radial pressure distribution in a journal bearing at different bearing gap widths
- bearing housing made of transparent plastic

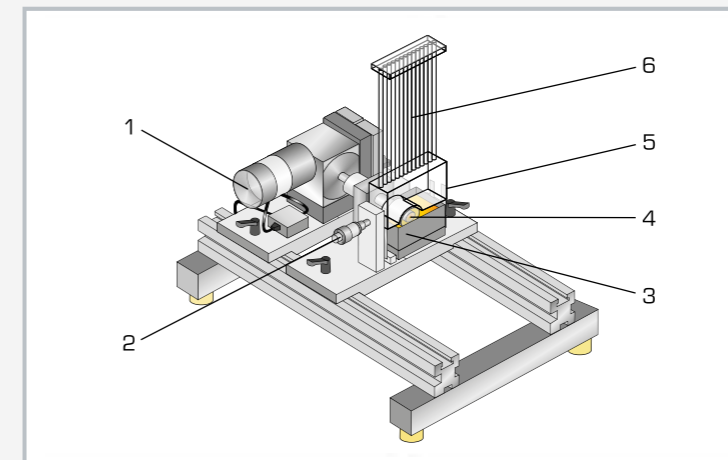
The field of tribology covers all forms of friction. Dry, mixed and fluid friction all occur in journal bearings. Under operating conditions there is completely distinct fluid friction, so that the shaft and bearing shell are separated by a supporting lubricating film. The supporting function of the lubricating film can be described by the pressure distribution in the bearing gap.

The experimental unit TM 260.06 is used to visualise the radial pressure profile in the journal bearing with hydrodynamic lubrication.

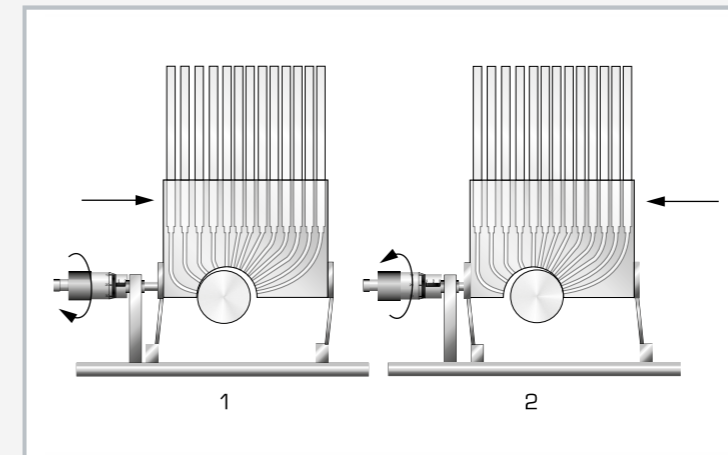
To this end, the experimental unit contains an open bearing shell which only encloses a shaft half way and which simulates the journal bearing. The bearing shell is secured to two spring plates in such a way that it can be moved. Unlike real hydrodynamic journal bearings, the gap width can be adjusted via the radially moveable bearing housing by means of the spring plates and a micrometer screw.

The TM 260 drive unit is required in order to conduct experiments. The experimental unit is quickly and easily mounted on the frame of the drive unit with quick-action chucks. The shaft is driven by a clampable coupling between drive unit and gear unit. The display and control unit of the drive unit shows frictional force and speed and allows the continuous adjustment of the speed.

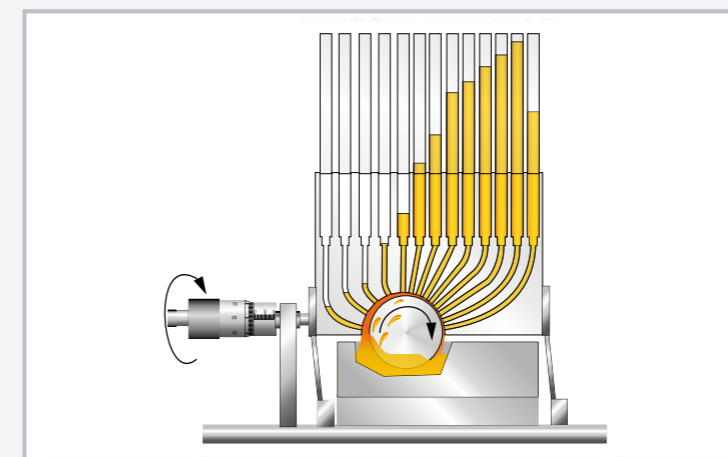
There are 13 measuring points around the circumference of the bearing shell to measure the pressure. The pressures are read off from a 13 tube manometers using the height of each column of liquid. The lubricant is supplied via an oil pan. The bearing shell is transparent, allowing close observation of the experiment.



