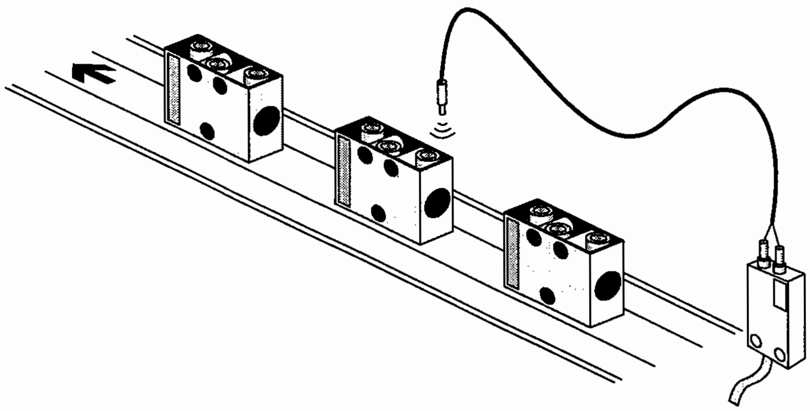
FESTO

Sensors for handling and processing technology

Sensors for distance and displacement

Workbook
FP 1120



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Layout of the workbook

The workbook D:LW-FP1120-GB (Order No. 090156) was designed for equipment set (Order No. 184475) of function package FP1120.

The workbook and the equipment set are part of the Learning System for Automation and Communications by Festo Didactic GmbH & CO.KG. The book was designed for both course training as well as self-tuition.

The book is divided into:
Section A   Course
Section B   Fundamentals
Section C   Solutions
Section D   Appendix

Section A – Course
The course provides the required subject knowledge with the help of selected exercises. The contents of individual topics have been coordinated in that the exercises supplement one another, yet can be carried out individually. References point out further and more detailed information contained in both the fundamentals section as well as the collection of component data sheets in the appendix section.

Section B – Fundamentals
This part comprises the theoretical fundamentals on the subject. Topics are arranged according to subject area. The fundamentals section can be worked through by chapter or used for reference.

Section C – Solutions
This section features the solutions to the exercises in the course section.

Section D – Appendix
The final section of the book contains a collection of component data sheets relating to the equipment set.

The book can be incorporated into an existing training program.

What are sensors?

1. Sensors and sensory organs

A sensor is a technical converter which converts a physical value such as temperature, distance or pressure, into a different value, which is easier to evaluate. This is usually an electrical signal such as voltage, current, resistance or frequency of oscillation. Alternative descriptions for sensors are encoders, detectors or transducers.

Sensor

The word 'sensor' is derived from the Latin 'sensus', in English 'feeling' or 'sensation'. The efficiency of many sensors is based on technical developments in semiconductor technology. They are used predominantly for the acquisition of measured data. Sensors can be broadly compared to the receptors of sensory organs, which also bring about the conversion of physical values, e.g. light, heat or sound pressure into a neuro-physiological sensation.

The efficiency of sensors and receptors for comparable measuring tasks or sensory perception respectively, varies considerably. As such our sensory organs perceive most values only approximately, and are therefore not suitable for the measurement of absolute values.

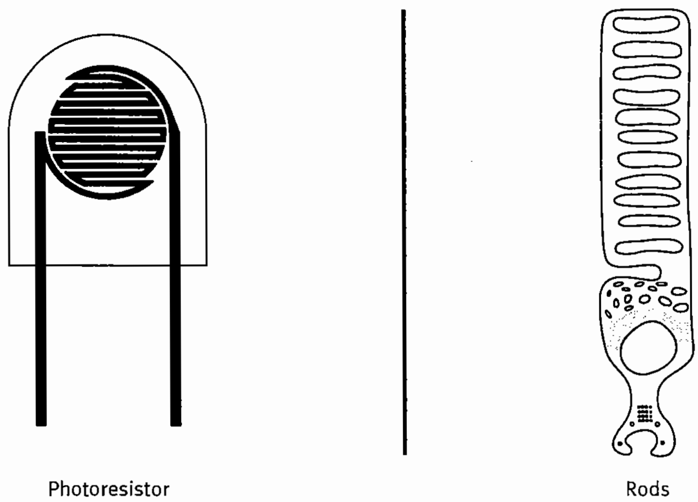


Fig. 1: Comparison of sensor and receptor

Rods are receptors in the retina of the eye and convey the black and white perception.

Sensory organs

The role of sensory organs consists primarily of the coordination of signals from several receptors, as well as the partial processing and evaluation of the signal. The human eye, for example, consists of the lens system, the iris diaphragm, the retina and approximately 120 million light-sensitive rods and approximately 6 million colour-sensitive cones. In addition to this are various muscles for the focussing of light beams and movement of the iris diaphragm. As such, some preliminary partial image processing already takes place in the nerve cells of the retina, e.g. the analysis of contours or movements. The brain then processes the images on a higher level, which includes the automatic focussing and control of the diaphragm, the perception of depth by means of superimposing the images from both eyes, compensating auto-movement of the eye and all other body movements. All this takes place prior to the actual, conscious function of seeing.

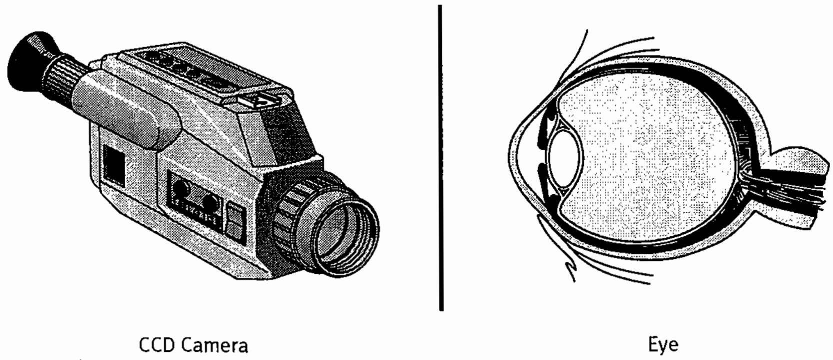


Fig. 2: Comparison of sensor system and sensory organ

Sensor systems

Here too, technology has adopted the line of copying the ingenuity of nature. Line or matrix-type configurations of several sensors of the same type, similar to CCD chips are described as sensor systems. CCD is the abbreviation for Charge Coupled Device and describes a CCD chip constructed from charge coupled semiconductors. The operational principle of a CCD chip is based on the premises that the electrical charge created by the photoelectric effect in the semiconductor is transmitted to a coupled memory, which is interrogated at a certain clock frequency.

Similarly, sensors where both sensor and signal processing are on the same semiconductor chip, are known as sensor systems. However, these sensor systems are still a long way off from achieving the complexity and capability of sensory organs.

Smart Sensor

In addition to the integration of amplifiers, attempts are being made to incorporate computing power into the sensor. This trend towards decentralised data processing results in improved data throughput. This type of sensor system, described as a "smart sensor" both in English and in German, could be more

Micro mechanics

With more recent micro mechanical developments, the mechanical elements of a sensor are also integrated into the silicon chip. Primarily, it is membrane, spring or oscillatory parts which are etched from silicon. Research laboratories have already succeeded in producing rotary and sliding connections, thereby paving the way for the construction of miniaturised mechanical devices. Micro mechanics combine the excellent mechanical properties of silicon, in particular its high elasticity, with the special electrical properties.

Biological sensors

A further interesting trend is the development of so-called biological sensors. These consist of a biologically active part, e.g. enzymes or bacteria, and a microelectronic part, which registers and processes the biological reactions. The first of these biological sensors are available specifically for the purpose of organic substances, e.g. determining blood sugar value. However, the future development of biological sensors cannot be predicted at this stage.

2. Use of sensors

Sensors are used in many areas of science and technology. In research, highly sensitive and specialised sensors are employed for the purpose of conducting experiments. In automation technology, both standard as well as specially developed sensors are in use. In the case of equipment for basic requirements, ordinary sensors are mainly used, though these need to function reliably and require no maintenance.

This workbook deals mainly with the use of sensors in automation with regard to achieving important criteria such as:

- Cost reduction
- Rationalisation
- Automation
- Flexibility
- Environmental protection

The use of sensors is however also due to the inherent developments in technology such as:

- increased sensitivity, precision, response rate and reliability
- adaptation to further developments in design and technology
- new technologies

Sensors are therefore used in automation because they:

- provide early and reliable signalling of error functions in automated systems, e.g. broken tools or congestion,
- localise the source of error as part of an intelligent error diagnosis,
- detect wearing tools,
- provide the measured values, which are required for continuous optimisation of the production process by means of adaptive control and adjustment,
- are used in automated quality control,
- monitor materials management and assist in automating material flow,
- perform product identification, which is essential in flexible automation,
- signal danger in the workplace, e.g. excessive concentration of pollutants,
- provide a more humane work environment, e.g. in the case of tiring or monotonous visual inspection, monitoring and measuring tasks in a hazardous environment.

Sensors are an integral part of complex equipment. In particular, the further development of robots will be based on the use of sensors. After all, even the CIM concept with all its technical, organisational and social structures would not be feasible without the use of sensor modules.

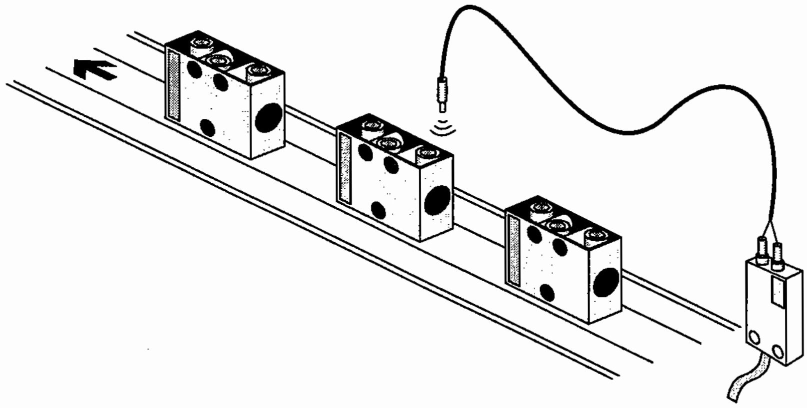


Fig. 3: A sensor monitors the assembly of a printed circuit board

3. Classification of sensors

The wide range of sensors is first of all classified on the basis of the physical quantity to be detected and secondly according to the operational principle or type of application.

Sensors	
for dimensional quantities	position, distance, length, travel, strain, gradient, speed, acceleration, angle of rotation, rotation as well as surface characteristics of work pieces
or force-related quantities	force, weight, pressure, torque and mechanical efficiency
for values of material quantity	flow rates and filling level of gaseous, liquid or solid materials
for temperature and heat quantity	
for evaluating quantities of optical radiance	radiant flux, radiant energy, radiant intensity, radiance and luminous quantities such as luminous flux, luminous energy, luminous intensity, luminance, illuminance. Moreover, this category should include all systems for image processing insofar as these are for the purpose of measuring tasks
for characteristics of acoustic waves	sound pressure, sound energy, sound level and audio frequency
for electromagnetic quantities	generally recognised elementary electrical quantities are voltage, current, electrical energy and power. Also included amongst these are electrical and magnetic field force and electromagnetic emission. The latter is limited by the above mentioned optical emission due to the wavelength supposition $\lambda > 10^{-3}$ m
for high-energy radiation	X-ray radiation, gamma radiation. The high-energy radiation is limited by the optical emission due to the wavelength supposition $\lambda < 10^{-10}$ m. Sensors for particle radiation such as electrons, alpha particles, elementary particles and nuclear fragments
for chemical substances	gases, ions and in particular water in the form of humidity, dew-point and icing sensors
for physical material properties	mechanical, electrical, optical, thermal and acoustic properties
for identification of objects and pattern recognition	This category generally includes sensor systems such as optical character readers, bar code readers, magnetic strip readers and image processing systems, which also could have been included in one of the previous categories, but form a separate group due to their specialised field of application

4. Sensor signals

Sensors convert a physical value, usually into an electrical signal. Sensors can be divided, according to the type of output signal, into binary sensors, also called switches, and analogue sensors.

Binary sensors

Binary sensors generate just two different output signals, i.e. the switching states "On" and "Off". The changeover from one switching state to another takes place at a very specific value of the physical variable; this switching value can often be set. In many instances, the switching point on the characteristic curve for an approaching object differs to that of a withdrawing object. The difference between the two switching points or threshold values is known as hysteresis. In many applications, hysteresis can be quite favourable in that it reduces the switching frequency in the case of closed loop control and leads to improved stability of the system.

Analogue sensors

Analogue sensors create an electrical signal which changes continually according to the constant change in physical value. This correlation need not necessarily be linear, but in contrast with binary sensors always indicates the actual size of the physical value. Analogue sensors offer more information than binary sensors; though the processing of signals is more costly.

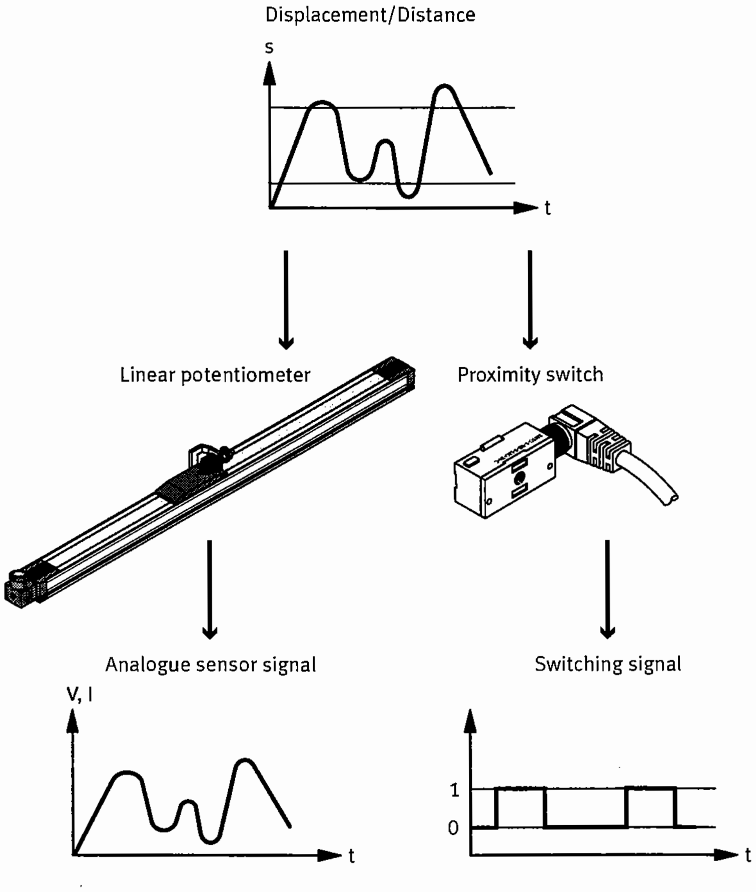


Fig. 4: Analogue and binary signals

This diagram illustrates the connection between a displacement and the binary and analogue sensor signals derived from this. In automation, analogue sensors are used, if a gradual change of the value is of significance. Binary sensors are however often used as limit monitors or alarm switches.

5. Information flow in automation

In research laboratories, quality assurance and process monitoring alike, sensors provide information on a technical production sequence or a physical or chemical reaction. These functions are known as a process. The information is indicated to the operator by means of a display instrument or fed into a data recording device, e.g. a computer. In this context, both the operator as well as the data recording device should be regarded as information processing systems. The term 'processors' is used to describe these systems.

Process measurement

In process measurement, information flows from the process via the sensor or generally speaking from the sensors to the processor.

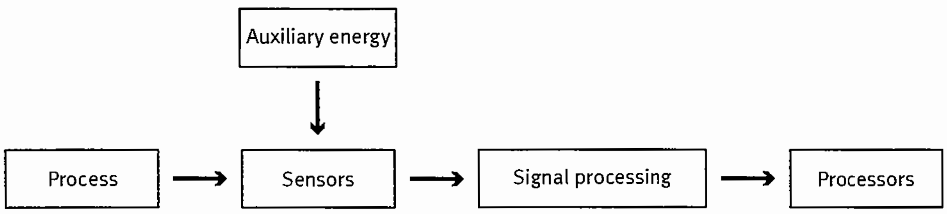


Fig. 5: Information flow in measuring technology

Process control

In process control the information flow is the reverse. The operator or a processor intervenes in the process with the help of actuators. The information flows from the processor to the process via the actuators.

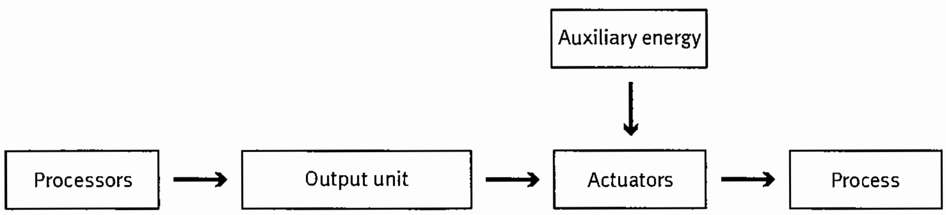


Fig. 6: Information flow in control technology

Automation technology

In automation technology, both types of information flow occur. The closed circuit of information ressembles closed loop control technology, i.e. processor to process and back again to the processor, but places the emphasis on the methods of transmitting and processing information. Control loops can be part of an automation system.