1 TM 260 base module, 2 bearing gap width adjustment, 3 oil pan, 4 shaft, 5 bearing housing with bearing shell, 6 tube manometers



How adjustment of the bearing shell (bearing gap width) works: 1 bearing shell in right-hand position, 2 bearing shell in left-hand position



Pressure distribution over the bearing shell; pressure increases as the bearing gap decreases

Specification

- [1] demonstration and visualisation of the pressure distribution in a journal bearing with hydrodynamic lubrication
- [2] quick and easy assembly of the experimental unit on the frame of the drive unit
- [3] roller is driven by a clampable coupling between drive unit and gear unit
- [4] bearing housing is completely transparent
- [5] moveable bearing housing, adjustable bearing gap
- [6] 13 radial pressure measuring points on the bearing shell
- [7] radial pressure distribution indicated with 13 tube manometers
- [8] TM 260 base module required for operation

Technical data**Shaft**

- diameter: 50mm
- length: 50mm
- material: stainless steel

Bearing shell

- diameter: 52,5mm
- bearing gap adjustable from: 0...2,5mm

Adjustment mechanism for bearing shell

- graduation: 0,01mm

Oil

- ISO viscosity grade: VG 32

Measuring ranges

- pressure: 360mm oil column
- speed: 0...200min⁻¹

LxWxH: 350x150x450mm

Weight: approx. 4kg

Scope of delivery

- 1 experimental unit
- 1 oil (0,5L)
- 1 set of instructional material

TM 232

Bearing friction



Learning objectives/experiments

- determine the frictional moment in slide bearings with various friction pairs
- determine the frictional moment of a rolling bearing
- comparison of slide and rolling bearings
- basic experiments on rotational dynamics

Description

- **friction in slide bearings and roller bearings**
- **interchangeable bearing shells for slide bearings of different materials**

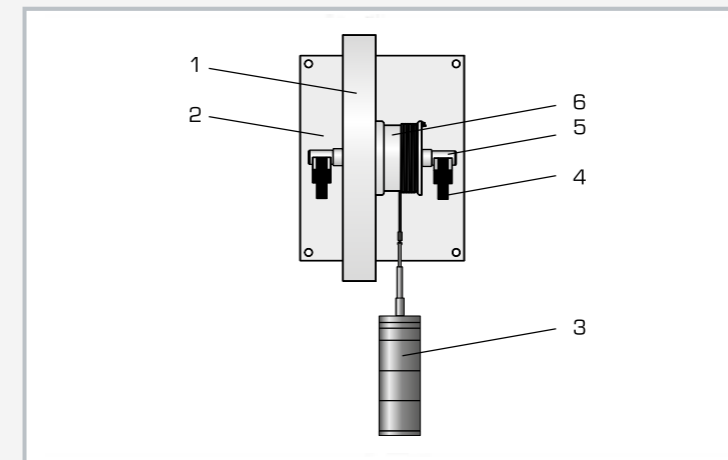
Bearings can be classified as slide bearings or roller bearings depending on the nature of their motion. In slide bearings, there is a sliding motion between the bearing and the supported component. In roller bearings, there is both sliding motion and rolling motion between rolling bodies and the supported component. Sliding motion is undesirable in roller bearings, e.g. between rolling body and cage. The bearing force is transferred in the roller bearing by means of rolling.

In both types of bearings—the slide bearing and the roller bearing—frictional forces occur during operation, which oppose resistance to the movement.

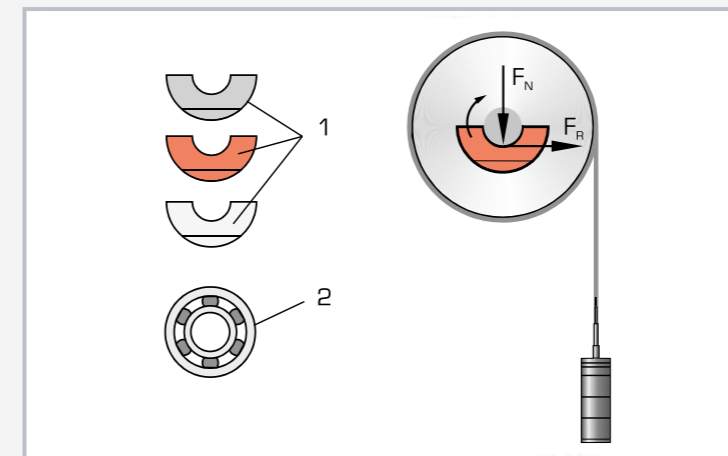
The TM 232 experimental unit allows investigations of friction on slide bearings with different bearing shells and on roller bearings. A shaft with a cable drum and flywheel is mounted on a base plate. The weight of the heavy flywheel generates bearing forces. A moment is applied by means of weights, which is equal to the friction moment at the start of the rotation. Replaceable bearing shells are used as slide bearings.

The coefficients of friction are determined in experiments. Bearing shells made of different materials are included in the scope of delivery in order to study different friction pairings. The bearing friction is very low when using the roller bearing. In this case, the flywheel can be used for basic experiments on rotational dynamics.

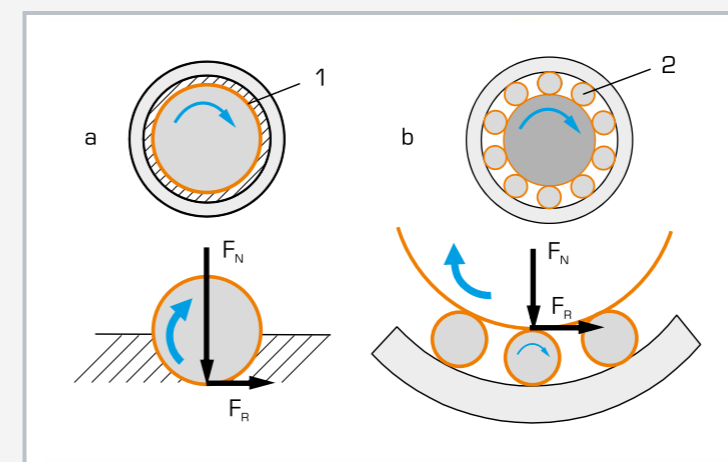
The experimental unit is designed to be fixed to a wall. The parts of the experiment are clearly laid out and securely housed in a storage system.



1 flywheel, 2 base plate, 3 weight, 4 bearing seat, 5 shaft, 6 cable drum



1 interchangeable bearing shells of cast iron, red bronze and plastic (PTFE), 2 roller bearing; F_N normal force, F_R frictional force



a dynamic friction in the slide bearing, 1 sliding surface
b dynamic friction and rolling friction in the rolling bearing, 2 roller bearing; F_N normal force, F_R frictional force

Specification

- [1] comparison of dynamic friction and rolling friction
- [2] experiments on rotational dynamics are possible
- [3] bearing shells of different materials as slide bearings
- [4] steel flywheel, galvanised
- [5] drive via cable drum and weights
- [6] storage system for parts
- [7] bracket for wall mounting

Technical data

Bearing shells as slide bearing, half-shells

- GG-25
- red bronze
- PTFE (Teflon)

Deep-groove ball bearing

- type 6203

Shaft bearing journal

- $\varnothing=17\text{mm}$

Flywheel

- $\varnothing=300\text{mm}$
- weight: 22,2kg

Weights

- 1x 1N (hanger)
- 5x 1N
- 1x 2N
- 3x 5N

Base plate

- LxW: 250x200mm

LxWxH: 200x330x300mm

Weight: approx. 30kg

LxWxH: 290x140x130mm (storage system)

Scope of delivery

- 1 experimental unit
- 6 bearing shells
- 2 roller bearings
- 1 set of weights
- 1 storage system
- 1 set of instructional material

TM 282

Friction in journal bearings



Description

- fundamentals of hydrodynamic lubrication
- friction states under different operating conditions
- electronic speed control and digital display of speed and lubricant temperature

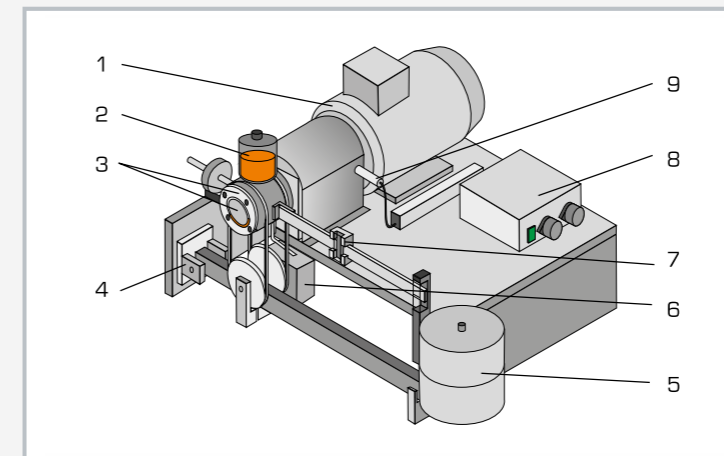
There are many factors that influence the friction states in a hydrodynamic journal bearing. Speed, load and viscosity of the lubricant used are focused on in particular.

TM 282 allows the study of various factors that influence friction. The journal bearing comprises an electrically driven shaft journal that rotates in a freely movable bearing housing. The movement of the oil in the bearing can be observed.