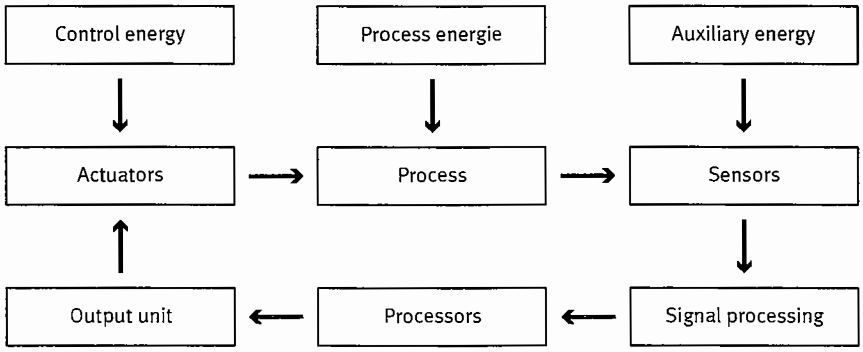


Fig. 7: Information flow in automation

User notes

FP 1120

The core subject of function package FP 1120 is sensors for distance and displacement. The equipment is assembled on an aluminium profile plate and measurements are conducted by means of a digital multimeter.

The use of graph paper is recommended for the graphic representation of results for individual exercises.

Practical and theoretical knowledge is taught regarding inductive, potentiometric, optical and ultrasonic analogue sensors. Sensor characteristics can be determined by means of experiments, e.g. accuracy, resolution, linearity and hysteresis.

Operating notes

Apart from the general notes on safety, the following operating notes should be observed:

To set the equipment for measurement

- Switch off voltage supply
- Complete the electrical circuit and note the polarity of the voltages to be connected
- Check the circuit by means of the circuit diagram
- Switch on the power supply at a regulated voltage of 24 V DC/4.5 A

Having completed the measurements

- Switch off power supply
- Disconnect measuring lines

Signal changeover switch
Order No. 150538

The voltage signals are connected to output 0 via the signal changeover switch, and the current signals are connected to output 1. The signal changeover switch switches the signals of both input sockets to the respective output sockets for each switching position.

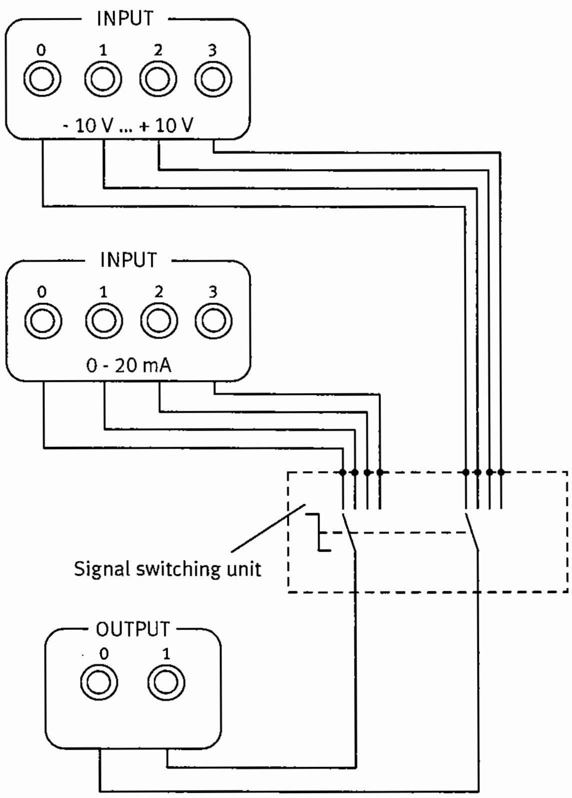


Fig. 8: Principle of interconnection of the signal switching unit and the connection

Equipment set

Equipment set FP 1120
Order No. 184475

Quantity	Order No.	Components
1	019500	Intermediate plate
1	019505	Adapter for height setting
1	034009	Set of weights
1	034070	Reflector for LU
1	034083	Set of test objects
1	034094	Positioning slide*
1	036279	Deflecting strip
1	080824	Spindle drive unit
1	080828	Geared motor
1	109383	Profile rail, length 318 mm
1	115615	Profile rail, length 168 mm (C/E)
1	115616	Profile rail, length 168 mm (B/C)
1	150519	Adapter for profile plate
1	150536	Mountable vernier caliper
1	150538	Signal switching unit
1	150539	Assembly set for rotary drive
1	150540	Mounting set for mountable vernier caliper
1	162247	Connection unit, analogue*
1	162249	Motor controller *
1	167051	Analogue optical distance sensor
1	177465	Linear potentiometer
1	177469	Analogue ultrasonic distance sensor
1	184117	Analogue inductive distance sensor
2	184130	Proximity sensor, inductive magnetic, non-contact
12	323571	Plug-in adaptors

* In order to assemble the designated unit on the profile plate, 4 plug-in adaptors order no. 323571 are required.

Equipment set

The following components have been designed for use with the equipment set:

Accessories

Quantity	Order No.	Components
1	035653	Vernier caliper
1	035681	Digital multimeter

Equipment

Quantity	Order No.	Components
1	159411	Profile plate, large, 1100 mm x 700 mm
		or
1	159409	Profile plate, small, 550 mm x 700 mm
		or
1	159410	Profile plate, quadratically 700 mm x 700 mm
		or
1	159331	Slotted mounting plate, 297 mm x 532 mm**

Power supply units

Quantity	Order No.	Components
1	164417	Power supply unit, tabletop version Germany, Austria et al.
		or
1	162381	Power supply unit, tabletop version Switzerland
1	159396	Power supply unit for ER mounting frame, version Germany, Austria et al.
		or
1	162414	Power supply unit for ER mounting frame, version Switzerland
1	167091	Set of cables

** The slotted mounting plate is suitable for examples 1, 2, 4, 5, 7, 8, 9. Possibly two of them are needed.
For exercises 3 and 6 the use of a profile plate is recommended.

Components-exercises table

Order No.	Components	Exercises								
		1	2	3	4	5	6	7	8	9
019500	Intermediate plate						1			
019505	Adapter for height setting					1	1			
034009	Set of weights			1						
034070	Reflector for LU						1			
034083	Set of test objects	1	1					1	1	1
034094	Positioning slide	1	1	1	1			1	1	1
036279	Deflecting strip			1						
080824	Spindle drive unit					1	1			
080828	Geared motor				1	1	1			
109383	Profile rail, length 318 mm			1			1			
115615	Profile rail, length 168 mm (C/E)			1						
115616	Profile rail, length 168 mm (B/C)			1	1					
150519	Adapter for PP					1	1			
150536	Mountable vernier caliper					1	1			
150538	Signal switching unit	1	1	1	1	1	1	1	1	1
150539	Mounting kit DE				1					
150540	Mounting kit for mountable vernier caliper					1	1			
162247	Connection unit, analogue	1	1	1	1	1	1	1	1	1
162249	Motor controller				1	1	1			
167051	Analogue optical distance sensor							1	1	1
177465	Linear potentiometer					1				
177469	Analogue ultrasonic distance sensor						1			
184117	Analogue inductive distance sensor	1	1	1	1					
184130	Proximity sensor, inductive magnetic, non-contact					2	2			
323571	Plug-in adaptors	1	1	1	1	1	1	1	1	1
035653	Vernier caliper	1	1	1	1			1	1	1
035681	Digital multimeter	1	1	1	1	1	1	1	1	1
diverse	Profile plate, large or small	1	1	1	1	1	1	1	1	1
diverse	Power supply units	1	1	1	1	1	1	1	1	1
167091	Set of cables	1	1	1	1	1	1	1	1	1

Section A – Exercises

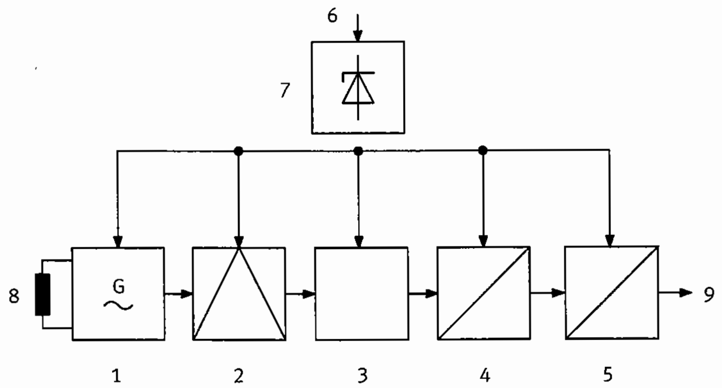
Determining the characteristic curve of an analogue inductive sensor

Learning contents

- To learn about the response characteristics of an analogue inductive sensor.
- Determining the characteristic curve of an analogue inductive sensor.
- Determining the responsivity of an analogue inductive sensor.
- Assess the reproducibility, linearity and hysteresis error of the measurements.

Technical knowledge

Analogue inductive sensors consist of an oscillator circuit made up of a parallel resonant circuit with coil (inductance) and a capacitor (capacitance) as well as an amplifier. The electromagnetic field is directed towards the outside by means of a ferrite shell core of the coil. If an electrically conductive material is introduced into the active zone of the stray field, eddy currents are induced into the material according to the laws of induction, which attenuate oscillation. Attenuation of the oscillator varies according to the conductivity, permeability, dimensions and proximity of the object. Attenuation of the oscillator is evaluated via subsequent electronic stages and an output signal is generated which, within a defined measuring range, is proportional to the distance between the sensor and the material.



1	Oscillator	6	External voltage
2	Demodulator	7	Internal constant voltage supply
3	Amplifier	8	Coil with active zone
4	Linearisation	9	Output: Current or voltage signal
5	Output signal conditioning		

Fig. 1/1: Block diagram of analogue inductive sensor

Problem description

The thickness of steel discs (S 235 JR) is to be determined by means of an analogue inductive sensor prior to further processing. Examine whether this type of sensor is suitable for this application and the degree of accuracy which can be achieved in the measurements if the discs are measured on a plane table. The steel discs are on a non-metallic base.

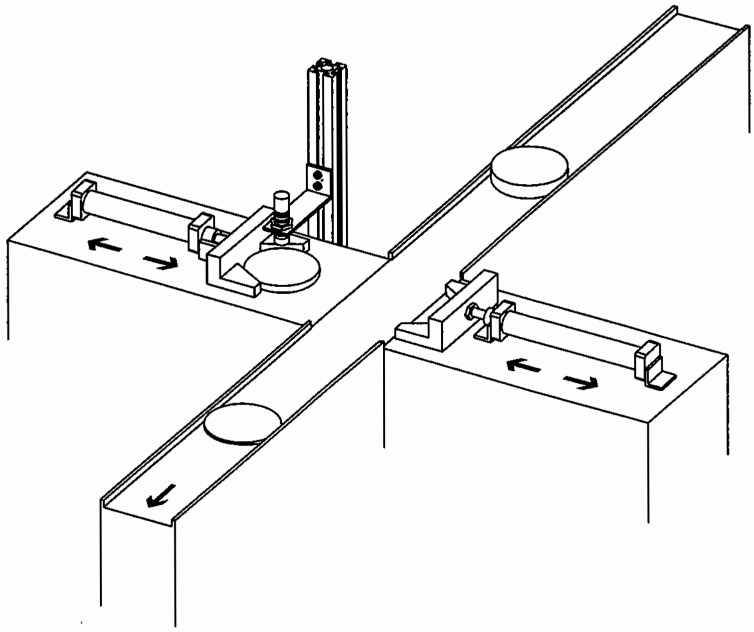


Fig. 1/2: Thickness measurement

Exercise

Carry out the following part exercises on the profile plate or slotted mounting plate. Evaluate the test results with the help of the worksheets.

a) Determining the characteristic curve of the analogue sensor (first series of measurements).
b) Carry out two repeat test measurements (measurement series 2 and 3).
c) Examine the hysteresis of the sensor (measurement series 4 and 5).

Note

If required, all the part exercises can be carried out using the analogue voltage output (black connector), instead of the analogue current output. Select the appropriate measuring range on the multimeter. The tables and diagrams contained in the worksheets and solution sheets are designed for the current output and need to be adapted if the voltage output is used.

Practical implementation

The component reference number in the equipment set refers to the layout diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Analogue connection unit
2	1	Signal switching unit
3	1	Analogue inductive sensor
4	1	Positioning slide
	1	Objektsortiment ?, part 3: Steel (S 235 JR), 90 mm x 30 mm
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
5	1	Vernier caliper
6	1	Digital multimeter

For the necessary equipment and supply units see page 20.

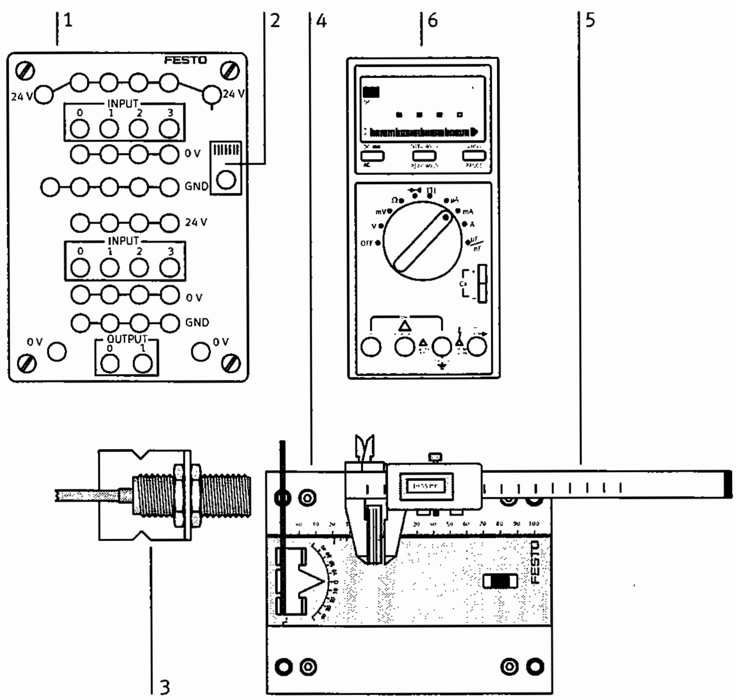


Fig. 1/3: Layout diagram

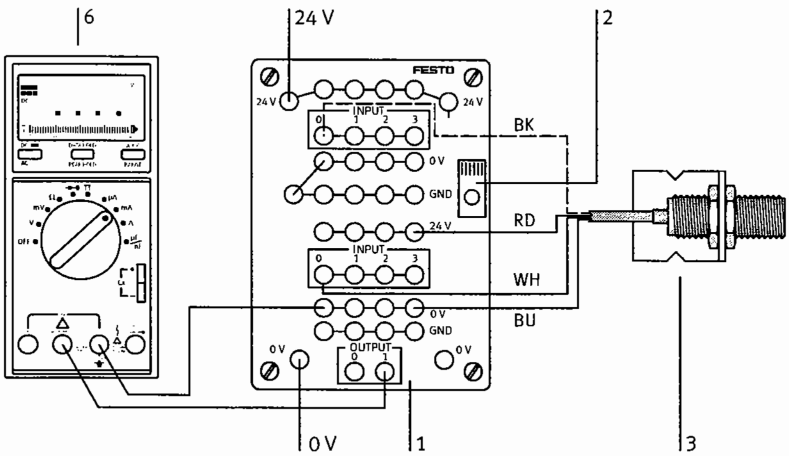


Fig. 1/4: Electrical connection

Note

The voltage output of the connection plate is socket OUTPUT 0, and the current output socket OUTPUT 1.
Please also follow the user notes at the beginning of the book.

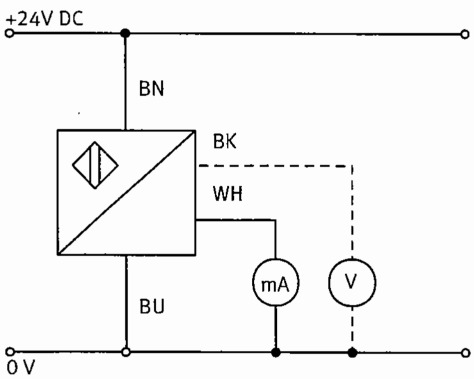


Fig. 1/5: Electrical circuit diagram

Procedure

Assemble the mechanical components on the profile plate or slotted mounting plate:

- See fig. "Layout diagram" and table "Equipment set".
- When mounting the vernier caliper, the slide unit of the positioning slide is set at "0". The two pointers of the vernier caliper are moved apart by approximately 10 mm. The vernier caliper is placed parallel to the base plate flush with the edge in such a way that the front pointer rests against the stop for the vernier caliper. The caliper body is attached on the base plate of the positioning slide by the two retaining magnets.
- Insert the object to be measured (steel plate S235 JR, 90 mm x 30 mm) in the material retainer of the positioning slide.
- Mount the analogue inductive sensor laterally offset by 5 cm in relation to the centre of the positioning slide.

Establish all the electrical connections:

- See fig. "Electrical connection" and "Electrical circuit diagram".
- In this exercise, the connection plate is used solely as a connecting aid without PLC interfacing.
- Connection of inductive sensor:

Plug	**Connection**
red (RD)	+24 V
blue (BU)	0 V
white (WH)	analogue current output

To set the equipment for measurement:

- Move the item to be measured towards the analogue inductive sensor by using the positioning slide. Set the digital indicator of the vernier caliper to "0" when the plate touches the sensor.
- Latch the signal changeover switch at "0" position.
- Select the appropriate range on the multimeter, see sensor data sheet.
- Switch on the 24 V power supply.

Part exercise a)

Carry out the first series of measurements, and record the values in the table of the worksheet.

- Make a note of the output current of the analogue inductive sensor in relation to the distance of the steel plate from the sensor. The active sensing range of the sensor is entered when the previously constant output current changes.
- Distance the item to be measured from the sensor in 1 mm increments.

Transfer the measured data to the diagram. Use a different designation for each series of measurements (e.g. colour), in order to obtain a clear representation.

Part exercise b)

Carry out two repeat series of measurements – series 2 and 3 – and record the values in the tables and on the diagram.

Part exercise c)

Examine whether the sensor displays a hysteresis.
Series of measurements 4 and 5: Move the item to be measured towards the sensor in 1 mm increments.
Record the values in the tables and in the diagram.

Note

In order to obtain the value of distance s for any output current I of the sensor, apply the line equation:

$$I = R \cdot S + S_0$$

$$R = \frac{\Delta I}{\Delta s}$$

R = Straight line gradient
s_0 = y-axis direction

The conversion factor R is described as the responsivity of the sensor.