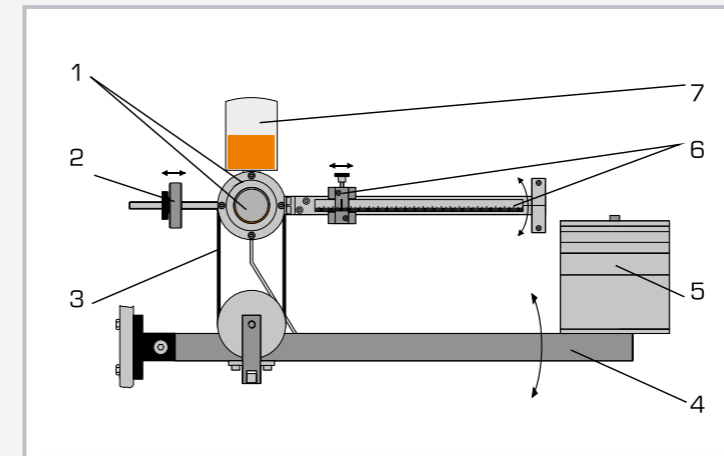
The applied load is transmitted to the bearing housing through a load application device and can be varied by means of weights. The frictional moment is determined by means of a movable weight that balances the moment on a balance beam. The journal is driven by an electric motor at a speed that can be adjusted by a frequency converter. The temperature (and therefore the viscosity) of the lubricant is recorded by a temperature sensor in the bearing shell and shown on a screen on the display and control unit. The lubricant is supplied via a wick oiler that applies the oil via two grooves in the bearing bush. The accumulated leakage oil is collected in a collecting tank.

Learning objectives/experiments

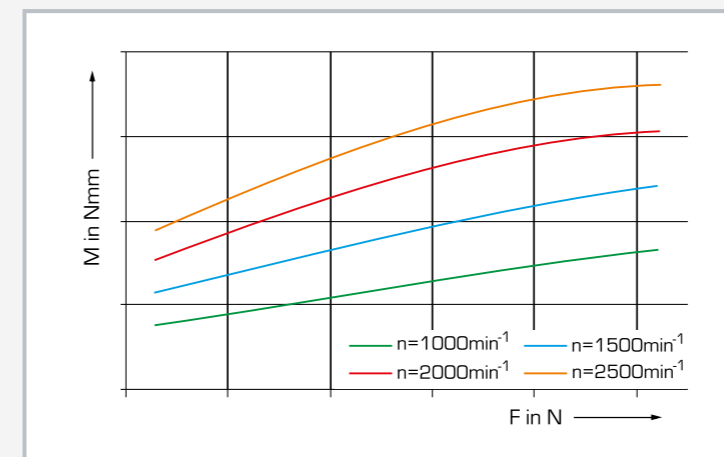
- develop an understanding of technological relationships of hydrodynamic lubrication by experimentation
- frictional moment in a journal bearing as a function of
 - ▶ speed
 - ▶ bearing load
 - ▶ lubricant and lubricant temperature



1 motor, 2 drip oiler, 3 journal bearing housing with shaft journal, 4 fixed support for loading lever, 5 weights, 6 tank for leak oil, 7 sliding weight to measure frictional moment, 8 switch box, 9 speed sensor



1 journal bearing housing with shaft journal, 2 tare weight, 3 belt to transfer force to the bearing housing, 4 loading lever, 5 weights, 6 measuring lever with scale and sliding weight, 7 drip oiler



Influence of the loading force F and the speed n on the frictional moment M

Specification

- [1] investigation and visualisation of hydrodynamic bearing
- [2] radial journal bearing with stainless steel journal and freely movable bronze bearing shell
- [3] drip lubrication for continuous supply of lubricant (drip oiler)
- [4] journal bearing subjected to load by means of mechanical lever
- [5] variable speed via frequency converter
- [6] frictional moment measured by level with sliding weight
- [7] inductive speed measurement
- [8] thermocouple in the bearing housing to measure the oil temperature
- [9] display and control unit with digital displays for oil temperature and speed

Technical data

Journal bearing

- shaft diameter: $\varnothing=30\text{mm}$
- bearing width: 45mm
- friction pair: steel/bronze

Motor: 0,37kW

Oil viscosity grade: ISO VG 32

Weights

- 1x 50N, 1x 20N, 2x 10N, 2x 5N, 2x 5N
- lever transmission ratio: 5:1

Measuring ranges

- temperature: $-50\dots 200^\circ\text{C}$
- speed: $100\dots 3000\text{min}^{-1}$
- bearing load: max. 525N
- friction moment: max. 295Nmm

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 610x440x360mm (experimental unit)

LxWxH: 360x340x160mm (display and control unit)

Weight: approx. 40kg

Scope of delivery

- 1 experimental unit
- 1 display and control unit
- 1 set of weights
- 1 oil (0,5L)
- 1 set of instructional material

TM 280

Pressure distribution in journal bearings



Learning objectives/experiments

- visualisation and investigation of instability in journal bearings
- displacement of the shaft journal as a function of the speed
- pressure distribution in the bearing under constant load and different speeds
- critical speed as a function of the load
- critical speed as a function of the oil temperature

Description

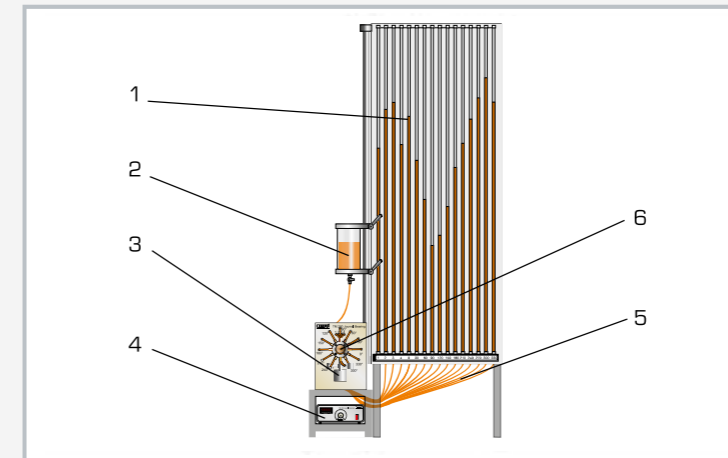
- ideal observation of the function thanks to transparent bearing housing
- clear representation of the pressure distribution in the journal bearing
- investigation and visualisation of instability in journal bearings

In hydrodynamic journal bearings, the shaft and the bearing shell are separated from each other by a lubricating film during operation. The supporting function of the lubricating film in a journal bearing can be described by the pressure distribution in the bearing gap.

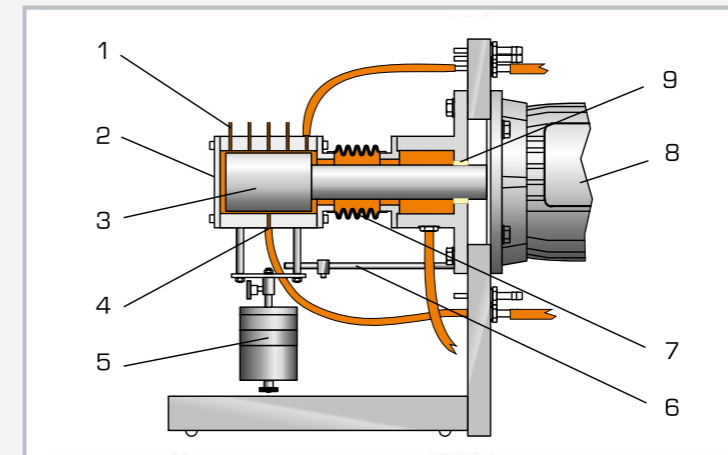
The TM 280 unit is used to visualise the pressure curve in the journal bearing with hydrodynamic lubrication. To do this, there are twelve measuring points around the circumference of the bearing shell and four measuring points in the longitudinal direction. The respective pressures can be read via a 16 tube manometers with reference to the height of the liquid columns.

The journal bearing comprises an electrically driven shaft journal that rotates in a freely movable bearing housing. Oil is used as the lubricant.

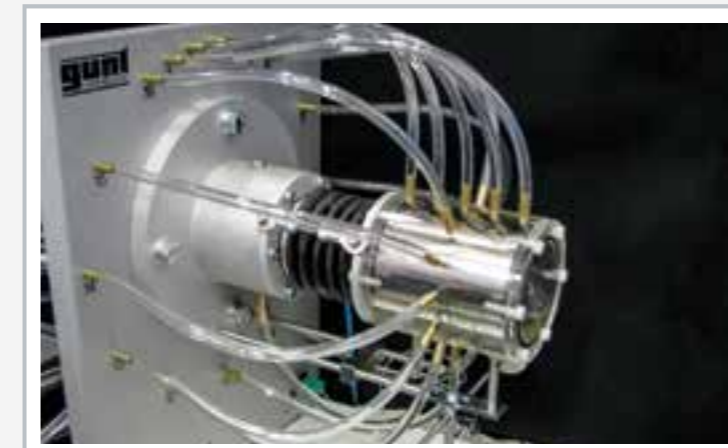
The displacement of the shaft journal depends on the speed and direction of rotation as well as the characteristic behaviour during start-up, and can be observed through the transparent bearing housing. Speed and direction can be adjusted. The load on the journal bearing can be adjusted by varying the weights. The temperature in the bearing gap is measured in order to determine the viscosity of the lubricant.