Part exercise a)

Measurement series 1								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)								
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)								

Part exercise b)

Measurement series 2								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)								
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)								

Measurement series 3								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)								
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)								

Part exercise c)

Measurement series 4								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)								
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)								

Measurement series 5								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)								
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)								

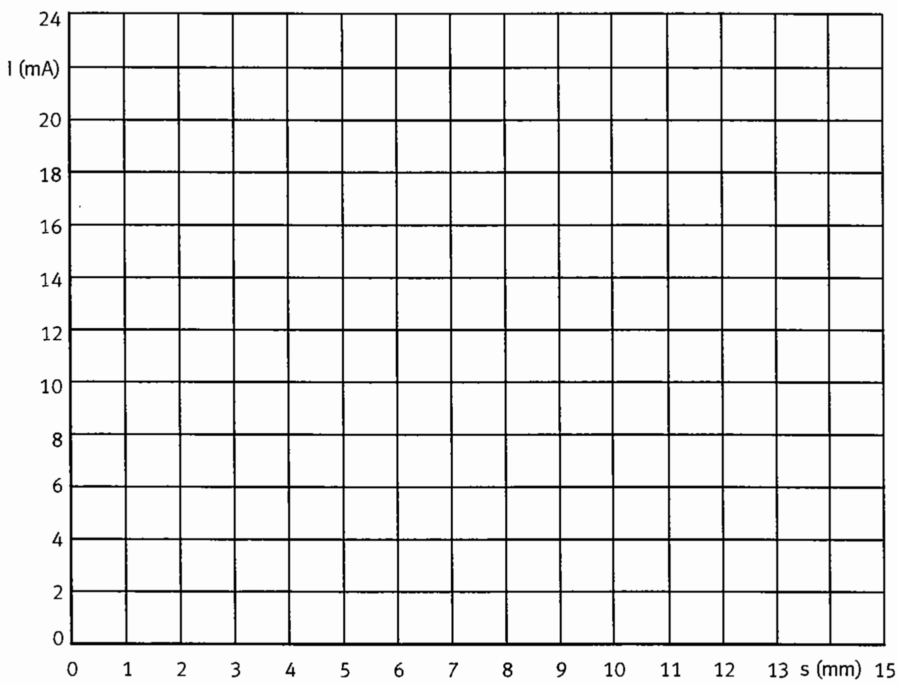


Fig. 1/6: Diagram I=f(s) of an inductive sensor

Questions

From what distance s_0 does the range of measurements start?

____

From what distance do you obtain a linear correlation between the object distance and the output signal of the sensor?

____

Calculate the conversion factor R for steel (S 235 JR)

$$R = \frac{\Delta l}{\Delta s} = \frac{l_2 - l_1}{s_2 - s_1} = \_\_\_\_\_\_ = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

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You have examined the inductive distance sensor. Is the sensor suitable for measuring the thickness of steel discs? What is the degree of accuracy?

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Distance measurement by means of inductive sensors
Exercise 2

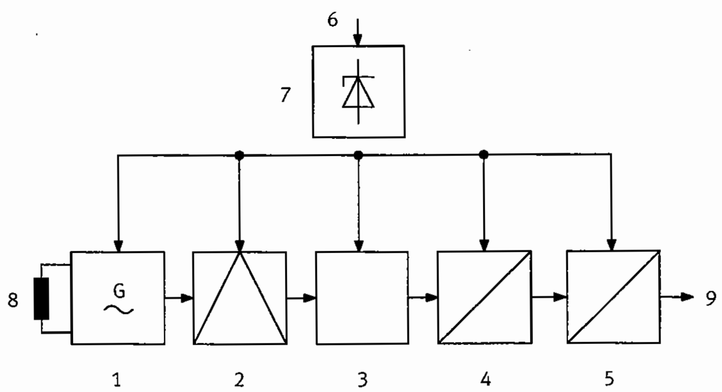
Effect of the object to be measured on the output signal of an analogue inductive sensor

Learning contents

- To identify the dependence of the output current on the material and the distance of the object to be measured.
- To identify the dependence of the output current on the cross-sectional area and on the distance of the object to be measured.

Technical knowledge

Analogue inductive sensors contain an oscillator circuit, which is made up of a parallel resonance circuit with coil (inductance) and a capacitor (capacitance) as well as an amplifier. The electromagnetic field is directed towards the outside by means of a ferrite shell core of the coil.
If an electrically conductive material is introduced into the electromagnetic stray field, eddy currents are induced into the material in accordance with the laws of induction, which attenuate oscillation. The degree of attenuation varies depending on the conductivity, permeability, dimensions and proximity of the approaching object. Attenuation of the oscillator is evaluated via subsequent electronic stages and an output signal is generated which, within a defined measuring range, is proportional to the distance between the sensor and the material.



1	Oscillator	6	External voltage
2	Demodulator	7	Internal constant voltage supply
3	Amplifier	8	Coil with active zone
4	Linearisation	9	Output: Current or voltage signal
5	Output signal conditioning		

Fig. 2/1: Block diagram of analogue inductive sensor

Problem description

Punched flat seals made of various metals in sizes R 1/4" and R 3/8" are sensed by means of an analogue inductive sensor and subsequently sorted.

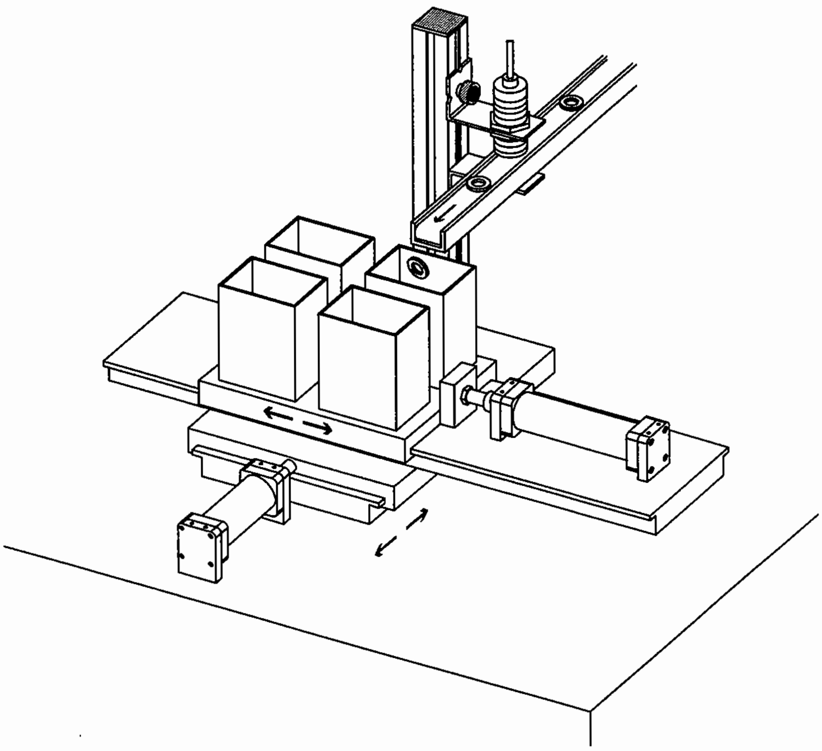


Fig. 2/2: Sorting device

Exercise

Carry out the following part exercises on the profile plate or Slotted mounting plate. Evaluate the test results with the help of the worksheets.

a) Determine the characteristic curve of the analogue sensor in respect of stainless steel, aluminium, brass and copper.
b) Examine the inter-relationship between the output current and the size of the object surface for measuring plates in steel.

Note

If required, all the part exercises can be carried out using the analogue voltage output (black connector), instead of the analogue current output. Select the appropriate measuring range on the multimeter. The tables and diagrams contained in the worksheets and solution sheets are designed for the current output and need to be adapted if the voltage output is used.
Please observe the operating notes!

Practical implementation

The component reference number in the equipment set refers to the layout diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Analogue connection unit
2	1	Signal switching unit
3	1	Analogue inductive sensor
4	1	Positioning slide
	1	Set of test objects Part exercise 1 Part 4: Stainless steel, 90 mm x 30 mm Part 5: Aluminium, 90 mm x 30 mm Part 6: Brass, 90 mm x 30 mm Part 7: Copper, 90 mm x 30 mm Part exercise 2 Part 11: Steel (S 235 JR), 30 mm x 30 mm Part 12: Steel (S 235 JR), 25 mm x 25 mm Part 13: Steel (S 235 JR), 20 mm x 20 mm Part 14: Steel (S 235 JR), 15 mm x 15 mm Part 15: Steel (S 235 JR), 10 mm x 10 mm Part 16: Steel (S 235 JR), 5 mm x 5 mm
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
5	1	Vernier caliper
6	1	Digital multimeter

For the necessary equipment and supply units see page 20.

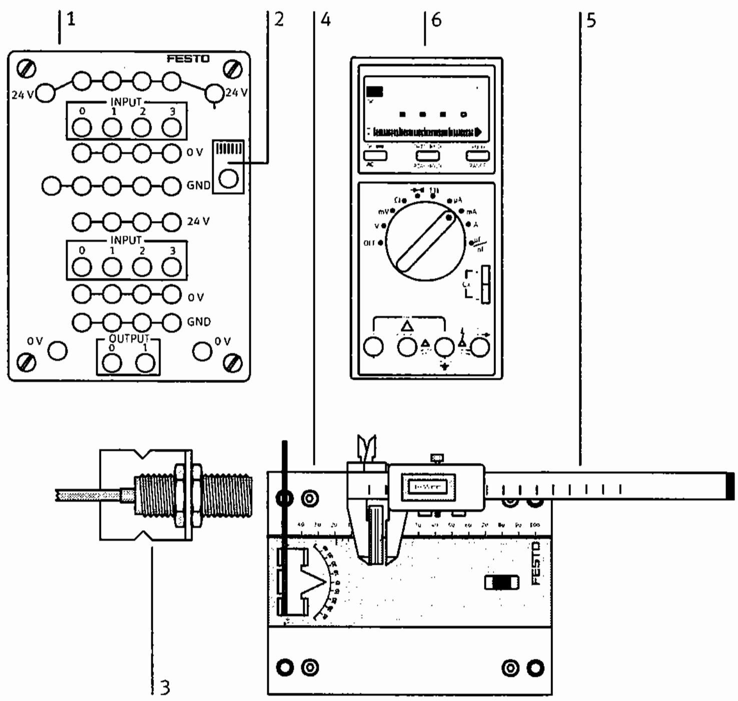


Fig. 2/3: Layout diagram

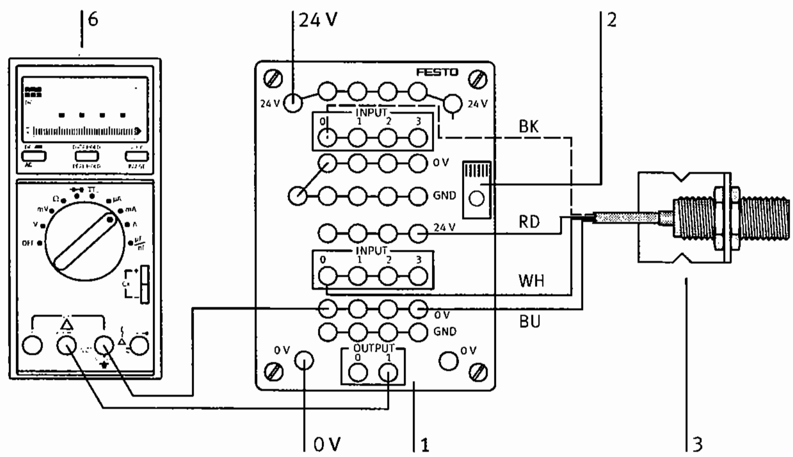


Fig. 2/4: Electrical connection

Note

The voltage output of the connection plate is socket OUTPUT 0 and the current output socket OUTPUT 1.
Please also follow the user notes at the beginning of the book.

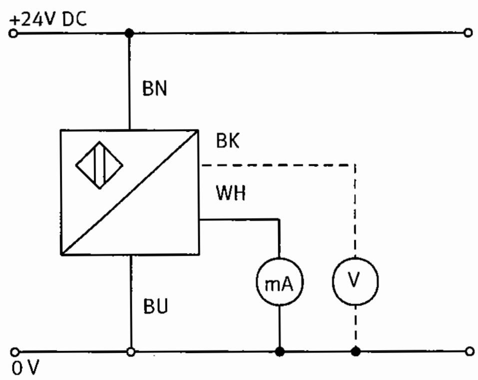


Fig. 2/5: Electrical circuit diagram

Procedure

Assemble the mechanical components on the profile plate or Slotted mounting plate:

- See fig. "Layout diagram" and table "Equipment set".
- When mounting the vernier caliper, the slide unit of the positioning slide is set at "0". The two pointers of the vernier caliper are moved apart by approximately 10 mm. The vernier caliper is placed parallel to the base plate flush with the edge in such a way that the front pointer rests against the stop for the vernier caliper. The caliper body is attached to the base plate of the positioning slide by the two retaining magnets.
- Insert the first object to be measured (stainless steel 90 mm x 30 mm) in the material retainer of the positioning slide.
- Mount the analogue inductive sensor laterally offset by 5 cm in relation to the centre of the positioning slide.

Establish all the electrical connections:

- See figs. "Electrical connection" and "Electrical circuit diagram".
- In this exercise, the terminal unit is used solely as a connecting aid without PLC interfacing.
- Connection of the inductive sensor:

Plug	**Connection**
red (RD)	+24 V
blue (BU)	0 V
white (WH)	analogue current output

Set the equipment for measurement:

- Move the item to be measured towards the inductive analogue sensor by using the rubber roller of the positioning slide. Set the digital indicator of the vernier caliper at "0", when the plate touches the sensor.
- Latch the signal changeover switch at "0" position.
- Select the appropriate measuring range on the multimeter, see sensor data sheet.
- Switch on the 24 V power supply.

Part exercise a)

Determine the characteristic curve of the analogue sensor for a stainless steel object.

- Carry out the measurements and record the values in the table of worksheet 1.
- Move the object to be measured away from the analogue inductive sensor by using the rubber roller of the positioning slide.
- Transfer the values to fig. 2/6 (diagram for part exercise a).

Determine the characteristic curve of the analogue sensor for the objects to be measured in aluminium, brass and copper.

- When changing the object, please ensure that the total sensor surface is covered by the object.
- Carry out the measurements and record the values in the tables.
- Transfer the values to fig. 2/6 (diagram for part excercise a)

Part exercise b)

Examine the inter-dependence between the output current and size of the object surface.

- Carry out three measurements with each of the six test sizes and enter the values in the table. Select a distance of 3 mm between the sensor and the object to be measured.
- Calculate the mean value for six test sizes.
- Transfer the values to fig. 2/7 (diagram for part exercise b).

Select a distance of 4 mm between the sensor and the object to be measured. Repeat all the measurements and evaluations.

Part exercise a)

Measuring object: Stainless steel

Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)										
Measurement series 2 Output current I (mA)										
Mean value Output current I (mA)										

Measuring object: Aluminium

Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)										
Measurement series 2 Output current I (mA)										
Mean value Output current I (mA)										

Measuring object: Brass

Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)										
Measurement series 2 Output current I (mA)										
Mean value Output current I (mA)										

Measuring object: Copper										
Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)										
Measurement series 2 Output current I (mA)										
Mean value Output current I (mA)										

Question

Which materials are particularly easy to differentiate?

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Part exercise b)

Test condition: Distance of sensor to measuring object 3 mm

Test size	**Output current I (mA)**			
Steel S 235 JR	Measured value 1	Measured value 2	Measured value 3	Mean value
Part 11: 30 x 30				
Part 12: 25 x 25				
Part 13: 20 x 20				
Part 14: 15 x 15				
Part 15: 10 x 10				
Part 16: 5 x 5				

Test condition: Distance of sensor to measuring object 4 mm

Test size	**Output current I (mA)**			
Steel S 235 JR	Measured value 1	Measured value 2	Measured value 3	Mean value
Part 11: 30 x 30				
Part 12: 25 x 25				
Part 13: 20 x 20				
Part 14: 15 x 15				
Part 15: 10 x 10				
Part 16: 5 x 5				

Question

f you transfer the result to the initial problem description given, is it then possible to differentiate between the metal rings (flat seals) on the basis of the above results as regards the effect of the material type and size?

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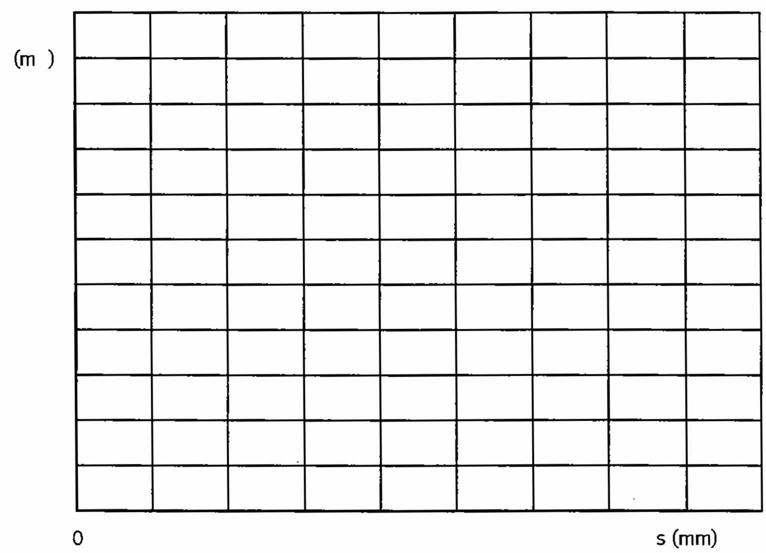


Fig. 2/6: Diagram for part exercise a)

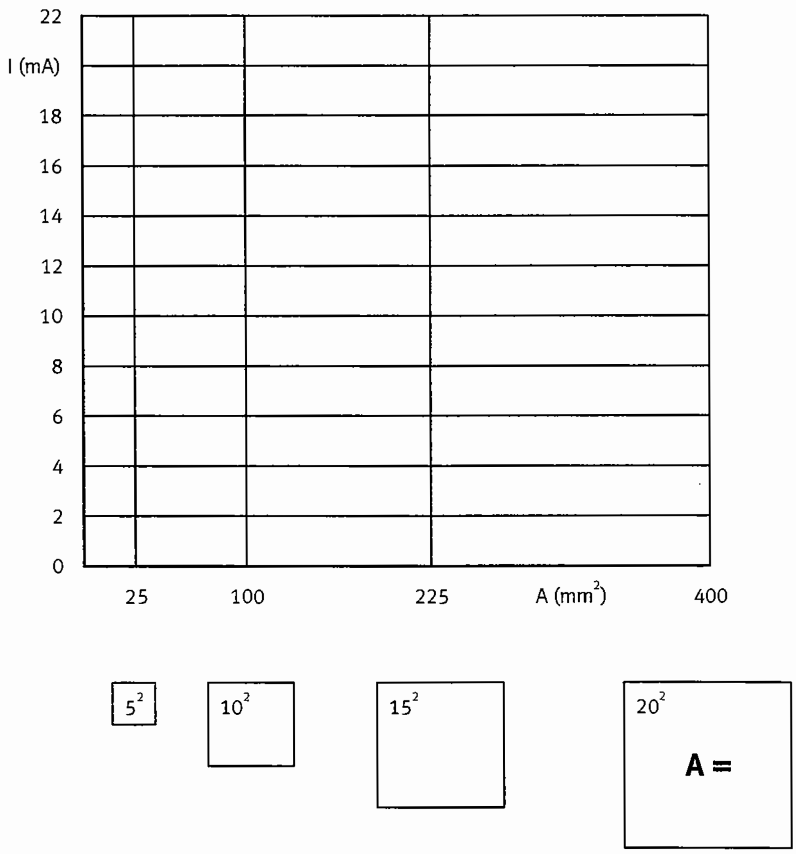


Fig. 2/7: Diagram for part exercise b)

Distance measurement by means of inductive sensors
Exercise 3

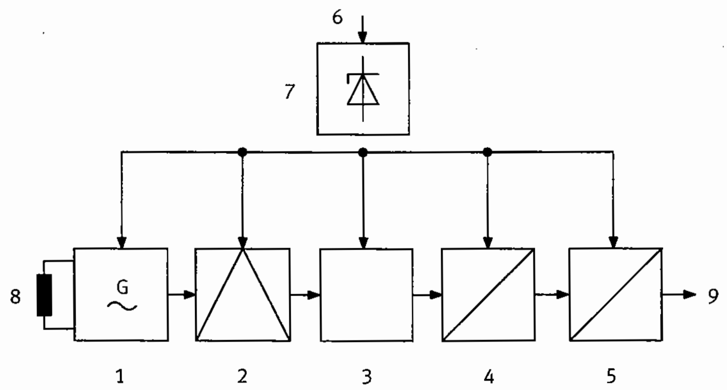
Measuring the deflection of flat material

Learning contents

- To determine the characteristic curve for an object to be measured and to determine the conversion factor (responsivity).
- Determine the correlation between load force F and output current I in respect of a load.
- Represent the correlation between load force F and centre deflection s.

Technical knowledge

Inductive analogue sensors contain an oscillator circuit, which consists of a parallel resonance circuit with coil (inductance) and a capacitor (capacitance) as well as an amplifier. The electromagnetic field is directed towards the outside by means of a ferrite shell core of the coil. If an electrically conductive material is introduced into the electromagnetic stray field, eddy currents are created in the material in accordance with the laws of inductance, which attenuate oscillation. The degree of attenuation varies depending on the conductivity, permeability, dimensions and proximity of the approaching object. Attenuation of the oscillator is evaluated via subsequent electronic devices and an output signal is generated which is, within a defined measuring range, proportional to the distance between the sensor and the material.



1	Oscillator	6	External voltage
2	Demodulator	7	Internal constant voltage supply
3	Amplifier	8	Coil with active zone
4	Linearisation	9	Output: Current or voltage signal
5	Output signal conditioning		

Fig. 3/1: Block diagram of analogue inductive sensor

Problem description

Tins are subjected to a vacuum test after sealing. If the deflection (dishing) of the lid is to small, the tin is rejected.

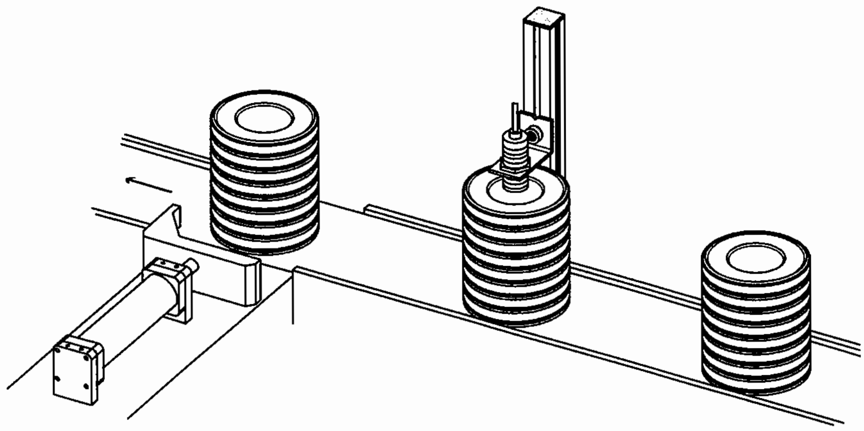


Fig. 3/2: Sorting device

Due to the height variations of the tins and due to different gap profiles whilst passing the tins under the sensor, the problem could not be solved by simply mounting an inductive proximity sensor. However, by using an analogue inductive distance sensor, it is possible to monitor the deflection of each lid once the gap profile has been recorded in a programmable logic controller. Then the gap difference between the rim of the tin lid and its centre can be evaluated.

Exercise

Carry out the following part exercises on the profile plate.
Evaluate the test results with the help of the worksheets.

a) Determine the characteristic curve of the sensor for a given deflecting strip. Determine responsivity R.
b) Determine the correlation between the mass m and deflection s.

Note

If required, all the part exercises can be carried out using the analogue voltage output (black connector), instead of the analogue current output. Select the appropriate range on the multimeter. The tables and diagrams contained in the worksheets and solution sheets are designed for a current output and need to be adapted if a voltage output is used.
Please observe the operating notes!

Practical implementation

The component reference number in the equipment set refers to the layout diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Analogue connection unit
2	1	Signal switching unit
3	1	Analogue inductive sensor
4	1	Positioning slide
7	1	Set of weights
8	1	Profile rail, length 318 mm
9	2	Profile rail, length 168 mm
10	1	Deflecting strip
	8	Adapter

Accessories

Component Ref. No.	Quantity	Description/Designation
5	1	Vernier caliper
6	1	Digital multimeter

For the necessary equipment and supply units see page 20.

Part exercise a)

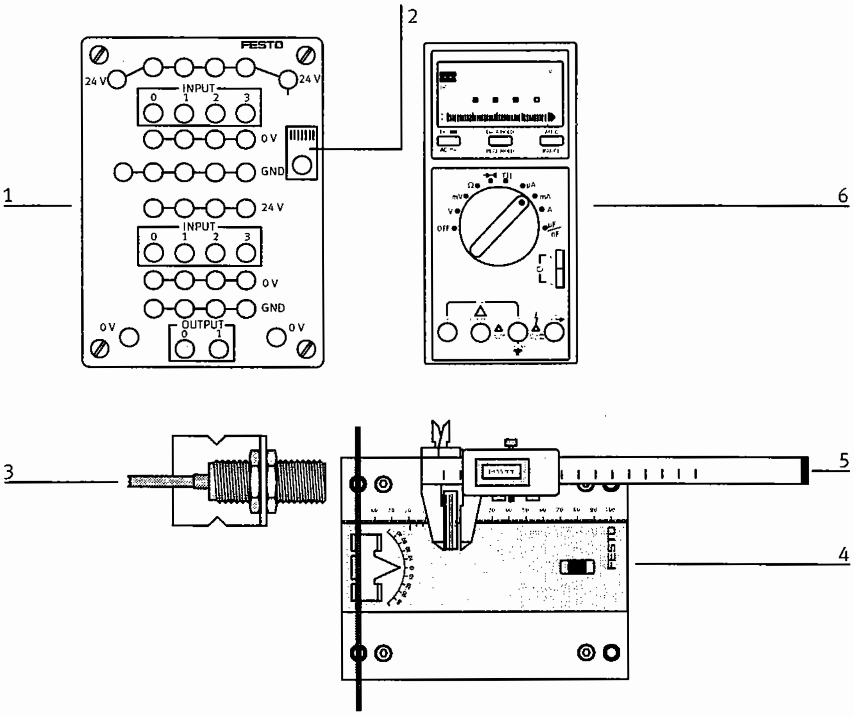


Fig. 3/3: Layout diagram

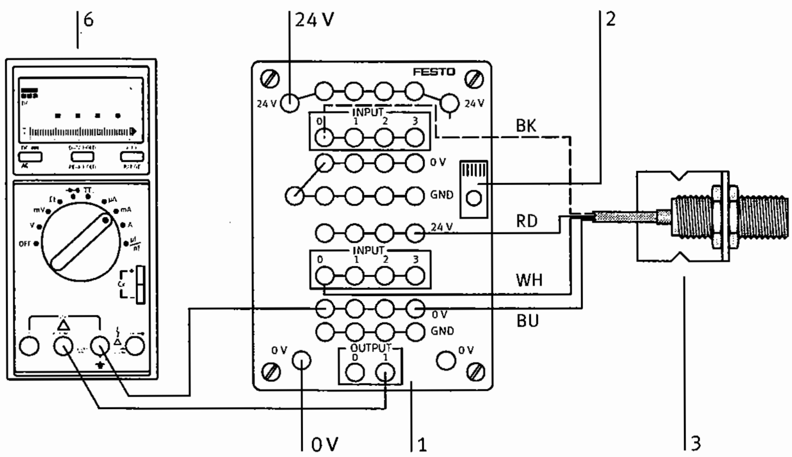


Fig. 3/4: Electrical connection

Note

he voltage output of the connection plate is socket OUTPUT 0, and the current output socket OUTPUT 1.Please also follow the user notes at the beginning of the book.

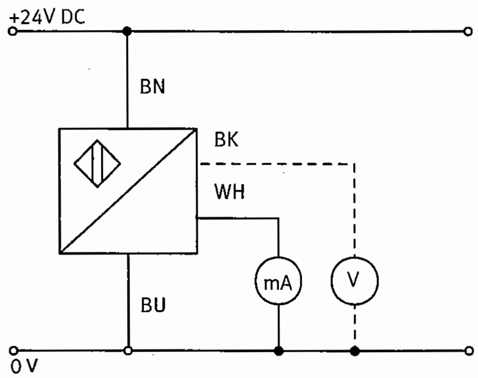


Fig. 3/5: Electrical circuit diagram

Procedure

Assemble the mechanical components on the profile plate:

- See fig. "Layout diagram" and table "Equipment set".
- When mounting the vernier caliper, the slide unit of the positioning slide is set at "0". The two pointers of the vernier caliper are moved apart by approximately 10 mm. The vernier caliper is positioned parallel to the base plate flush with the edge in such a way that the front pointer rests against the stop for the vernier caliper. The caliper body is retained on the base plate of the positioning slide by the two retaining magnets.
- Insert the item to be measured (deflecting strip) in the material retainer of the positioning slide.
- Mount the analogue inductive sensor laterally approximately 5 cm in relation to the centre of the positioning slide.

Establish all the electrical connections:

- See fig. "Electrical connection" and "Electrical circuit diagram". In this part exercise, the connection plate is used solely as a connection aid without PLC interfacing.
- Connection of the inductive sensor:

Plug	**Connection**
red (RD)	+24 V
blue (BU)	0 V
white (WH)	analogue current output

To set the equipment for measurement:

- Move the item to be measured towards the analogue inductive sensor by using the positioning slide. Set the digital indicator of the vernier caliper at "0", when the plate touches the sensor.
- Latch the signal changeover switch at "0" position.
- Select the appropriate range on the multimeter, see sensor data sheet.
- Switch on the 24 V power supply.

Carry out the measurements and enter the values in the table of the worksheet:

- Record the output current of the analogue inductive sensor in relation to the distance of the deflecting strip from the sensor.
- Move the item to be measured away from the sensor in steps of 0.5mm.

Transfer the measured values to the diagram, fig. 3/8.
Calculate the conversion factor R. (R=Responsitivity).

Part exercise b)

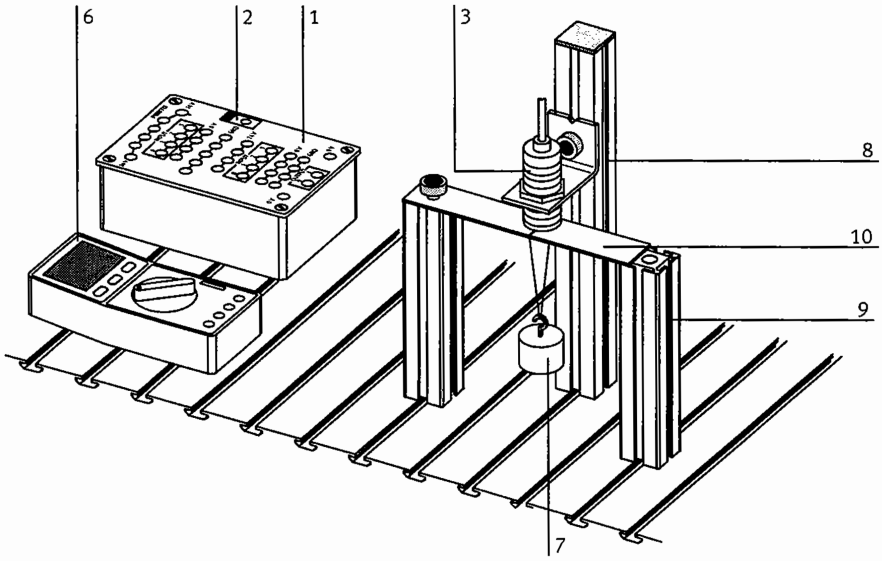


Fig. 3/6: Layout diagram

Description of the load

A deflecting strip with a constant cross section is clamped on one side of a support and hinged on the other. A vertically active force is applied to the centre of the horizontally positioned deflecting strip of length l. The deflection or sag s is measured in the centre. The maximum sag s_{max} is to the right of centre.

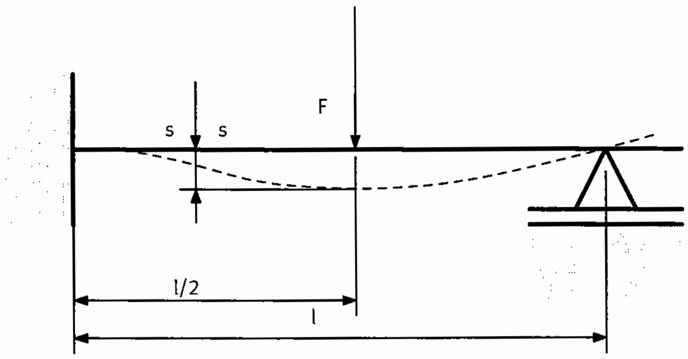


Fig. 3/7: Example of load

Procedure

Assemble the mechanical components on the profile plate:
- See fig. "Layout diagram" and table "Equipment set".
- Mount the aluminium deflecting strip on the supports.
- The distance between sensor and aluminium strip is approx. 1.5 mm.

Establish all the electrical connections:
- See fig. "Electrical connection" and "Electrical circuit diagram" of part exercise a).
- Connection of inductive sensor:

Plug	**Connection**
red (RD)	+24 V
blue (BU)	0 V
white (WH)	analogue current output

To set the equipment for measurement:
- Using a soft pencil, mark the centre of the aluminium strip which forms the deflecting arm between the points of support. The weights are attached by means of a string.
- Select the appropriate range on the multimeter, see sensor data sheet.
- Switch on the 24 V power supply.

Carry out the measurements and enter the values in the table. Suspend the weights in succession by the string provided and record the output current.
Transfer the measured values to the diagram fig. 3/9.
Determine the correlation between the mass m and the sag s. Draw the characteristic curve in the diagram (fig. 3/10).