1 tube manometers, 2 tank for oil, 3 weight, 4 display and control unit for speed control, 5 measuring hoses, 6 journal bearing with drive



1 measuring points, 2 transparent bearing housing, 3 journal, 4 measuring point, 5 weight, 6 anti-twist device, 7 bellows, 8 drive motor, 9 radial sealing ring



Detailed view of the TM 280 journal bearing unit

Specification

- [1] visualisation and investigation of pressure distribution in journal bearings
- [2] bearing housing is completely transparent
- [3] continuously adjustable speed, electronically controlled
- [4] bearing subjected to load by means of weights
- [5] temperature measurement in the bearing housing
- [6] 12 measuring points on the periphery, 4 measuring points in the longitudinal direction
- [7] pressure distribution indicated with 16 tube manometers
- [8] digital display of speed on the display and control unit

Technical data

Bearing

- nominal bearing diameter: 51mm
- bearing gap width: 4mm
- bearing width: 75mm
- bearing load: 6,7...16,7N

Motor

- power: 0,37kW
- max. speed: 3000min⁻¹

Oil ISO viscosity grade: VG 32

Tank for oil: 2,5L

Weights

- 1x 1N (hanger)
- 2x 2N
- 1x 5N

Measuring ranges

- pressure: 1770mm oil column, 16x
- temperature: -10...50°C
- speed: 0...3000min⁻¹

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 1100x750x2650mm

Weight: approx. 110kg

Scope of delivery

- 1 trainer
- 1 display and control unit
- 1 set of tools
- 1 set of weights
- 1 hydraulic oil [5L]
- 1 handheld temperature measuring unit
- 1 set of instructional material

TM 290

Journal bearing with hydrodynamic lubrication



Learning objectives/experiments

- determine the coefficients of friction at various loads and speeds, compare with Stribeck curves
- influence of speed, bearing clearance and bearing load on the displacement of the shaft
- influence of speed, bearing clearance, bearing load and lubricant on the frictional moment
- locus of the shaft



Description

- frictional moment under different bearing clearances and loads
- pressure distribution in the journal bearing
- locus of the shaft under different loads and speeds

In hydrodynamic bearings, the shaft and the bearing shell are separated from each other during operation by a supporting lubricating film. The pressure in the lubricating film in hydrodynamic journal bearings is generated by the relative motion between bearing shell and shaft. The position of the shaft in relation to the speed and the load is important for an analysis of the tribological process in the bearing shell of a journal bearing.

The TM 290 trainer allows the study of a hydrodynamically lubricated radial journal bearing. Five shafts with different diameters allow the operating behaviour to be analysed as a function of the bearing clearance.

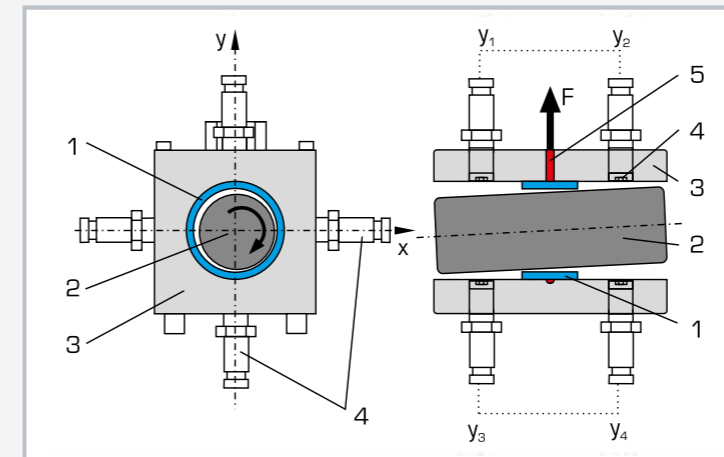
The radial load on the journal bearing is applied by means of a handwheel and measured electronically. Similarly, the frictional moment is measured using a force sensor. The shaft is driven by a three-phase motor. The speed is continuously adjustable via a frequency converter and is displayed digitally. The oil temperature is adjusted using a controller.

Inductive sensors detect the relative motion of the shaft in the bearing. This measurement makes it possible to plot a locus of the shaft as a function of load and speed. The position is measured, averaged and displayed at four points on the shaft in each of the X and Y directions.

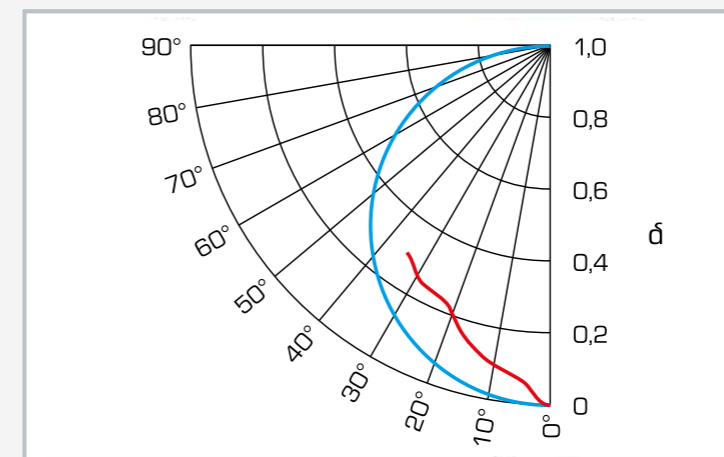
Oil temperature, oil pressure and oil peak pressure in the bearing are measured and displayed by additional sensors. The measured values are read from digital displays and can be transmitted simultaneously via USB directly to a PC where they can be analysed using the software included.