Part exercise a)

Measurement series									
Distance s (mm)	0	0.5	1	1.5	2	2.5	3	3.5	4.0
Output current I (mA)									

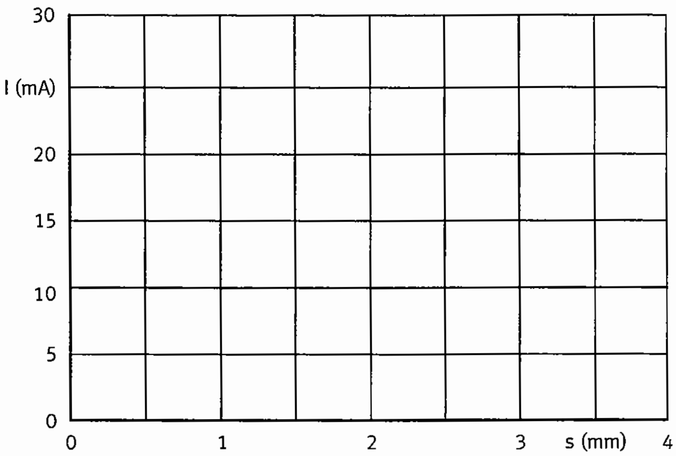


Fig. 3/8: Diagram for part exercise a)

Question

Calculate the conversion factor R:

$$R = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Part exercise b)

Measurement series							
Load m (g)	0	10	20	50	100	200	500
Output current I (mA)							

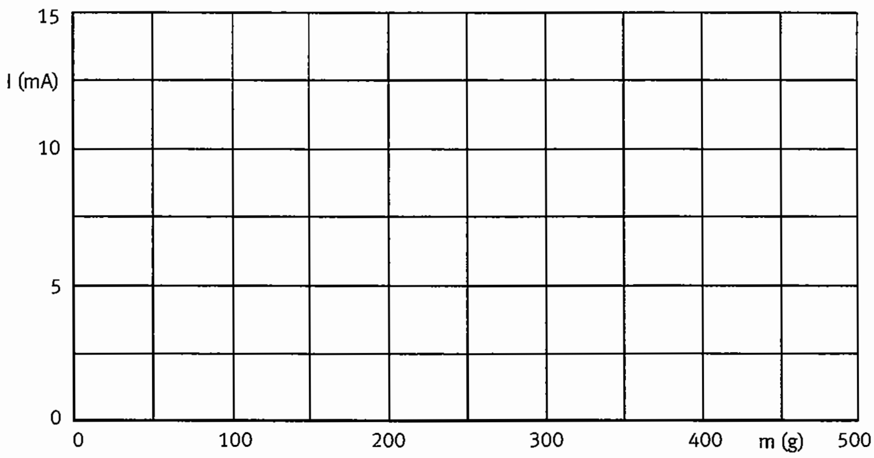


Fig. 3/9: Diagram for part exercise b)

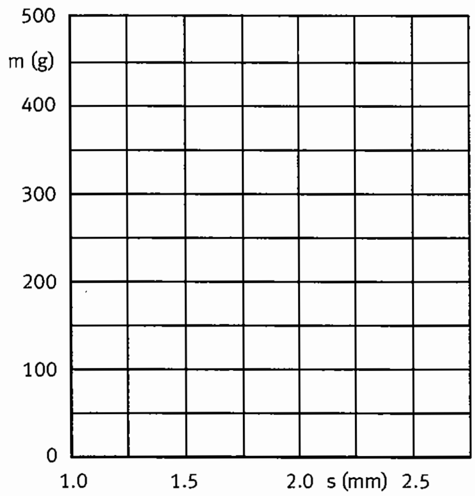


Fig. 3/10: Load-displacement diagram

Question

Which requirements must be fulfilled with regard to transport devices in order to determine the comparable surface contours of the tins?

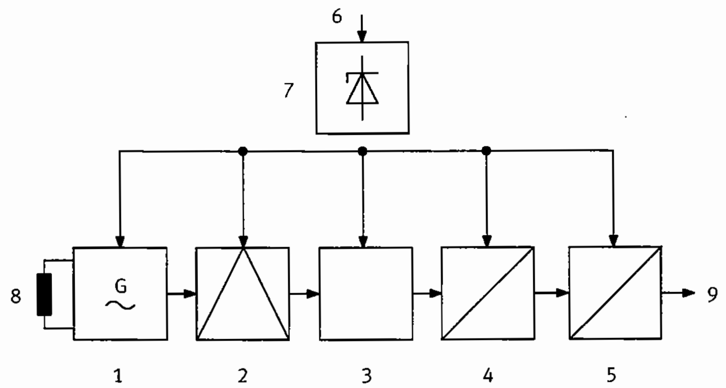
Determining the eccentricity of a rotating disc

Learning contents

- To recognise that the response characteristics of an analogue inductive sensor depend on the geometrical shape of the item to be measured.
- To define the characteristics of an item to be measured and the calculation of the conversion factors.
- To establish the axial and radial eccentricity of a rotating steel disc by means of an analogue inductive sensor.
- To carry out a check measurement.

Technical knowledge

Analogue inductive sensors contain an oscillator circuit, which consists of a parallel resonance circuit with coil (inductance) and a capacitor (capacitance) as well as an amplifier. The electromagnetic field is directed towards the outside by means of the ferrite shell core of the coil.
If an electrically conductive material is introduced into the electromagnetic stray field, eddy currents are induced into the material, in accordance with the laws of induction, which attenuate oscillation. The degree of attenuation varies depending on the conductivity, permeability, dimensions and proximity of the approaching object. Attenuation of the oscillator is evaluated via subsequent electronic stages and an output signal is generated which, within a defined range, is proportional to the distance between the sensor and the material.



1	Oscillator	6	External voltage
2	Demodulator	7	Internal constant voltage supply
3	Amplifier	8	Coil with active zone
4	Linearisation	9	Output: Current or voltage signal
5	Output signal conditioning		

Fig. 4/1: Block diagram of analogue inductive sensor

Problem description

A steel workpiece which is held in the concentric chuck of a lathe is to be tested for axial and radial eccentricity by means of random sampling. Two analogue inductive sensors are to check whether the axial and radial eccentricity is less than 0.05 mm.

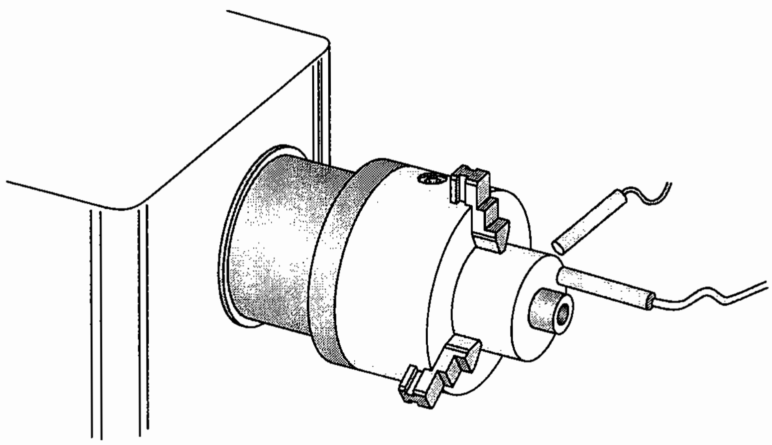


Fig. 4/2: Determining axial and radial eccentricity

Exercise

A steel disc, powered by an electric motor, is to be checked for axial and radial eccentricity.
Carry out the following part exercises on the profile plate.
Evaluate the test results with the help of the worksheets.

a) Determine the conversion factor R_a for the axial eccentricity of the steel disc.
b) Determine the conversion factor R_r for the radial eccentricity of the steel disc.
c) Determine the axial eccentricity s_a of the steel disc.
d) Determine the radial eccentricity s_r of the steel disc.

Additional exercise

e) Check your test results with the help of a dial gauge.

In order to carry out the additional exercise(s), some equipment will be required, which is not included in the equipment set.

Note

If required, all part exercises can be carried out using the analogue voltage output (black connector), instead of the analogue current output. Select the appropriate range on the multimeter. The tables and diagrams in the worksheets and solution sheets are designed for a current output and need to be adapted if a voltage output is used.

Please observe the operating notes!

The measurement of axial and radial eccentricity in the arrangement specified does not determine the inaccuracy of the disc itself. The measured axial/radial eccentricity includes that of the drive unit, disc and in particular the clamping position.

Practical implementation

The component reference number in the equipment set refers to the layout diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Analogue connection unit
2	1	Signal switching unit
3	1	Analogue inductive sensor
4	1	Gear motor
5	1	Motor controller
7	1	Positioning slide
9	1	Profile rail, length 168 mm
	1	Assembly kit DE
	12	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
6	1	Digital multimeter
8	1	Vernier caliper

For the necessary equipment and supply units see page 20.

Part exercise a)

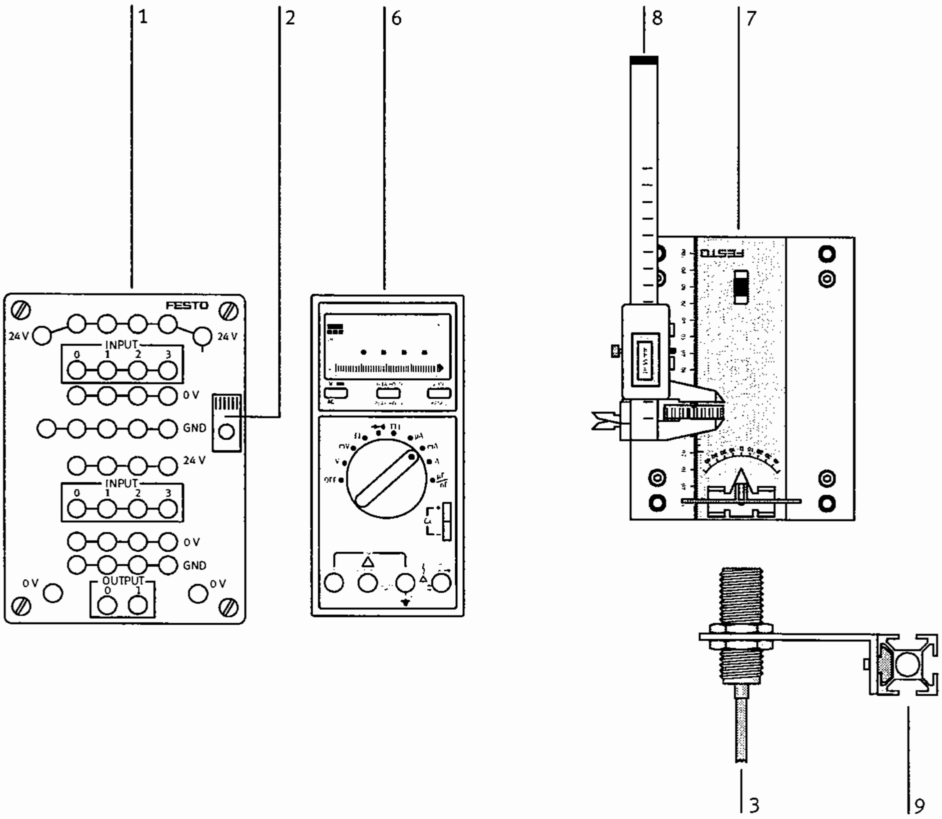


Fig. 4/3: Layout diagram

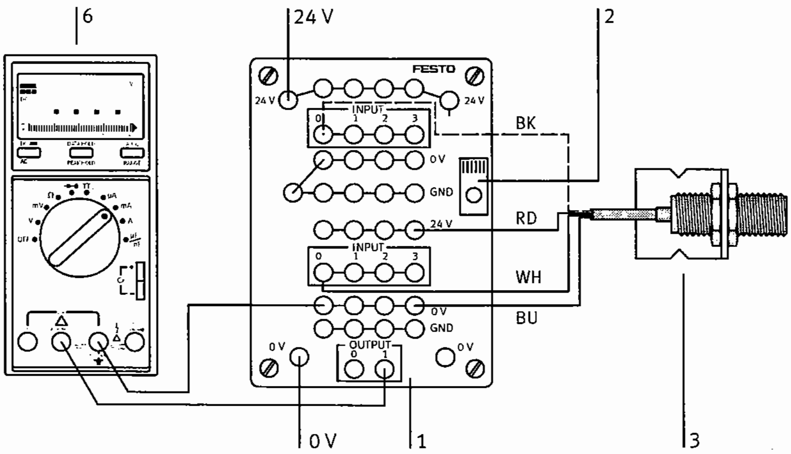


Fig. 4/4: Electrical connection

Note

The voltage output of the connection unit is socket OUTPUT 0, and the current output socket OUTPUT 1.
Please also follow the user notes at the beginning of the book.

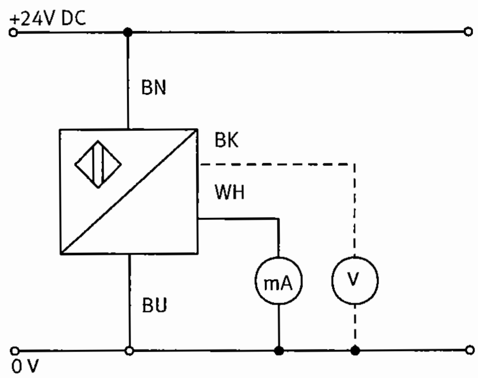


Fig. 4/5: Electrical circuit diagram

Procedure

Assemble the mechanical components on the profile plate or Slotted mounting plate:

- See fig. "Layout diagram" and table "Equipment set".
- When mounting the vernier caliper, the slide unit of the positioning slide is set at "0". The two pointers of the vernier caliper are moved apart by approximately 10 mm. The vernier caliper is positioned parallel to the base plate flush with the edge in such a way that the front pointer rests against the stop for the vernier caliper. The body of the vernier caliper is retained on the base plate of the positioning slide by the two retaining magnets.
- Insert the steel disc into the material retainer of the positioning slide with the flat side of the steel disc facing the sensor. Align the sensor with the steel disc by vertically adjusting the retaining bracket on the profile support 9.

Establish all the electrical connections:

- See fig. "Electrical connection" and "Electrical circuit diagram". In this part exercise the connection unit is used solely as a connection aid without PLC interfacing.
- Connection of the inductive sensor:

Plug	**Connection**
red (RD)	+24 V
blue (BU)	0 V
white (WH)	analogue current output

To set the equipment for measurement:

- Move the item to be measured towards the analogue inductive sensor by using the positioning slide. Set the digital indicator of the vernier caliper at "0", when the plate touches the sensor.
- Latch the signal changeover switch to "0" position.
- Select the appropriate range on the multimeter, see sensor data sheet.
- Switch on the 24 V power supply.

Carry out the measurements and enter the values in the measured value table in the worksheet.

- Record the output current of the analogue inductive sensor in relation to the distance of the steel disc from the sensor.
- Move the object away from the sensor in steps of 1 mm.

Transfer the measured values to the diagram of fig. 4/11.
Calculate the conversion factor R_a. (R_a = Responsitivity in the direction of eccentricity).

Part exercise b)

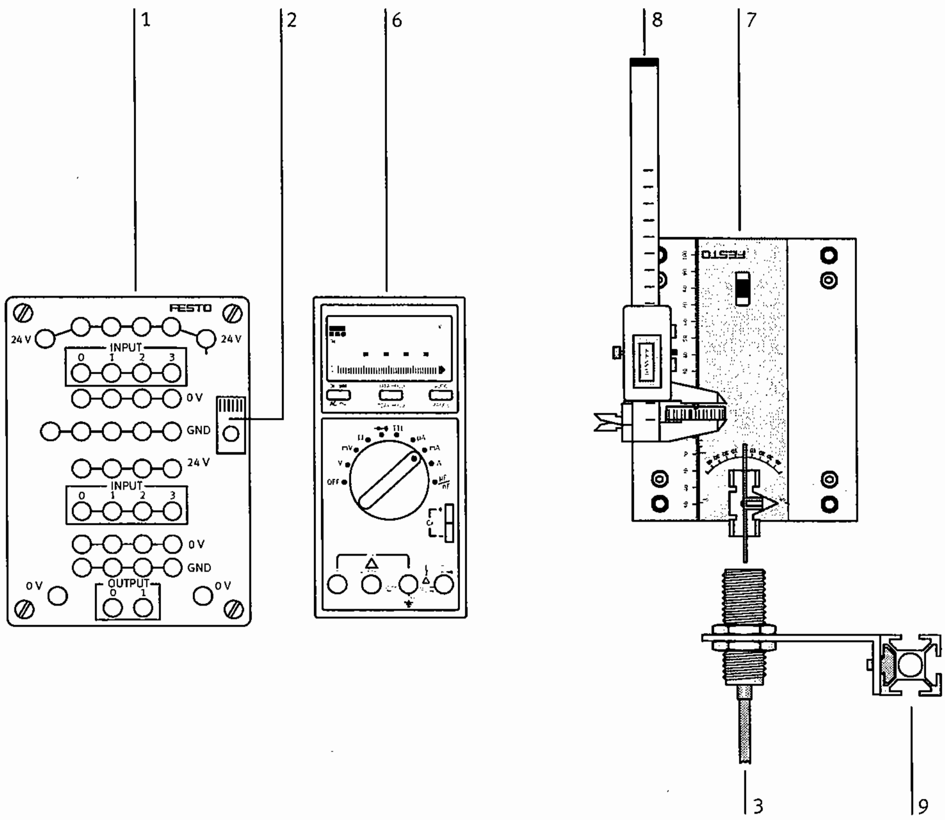


Fig. 4/6: Layout diagram

Procedure

Mechanical assembly as per part exercise a).

- Turn the material retainer of the positioning slide by 90°.
- The rim of the steel disc faces the sensor.

Electrical connections as per part exercise a).
Carry out the measurements and enter the values in the measured value table.
Transfer the measured values to the diagram of fig. 4/12.
Calculate the conversion factor R_r.
(R_r = Responsivity in the direction of radial eccentricity).

Part exercise c)

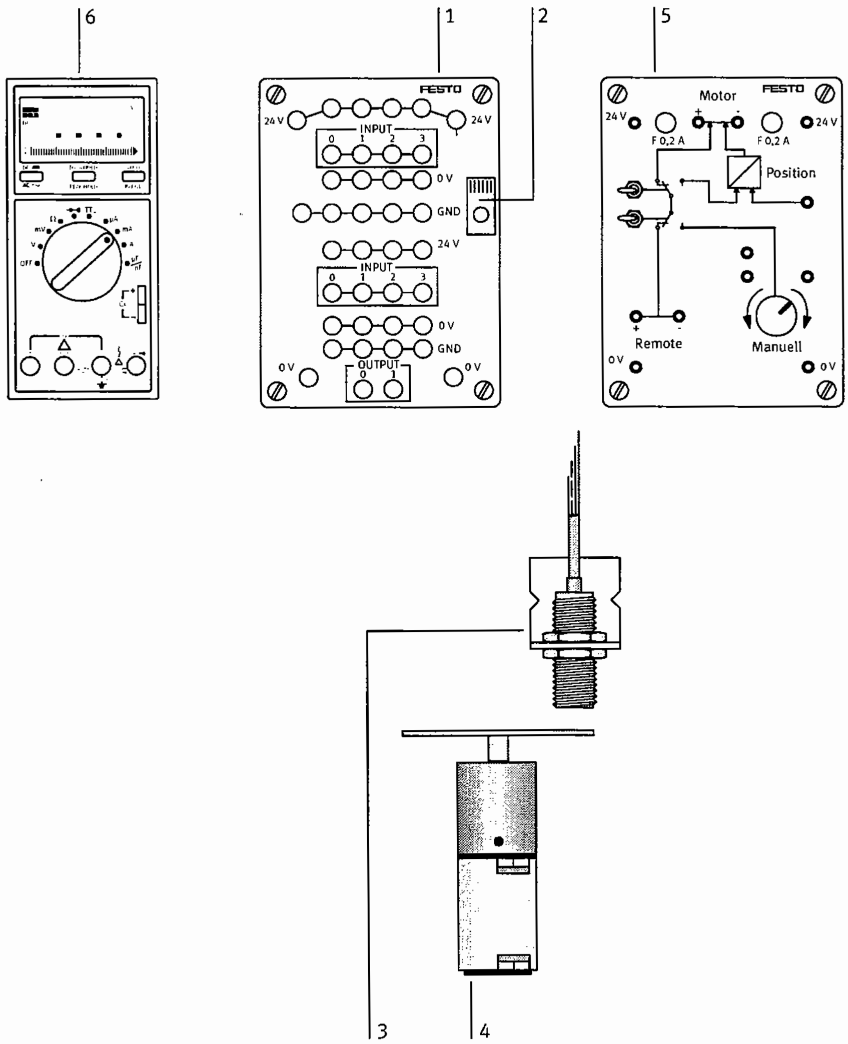


Fig. 4/7: Layout diagram

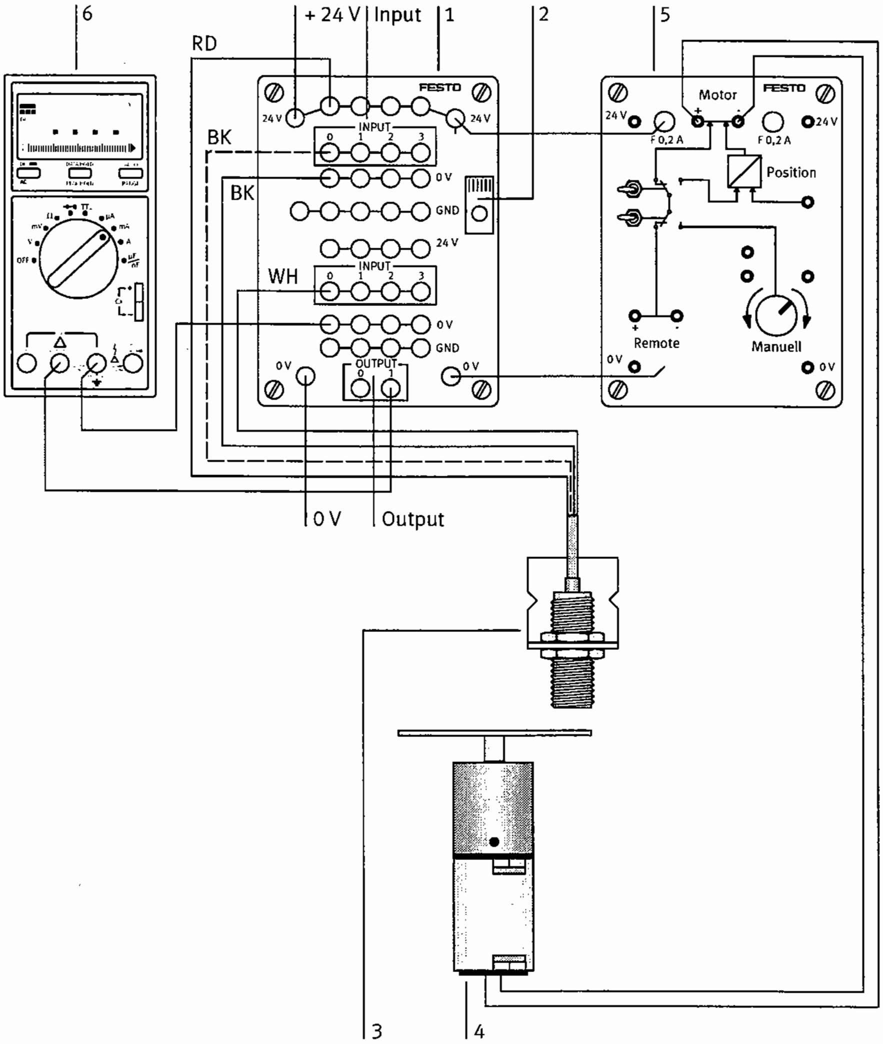


Fig. 4/8: Electrical assembly

Note

The voltage output of the connection unit is socket OUTPUT 0, and the current output socket OUTPUT 1.
Please also follow the user notes at the beginning of the book.

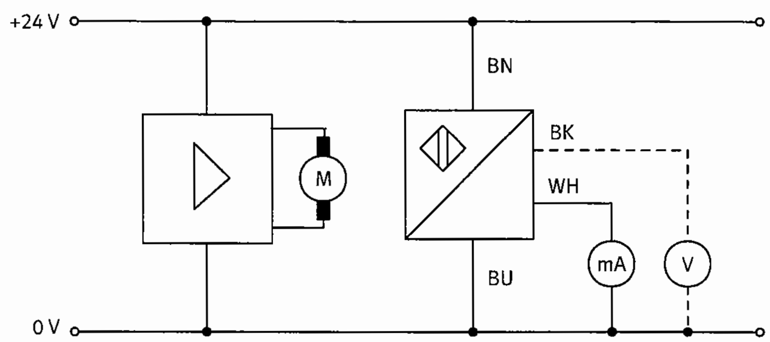


Fig. 4/9: Electrical circuit diagram

Procedure

Assemble the mechanical components on the profile plate or Slotted mounting plate:

- See fig. "Layout diagram" and table "Equipment set".
- Secure the steel disc on the shaft of the drive motor with the flat side of the steel disc facing the sensor.
- The distance from sensor to steel disc should be roughly the mean value from characteristic curve a) (fig. 4/11).

Establish all the electrical connections:

- See fig. "Electrical connection" and "Electrical circuit diagram".
- Connection of the inductive sensor:

Plug	**Connection**
red (RD)	+24 V
blue (BU)	0 V
white (WH)	analogue current output

To set the equipment for measurement:

- Select the appropriate range on the multimeter, see sensor data sheet
- Switch on the 24 V power supply.
- Set the motor control at the lowest possible speed.

Carry out three measurements and enter the values in the table.
Take a reading of the maximum and minimum value of the output current on the multimeter.
Calculate the mean value of the difference of the output current ΔI_{am}.
Calculate the axial eccentricity s_a of the steel disc.

Part exercise d)

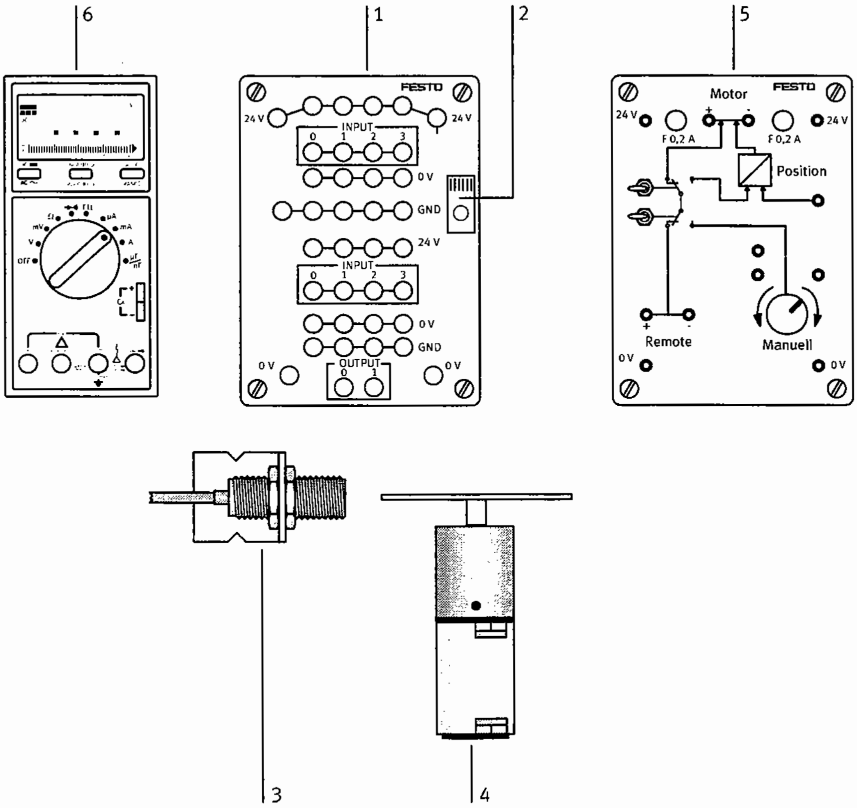


Fig. 4/10: Layout diagram

Procedure

Assemble the mechanical components on the profile plate or Slotted mounting plate:

- See fig. "Layout diagram" and table "Equipment set".
- The rim of the steel disc faces the sensor.
- The distance from sensor to steel disc should be roughly the mean value from characteristic curve b) (fig. 4/12).

Electrical connections as per part exercise c).
Carry out three measurements and enter the values in the table.

- Set the drive motor at the lowest possible speed.
- Take a reading of the maximum and minimum value of the output current on the multimeter.

Calculate the mean value of the difference of the output current ΔI_{rm}.
Calculate the radial eccentricity s_r of the steel disc.

Part exercise e)
Procedure

Measure the axial eccentricity s_a and the radial eccentricity s_r with the help of a dial gauge on a tripod. Make sure that the eccentricity is measured on the same pitch diameter as part exercise c).

Part exercise a)

Measurement series									
Distance s (mm)	1	2	3	4	5	6	7	8	9
Output current I (mA)									

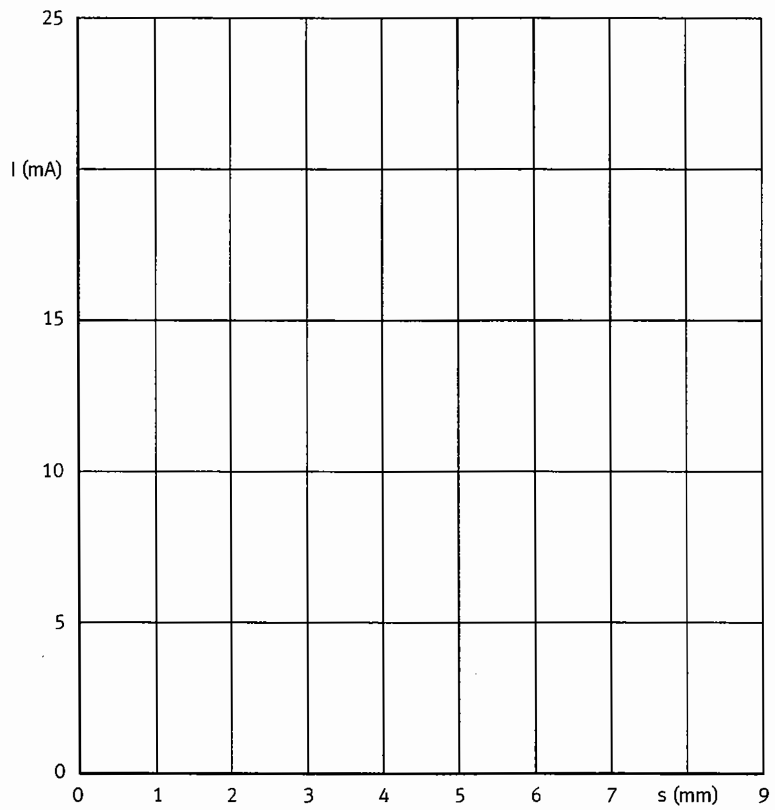


Fig. 4/11: Diagram for part exercise a)

Calculate the conversion factor R_a

$$R_a = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Part exercise b)

Measurement series									
Distance s (mm)	1	2	3	4	5	6	7	8	9
Output current I (mA)									

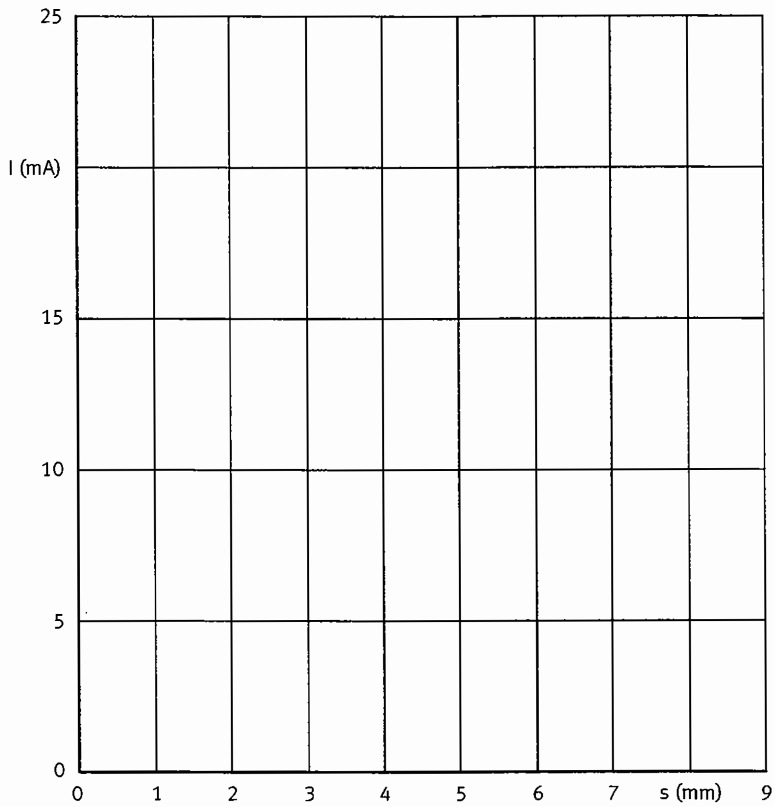


Fig. 4/12: Diagram for part exercise b)

Calculate the conversion factorR_r

$$R_r = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} =$$

Part exercise c)

Output current in respect of measurement of axial eccentricity	**1**	**2**	**3**
Output current I_{max} in mA			
Output current I_{min} in mA			
Difference of output current ΔI_a in mA			
Mean value of difference in output current ΔI_{am} in mA			

Axial eccentricity $s_a = \Delta I_{am}/R_a =$

Part exercise d)

Output current in respect of measurement of radial eccentricity	**1**	**2**	**3**
Output current I_{max} in mA			
Output current I_{min} in mA			
Difference of output current ΔI_r in mA			
Mean value of difference in output current ΔI_{rm} in mA			

Radial eccentricity $s_r = \Delta I_{rm}/R_r =$

Part exercise e)

Measurement with dial gauge	**Maximum value**	**Minimum value**	**Difference**
Axial eccentricity s_a in mm			
Radial eccentricity s_r in mm			

Questions

Is the sensor suitable for these measurements?

Up to what speed can measuring be carried out?

Position detection on a spindle drive unit by means of a linear potentiometer

Learning contents

- Mechanical assembly and electrical connection of a spindle drive unit
- Mechanical assembly and electrical connection of a linear potentiometer.
- Connection and operation of a motor controller for the spindle drive unit.
- To determine the correlation between voltage and displacement.

Technical knowledge

The function of a linear potentiometer is based on the voltage divider principle. The displacement data in the form of voltage is accessed via a slider on the linear potentiometer. The conductive plastic potentiometer used in this instance has a special resistive coating, which facilitates smooth slider movement.

Problem description

By means of a linear potentiometer, a direct relation can be established between displacement distances and voltage values. In order to be able to examine this relationship, a specific mechanical layout is required. With the help of this layout, a characteristic curve is established for the linear potentiometer.
The findings regarding the characteristics of potentiometers are the prerequisites for the use of displacement sensors of this type, e.g. for positioning of feeding devices, tools or assembly equipment or for injection moulding machines.

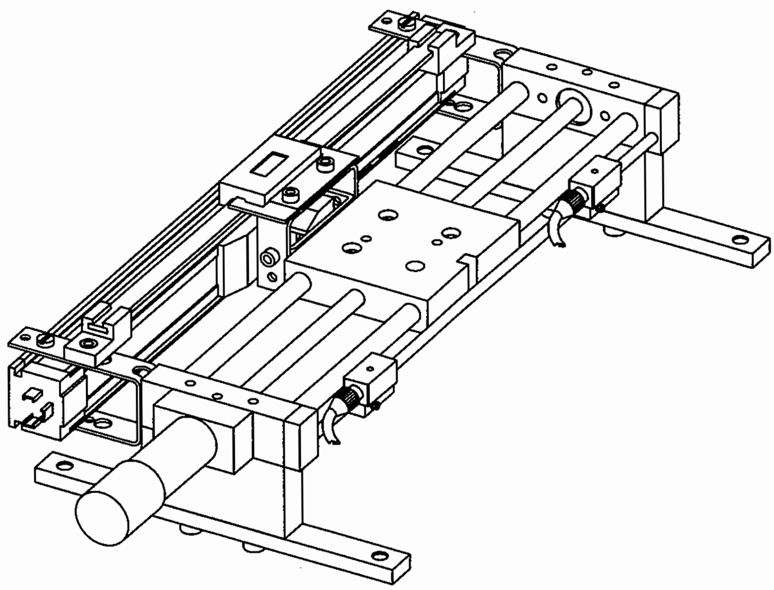


Fig. 5/1: Spindle drive unit with assembled linear potentiometer and – as a reference – a measuring slide

Exercise

a) Carry out the mechanical construction of the spindle slide unit and connect the drive motor to the motor controller.
b) Mount the proximity sensors onto the spindle drive unit.
c) Assemble the linear potentiometer and the measuring slide attachment and connect the linear potentiometer and the multimeter to the connection plate.
d) Familiarise yourself with the potentiometer.
e) Adjust the proximity sensors of the spindle drive unit to the positions specified and set the measuring slide.
f) Record the characteristic curve of the linear potentiometer.