1 handwheel for load, 2 force sensor for frictional moment, 3 inductive displacement sensors, 4 shaft, 5 bearing housing, 6 displays and controls



Sectional views of the journal bearing: 1 bearing shell, 2 shaft, 3 bearing housing, 4 displacement sensors (4 in X direction, 4 in Y direction), 5 oil supply, F load



Movement of the shaft centre point during operation or startup behaviour, blue: theoretical semicircle curve, red: measuring results of TM 290, δ relative lubricating film thickness

Specification

- [1] friction states in hydrodynamically lubricated journal bearing
- [2] 5 shafts with different diameters for experiments with different bearing clearances
- [3] shaft driven by three-phase motor with frequency converter for continuous adjustment of the speed controller to adjust the oil temperature
- [4] radial load of the bearing by means of compression spring and threaded spindle with handwheel and measured via force sensor
- [6] determine the frictional moment by means of lever arm with force sensor
- [7] 8 inductive displacement sensors for measuring the displacement of the shaft
- [8] digital displays for radial load, frictional moment, position of the shaft (X and Y direction), oil pressure, peak oil pressure, oil temperature and speed
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

Technical data

Journal bearing

- rated diameter of the shaft: 50mm
- radial load: 0...1000N
- bearing clearance: 0,12mm; 0,14mm; 0,16mm; 0,18mm; 0,28mm

Drive motor with frequency converter

- power: 0,55kW
 - speed: 0...1600min⁻¹
- Hydraulic unit to adjust the oil temperature
- flow rate: 1,4L/min, pressure: 2bar
 - tank capacity: 10L

Measuring ranges

- frictional moment: 0...1Nm
- radial load: 0...1000N
- displacement in X direction: $\pm 1,000$ mm
- displacement in Y direction: $\pm 1,000$ mm
- oil pressure supply: 1x 0...10bar
- oil pressure journal bearing: 1x 0...16bar
- oil temperature: 0...100°C
- speed: 0...1600min⁻¹

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 1200x800x1450mm
Weight: approx. 225kg

Required for operation

PC with Windows recommended

Scope of delivery

- 1 trainer
- 1 set of tools
- 1 oil (5L)
- 1 GUNT software CD + USB cable
- 1 set of instructional material

CE 105

Corrosion of metals



Description

- principles of corrosion and corrosion protection on metallic materials
- oxygen corrosion
- electrochemical corrosion (local elements)
- corrosion protection with external voltage and sacrificial anodes

Corrosion damage to metallic components causes considerable economic and technical damages. The issue of corrosion and corrosion protection therefore plays an important role in technical training.

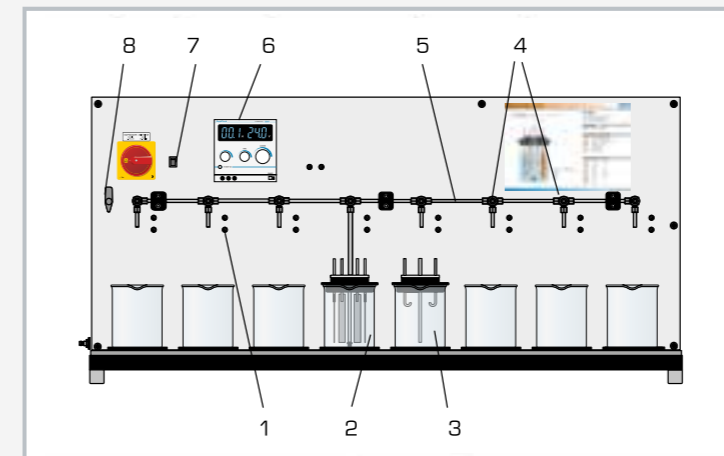
The CE 105 allows a variety of factors that influence corrosion processes to be investigated in parallel. Eight glass vessels are available to do this. They allow different materials to be compared under different conditions. The required electrolyte solution is added to the vessels. Up to six specimens can be attached to the cover of each vessel and these are immersed in the solution.

It is possible to connect specimens to an electrical conductor to investigate local elements and the principle of sacrificial anodes. An adjustable power pack allows an external voltage to be connected. This counters the current flow between precious and base metals in local elements. As a result the corrosion rate of the more base metal is reduced.