Note

Please observe the operating notes!

Practical implementation

The component reference number of the equipment set refers to the layout diagram and the electrical connections diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Sensor unit, LP analogue (Linear potentiometer)
2	1	Motor controller
3	1	Spindle drive unit
4	1	Gear motor
5	2	Proximity sensor, inductive/magnetic
6	1	Adapter for PP
7	1	Adapter for height setting
8	1	Analogue connection unit
9	1	Sensor unit MS incr. (attachment measuring slide)
10	1	Signal switching unit
	1	Mounting kit
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
13	1	Digital multimeter

For the necessary equipment and supply units see page 20.

Part exercise a)

Mount the height adapters onto the spindle drive unit.

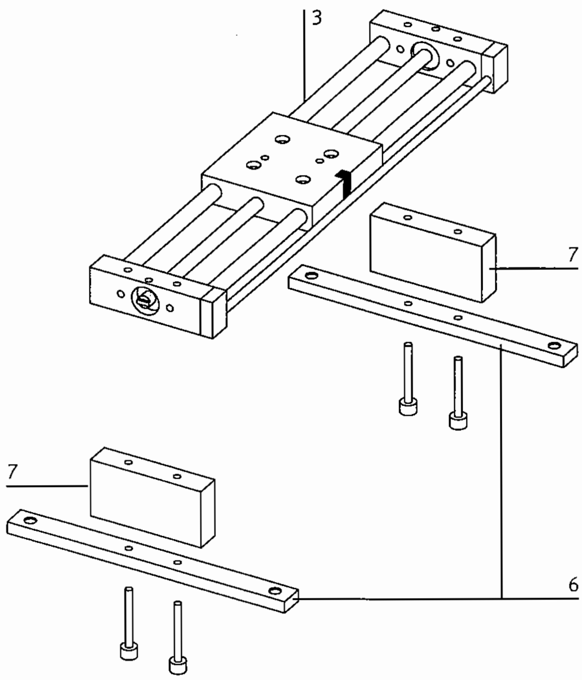


Fig. 5/2: Assembly of spindle drive unit

Mount the drive motor onto the spindle drive unit making sure that the coupling is aligned correctly. The connection between spindle drive unit and drive motor must be backlash-free in order to achieve reproducible measuring results.

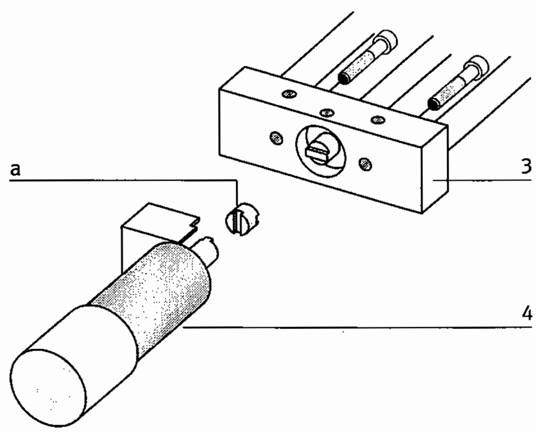


Fig. 5/3: Assembly of gear motor

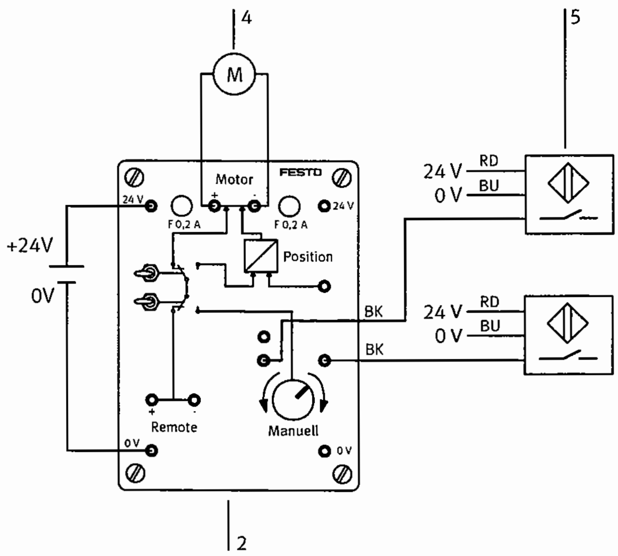


Fig. 5/4: Electrical connection

Practical implementation

Set the upper toggle switch of the motor controller to the left and the lower toggle switch to the right. Connect the drive motor in such a way that the spindle drive unit moves to the right if the rotary knob of the motor controller is turned to the right and to the left if the rotary knob is turned to the left.(If necessary, reverse the polarity of the motor!)

Check your assembly
- Are all the parts securely mounted?
- Does the direction of rotation of the drive motor coincide with the direction of the spindle drive unit?

Note

The magnetic proximity sensors are to be connected to the motor controller in such a way that when the sensor responds to the magnet on the slide, the unit is stopped at that position.
(If necessary, exchange the outputs of the proximity sensors on the motor controller!)

Part exercise b)

Mount the two magnetic proximity sensors onto the support rail of the spindle drive unit whilst maintaining a distance of approx. 5 cm from the limit stop on the left and righthand side respectively. The slide unit should be between the two proximity sensors for this.

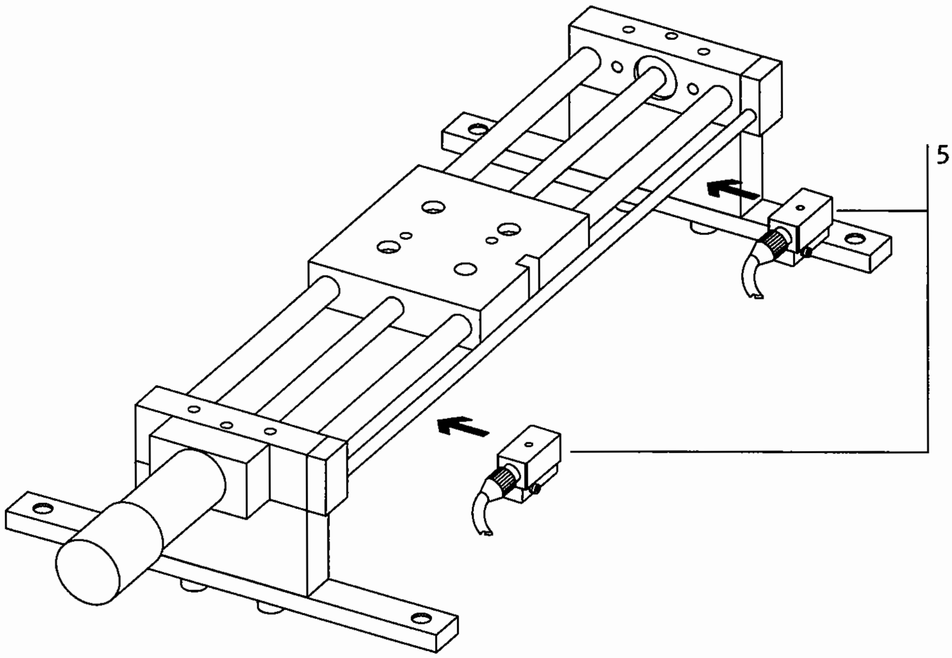


Fig. 5/5: Assembly of proximity sensors

Part exercise c)

Mount the linear potentiometer and the measuring slide onto the spindle drive unit. The end of the linear potentiometer must be flush with the spindle drive unit. Connect together the linear potentiometer, the measuring slide and the spindle drive unit using the adapters from the mounting kit.

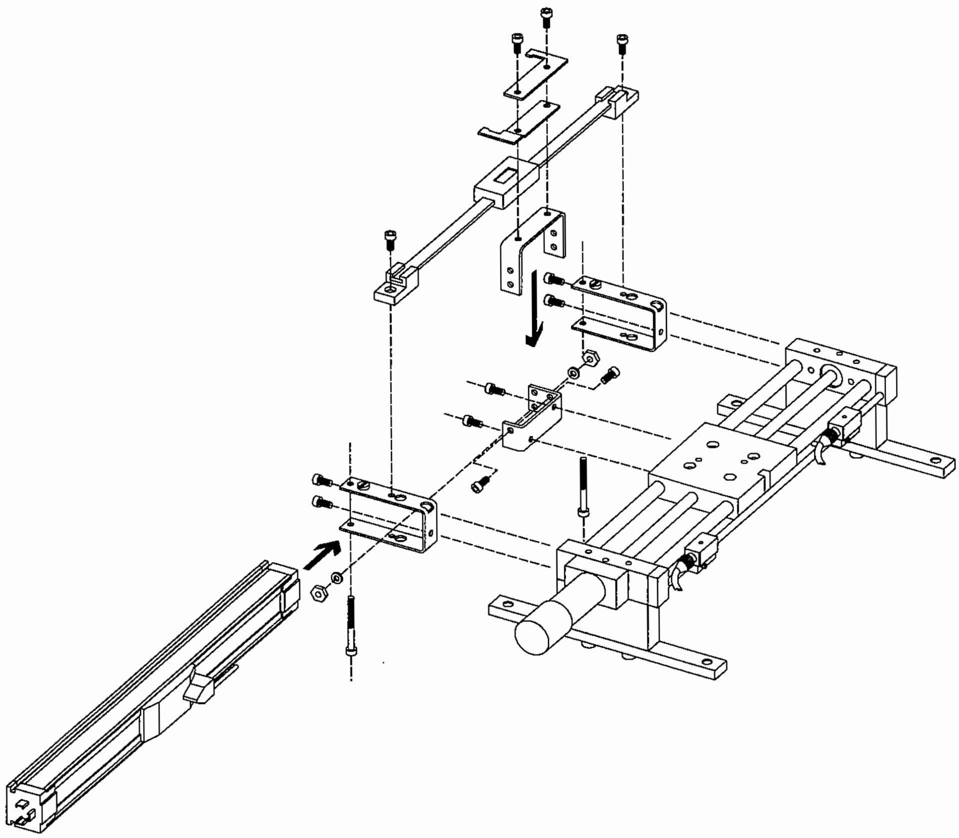


Fig. 5/6: Assembly of the measuring slide and linear potentiometer attachments

Connect the linear potentiometer and multimeter to the connection plate.

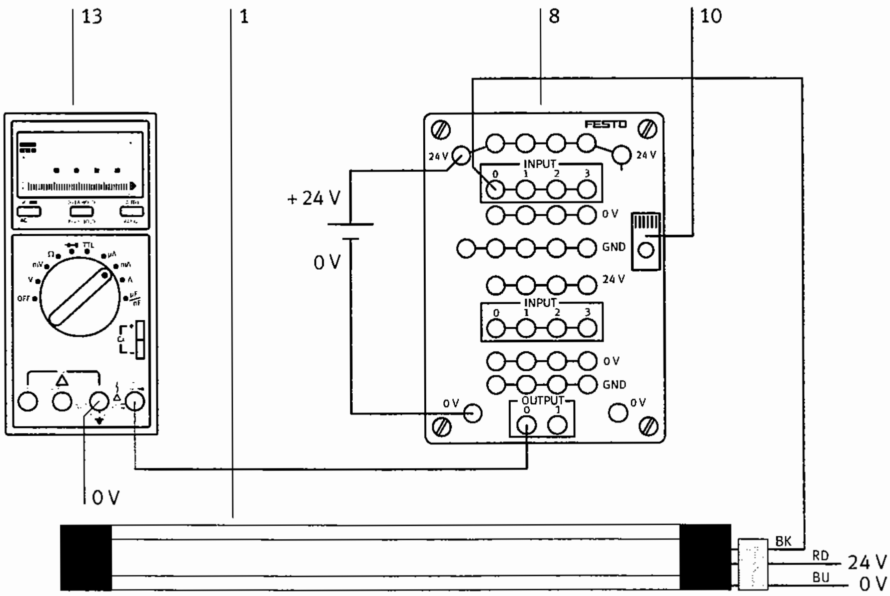


Fig. 5/7: Electrical connection

Part exercise d)

Take the data sheet on the subject of the linear potentiometer from the appendix section D of this workbook and familiarise yourself with this.
When you have done this, answer the questions for part exercise d) in the worksheet.

Part exercise e)

Adjust the two proximity sensors in such a way that the reading on the multimeter is 2 V at the lower end position of the displacement path of the positioning slide and 9 V at the farthest end. When you have made the initial setting, approach the proximity sensors a number of times and correct the position of the proximity sensors if necessary.

Procedure

- Move the spindle drive unit to the point where the multimeter reading is 2 V.
- Slowly move the proximity sensor from the left towards the spindle drive unit until the LED on the proximity sensor is illuminated.
- Clamp the proximity sensor securely at this position.

When the proximity sensors have been set accurately, approach the low voltage position (2 V) and set the measuring slide at 0.

Part exercise f)

Record the response characteristic of the linear potentiometer between the proximity sensors by means of the system of coordinates in fig. 5/8 of the worksheet. Enter each individual measurement in the measured values table.

Procedure

- Set the upper toggle switch of the motor control unit to the left and the lower toggle switch to the right.
- Move the spindle drive unit to the proximity sensor which is nearer to the sensor. The multimeter should now read 2 V and 0 should be displayed in the window of the measuring slide attachment.
- Move the spindle drive unit by 10 mm. The attached measuring slide provides a measuring reference.
- Take a reading of the voltage value from the multimeter.
- Enter the measured value in the respective table of the worksheet.
- Proceed as above for all measuring points.
- Transfer all the data of the measured values table to the system of coordinates and draw the characteristic curve (fig. 5/8).

Questions regarding part exercise d)

Which physical value does the linear potentiometer provide?

What should be taken into account with a standard linear potentiometer with regard to short circuit protection of the output?
By what method is short circuit protection achieved in the case of the linear potentiometer used?

Let the spindle drive unit travel alternately towards the left or the right whilst observing the multimeter. How does the reading change?

Part exercise f)

Measurement series											
s (mm)	0	10	20	30	40	50	60	70	80	90	100
U (V)											
s (mm)	110	120	130	140	150	160	170	180	190	200	210
U (V)											

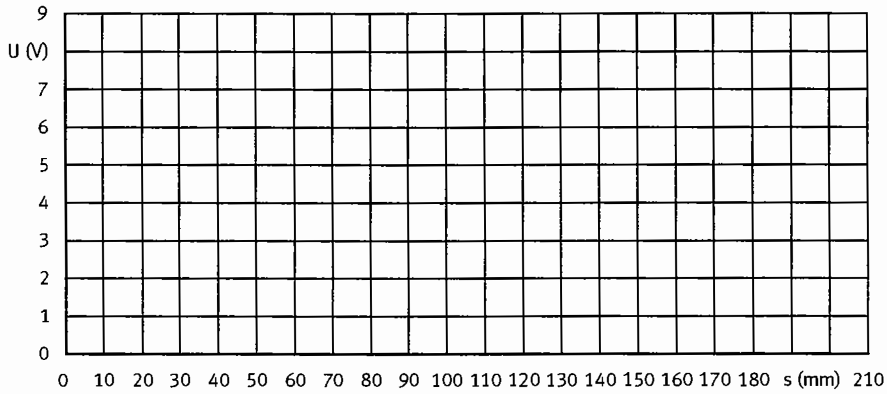


Fig. 5/8: Diagram for part exercise f)

Displacement measurement by means of ultrasonic sensors
Exercise 6

Position detection on a spindle drive unit by means of an ultrasonic sensor

Learning content

- Mechanical assembly and electrical connection of an ultrasonic sensor.
- Connection and operation of a spindle drive unit with motor control.
- Establishing the relationship between output current and displacement.
- Measuring response characteristics with different sizes of reflection area.

Technical knowledge

When ultrasonic waves, released by an emitter, impinge on a sound reflecting object, they are reflected. After a distance-related propagation time, the so-called echo reaches the sensor again, where it is detected by the receiver. By means of evaluating the propagation time through the air, the distance of the reflecting object from the sensor can thus be established.

The ultrasonic sensor used in this instance is equipped with separate transducer elements for emitting and receiving.

Problem description

Different types of car wheel rims, which are fed on a conveyor belt, are to be monitored on the basis of differences in design and dimension as to whether they are the correct wheel rims and that they arrive in the right order. By means of evaluating the echo signal of an ultrasonic sensor, it is possible to detect a characteristic profile sensing distance between the sensor and the moving wheel rim thereby enabling a differentiation to be made between wheel rims. To achieve this, the sensor must be capable of responding to different reflecting surfaces of wheel rims.

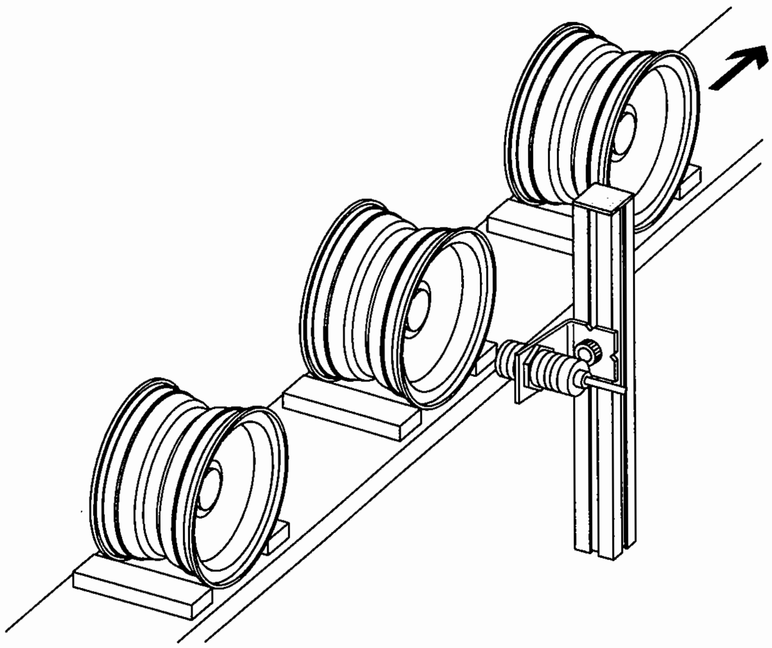


Fig. 6/1: Monitoring of car wheel rims

Exercise

In order to carry out the following part exercises, use the mechanical assembly of the spindle drive unit from exercise 5. This way, the position of the proximity sensors can be left unchanged.

a) Assemble the ultrasonic sensor and the reflector.
b) Connect the ultrasonic sensor and multimeter to the connection unit.
c) Familiarise yourself with the ultrasonic sensor.
d) Mount the measuring slide attachment onto the spindle drive unit.
   Record the response characteristic of the ultrasonic sensor; carry out this measurement with each of the three reflectors.
e) Determine the effect that the inclining of the reflecting surface has upon the measurements.