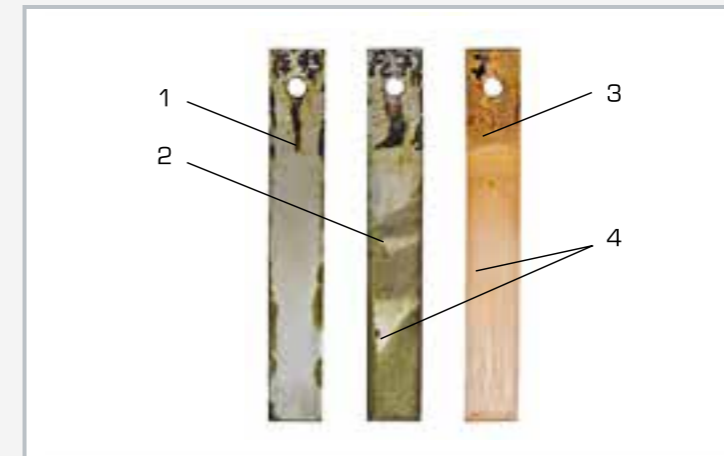
A diaphragm pump conveys ambient air into the electrolyte solution as required. Flow control valves can be used to individually adjust the gas flow rate for each vessel. It is also possible to feed other gases provided by the laboratory into the electrolyte solution. A pH meter is included to allow the influence of the electrolyte solution on corrosion processes to be investigated and compared.

Learning objectives/experiments

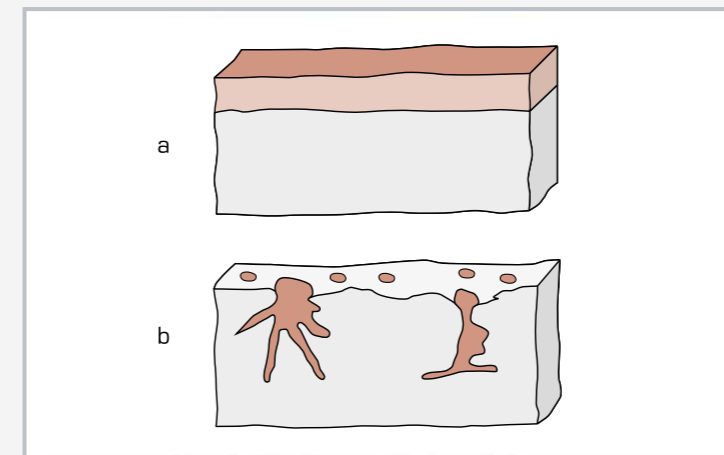
- corrosion behaviour of different metallic materials (rust / passivation)
- formation of local elements
- influence of pH value of the electrolyte solution
- influence of salt concentration in the electrolyte solution
- oxygen corrosion
- corrosion protection
 - ▶ external voltage
 - ▶ sacrificial anodes
 - ▶ protective layers



1 electrical connecting sockets, 2 electrolyte vessel with specimens and specimen holders (clamps), 3 electrolyte vessel with specimen holders (hooks), 4 flow control valves, 5 gas supply, 6 power pack, 7 diaphragm pump switch, 8 air / external gas supply reversing valve



Experimental result: a steel specimen (2) and a copper specimen (3) were electrically connected (4) and supplied with an external voltage. A steel specimen (1) with no electrical connection was used as a reference.



Two corrosion types: a surface corrosion, b pitting

Specification

- [1] investigation of corrosion and corrosion protection measures
- [2] 8 electrolyte vessels with covers and 6 specimen holders each
- [3] adjustable power pack for application of external voltage
- [4] air supply via diaphragm pump
- [5] reversing valve for air or external gas supply
- [6] adjustment of gas flow rate for each vessel using flow control valves
- [7] recording of pH value of electrolyte solutions using manual unit
- [8] pressure range for external gas supply: 0,2...1,0bar

Technical data

Electrolyte vessels
 ■ capacity: 1000mL
 ■ material: glass

Power pack
 ■ voltage: 0...30VDC
 ■ current: 0...5A

Diaphragm pump: approx. 260L/h

Specimens
 ■ 6x stainless steel, steel, copper, brass, aluminium
 ■ 3x glass
 ■ dimensions: 100x15x1mm

Measuring ranges
 ■ pH value: 0...14
 ▶ resolution: 0,01

230V, 50Hz, 1 phase
 230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase
 UL/CSA optional
 LxWxH: 1280x460x630mm (experimental unit)
 Weight: approx. 55kg
 LxWxH: 730x480x240mm (storage system)
 Weight: approx. 15kg

Scope of delivery

- 1 experimental unit
- 1 pH meter
- 1 set of specimens
- 1 set of cables
- 1 coupling to connect an external gas supply
- 1 storage system
- 1 set of instructional material