Note

Please observe the operating notes!

Practical implementation

The component reference number of the equipment set refers to the layout diagram and the illustrations of the electrical connection and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Sensor unit, LU analogue (analogue-ultrasonic sensor)
2	1	Motor controller
3	1	Spindle drive unit
4	1	Gear motor
5	2	Proximity sensor, inductive/magnetic
6	1	Adapter for PP
7	1	Adapter for height setting
8	1	Connection unit
9	1	Signal switching unit
10	1	Profile rail, length 318 mm (single end connection)
11	1	Reflector plate for ultrasonic sensor
12	1	Intermediate plate
13	1	Sensor unit MS incr. (attachment measuring slide)
	1	Mounting kit
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
	1	Digital multimeter

For the necessary equipment and supply units see page 20.

Part exercise a)

Carry out the mechanical assembly of the ultrasonic sensor. Use the slot of the profile rail and notch on the mounting bracket to correctly align the sensor and profile support.

Make sure that the limiting values for distance are not fallen below or exceeded. Use the data sheet for this purpose.

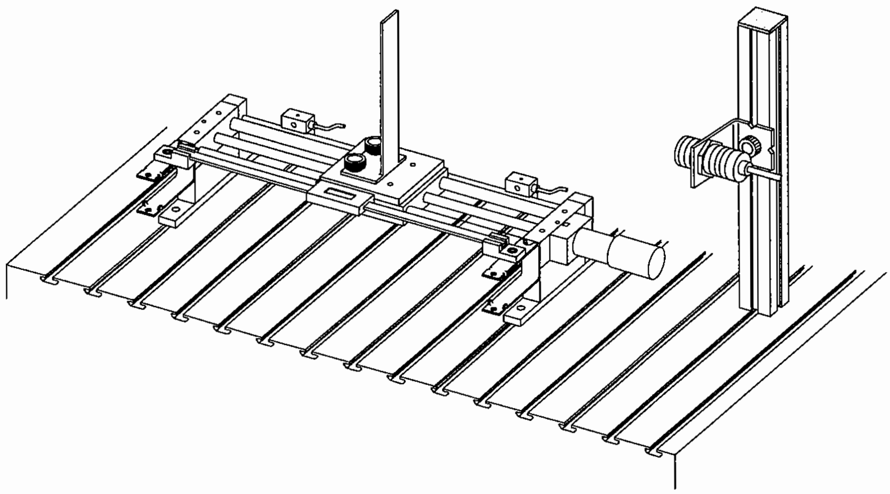


Fig. 6/2: Overall assembly

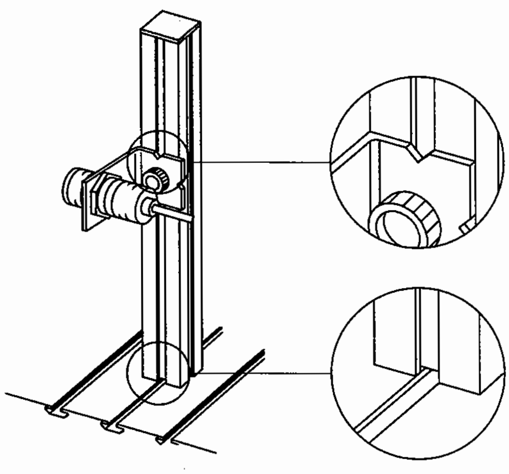


Fig. 6/3: Alignment of profile rail and sensor

Part exercise b)

Connect the ultrasonic sensor, distribution plate, motor control and digital multimeter.
Adjust the digital multimeter to mA measuring range by means of the selector switch.

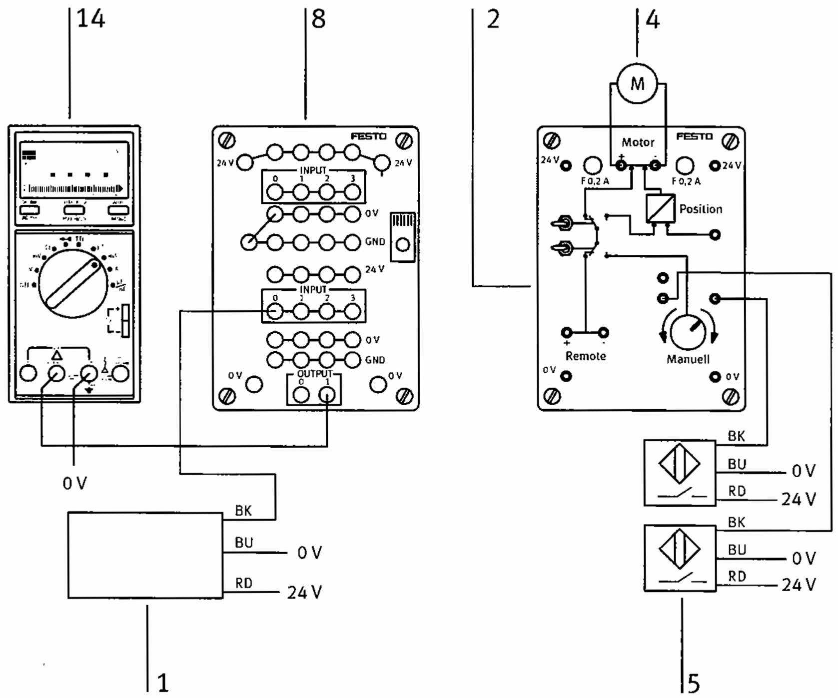


Fig. 6/4: Electrical connection

Part exercise c)

Take the data sheet on the subject of ultrasonic sensors from the appendix section D of this workbook and familiarise yourself with this.
When you have done this, answer the questions for part exercise c) on the worksheet.

Part exercise d)

Record the characteristic curve of the ultrasonic sensor between the limit switches. The increments between the two measuring points is 10 mm. Enter each individual measurement in the measured values tables. Draw the characteristic curves on the diagram fig. 6/6.

Procedure

- Move the spindle drive unit towards the limit switch which is nearest to the sensor.
- Set the display of the measuring slide to "0". Make sure that the millimetre indicator is in operation and not the inch indicator.
- Move the spindle drive unit by 10 mm.
- Take a reading of the current value from the multimeter.
- Enter the recorded value in the measured values table of the worksheet.
- Proceed as described above for all measuring points.
- Transfer all data from the measured values table to the system of coordinates and draw the characteristic response curve.

Carry out this measurement with all three reflectors.

The sound waves may miss the reflector if it is too small. This leads to an error measurement due to reflection on surrounding objects. Check which reflector size is required to obtain reliable measurements. Alternately hold a piece of cardboard or a metal plate next to the reflector and observe whether the output signal changes as a result of this.

CAUTION:

The limit switch must only be approached very slowly, as it will switch too late by several tenths of a millimetre, if the speed is too high. This leads to the zero point being shifted and inaccurate measuring results. To avoid this, approach the limit switch at different speeds and observe the indicator on the measuring slide whilst doing so.

Part exercise e)

Move the spindle drive unit as close as possible towards the ultrasonic sensor. Loosen one of the two locking screws securing the reflector. Slowly turn the reflector in the direction of the sensor or away from the sensor.

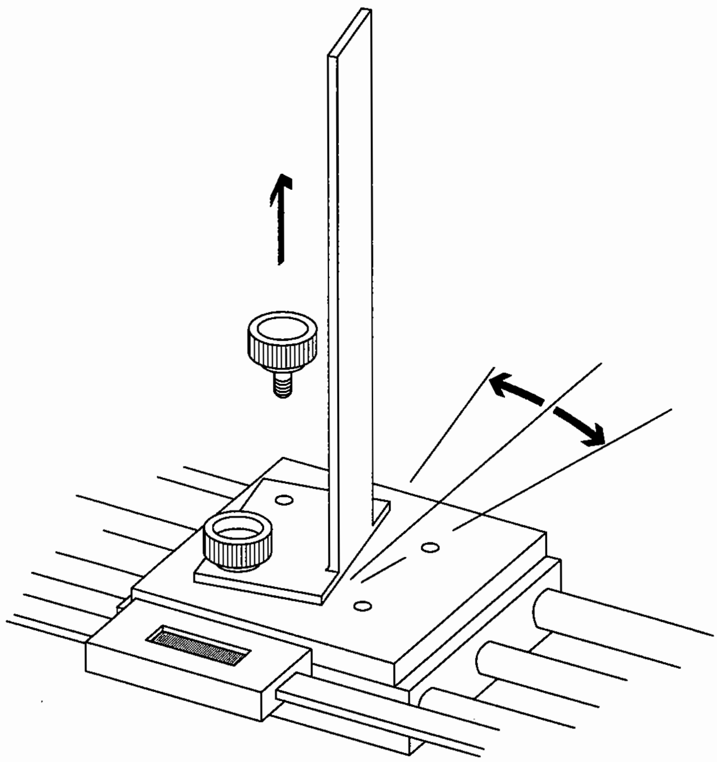


Fig. 6/5: Turning the reflector plate

Questions to part exercise c)

What is the physical value generated by an ultrasonic sensor?

____

What measuring range must be set on the multimeter?

____

Move the spindle drive unit alternately towards the left or the right whilst observing the multimeter. How is the reading affected?

Definition:
– to the left = The reflector moves towards the ultrasonic sensor
– to the right = The reflector moves away from the sensor

____

____

____

____

Why does the signal output of the ultrasonic sensor indicate a current value and not a voltage value?

____

____

____

____

Part exercise d)

Measurement series: With reflector width of 60 mm

s (mm)	0	10	20	30	40	50	60	70	80	90	100
I (mA)											
s (mm)	110	120	130	140	150	160	170	180	190	200	210
I (mA)											

Measurement series: With reflector width of 40 mm

s (mm)	0	10	20	30	40	50	60	70	80	90	100
I (mA)											
s (mm)	110	120	130	140	150	160	170	180	190	200	210
I (mA)											

Measurement series: With reflector width of 20 mm

s (mm)	0	10	20	30	40	50	60	70	80	90	100
I (mA)											
s (mm)	110	120	130	140	150	160	170	180	190	200	210
I (mA)											

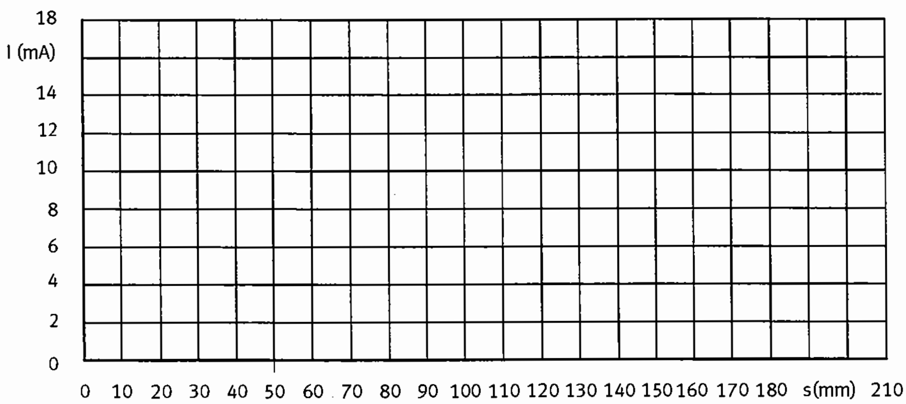


Fig. 6/6: Diagram of measurements using reflector plate

Questions to part exercise e)

Describe what you have observed on the multimeter.

If a specific angle is exceeded when the reflector is turned, the indicated current increases abruptly. What angle needs to be exceeded in order for this reaction to occur?

Substantiate your observations.

Is it possible to solve the task described in the problem description by means of the ultrasonic sensor provided?

What requirements need to be fulfilled in order to detect a definite profile of the wheel rims?

Distance measurement by means of optical sensors
Exercise 7

Determining the characteristic curve of an analogue diffuse optical sensor

Learning content

- To learn about the response characteristic of an analogue diffuse optical sensor.
- To determine the characteristic curve of an analogue diffuse optical sensor.
- To determine the responsivity of an analogue diffuse optical sensor.
- To evaluate the reproduceability and linearity of the measurements.

Technical knowledge

The optoelectronic diffuse sensor contains a photoelectronic receiver (photodiode or phototransistor) and an infrared light diode IRED = Infra - Red - Emitting - Diode).
The photoelectronic receiver receives the infrared light which has been emitted by the IRED and reflected by an object and converts it into an electrical current. If the light emission strength changes at the receiver in relation to the distance, then the electrical current also changes. By means of an electronic adjustment of the response characteristic in the sensor itself, a linear correlation between the output signal and the object distance can be achieved within a certain range. The sensing range can be changed by means of a built-in potentiometer.
The sensor is operated as an optical diffuse sensor with a fibre-optic cable. The distance measurement depends on the reflecting power of the object to be measured, i.e. from the surface and colour of the object.
By comparison with a reference curve, which has been obtained for a reference object, the distance or thickness of similar, other objects can be determined. The sensor can be used in applications where the measurement of variable distances within a range of 8mm to 40mm is required.

Problem description

In a testing station for steel springs, spring deflection is to be determined under a specified load. The zero point of spring deflection is determined by a stop. The spring is set prior to measurement in such a way that, in the unloaded condition the end touches the upper stop. If loaded with a drop weight of force F, the spring is deflected by spring displacement s.

In this way, the spring constant $C = \frac{F}{s}$ can be determined.

The spring displacement is to be measured by means of an analogue diffuse optical sensor.
The sensing distance of the analogue diffuse optical sensor must take into account the largest spring deflection to be measured. The characteristic curve of the sensor must be determined in order for the measurement to be evaluated in an electronic controller. To do this, you need to establish the extent to which various surfaces of an object to be measured affect the gradient of the characteristic curve of the sensor.

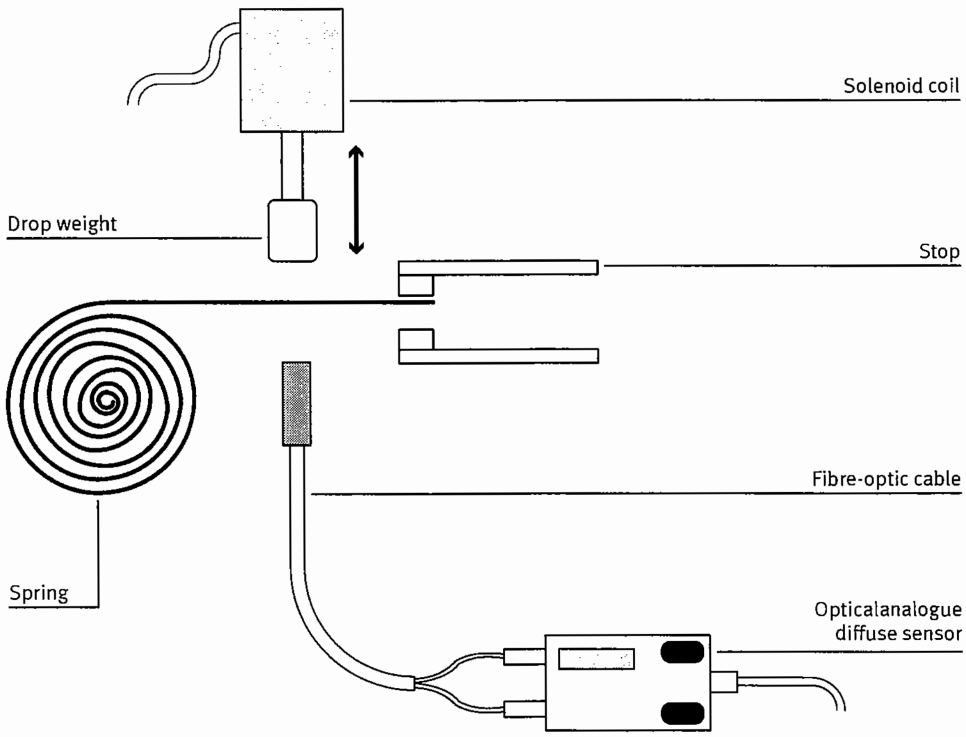


Fig. 7/1: Testing device for springs

Exercise

a) Mount the analogue sensor and the positioning slide onto the profile plate. Insert the Kodak grey card in the measuring object retainer, with the white side facing the sensor.
b) Connect the analogue diffuse sensor.
c) Answer the questions in the worksheet.
d) Record the characteristic curve of the analogue diffuse sensor at 0.0 mm to 55.0 mm in gaps of 5.0 mm using the white side. Carry out the measurements three times making sure that you start at 0.0 each time. If necessary, reset the vernier caliper to zero. Move in one direction only when carrying out the measurements with the sliding unit of the positioning slide.

Note

Please note that an accuracy of 0.1 mm is sufficient for the vernier caliper and an accuracy of 0.1 mA for the multimeter. Round off all the measurements accordingly.

Practical implementation

The component reference number of the equipment set refers to the layout diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Analogue connection unit
2	1	Signal switching unit
3	1	Sensor unit RT, optical analogue diffuse sensor
4	1	Positioning slide
	1	Set of test objects, part 3-7
	1	Set of test objects, part 17 Kodak- grey card 100 mm x 100 mm
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
5	1	Vernier caliper
6	1	Digital multimeter

For the necessary equipment and supply units see page 20.

Part exercise a)

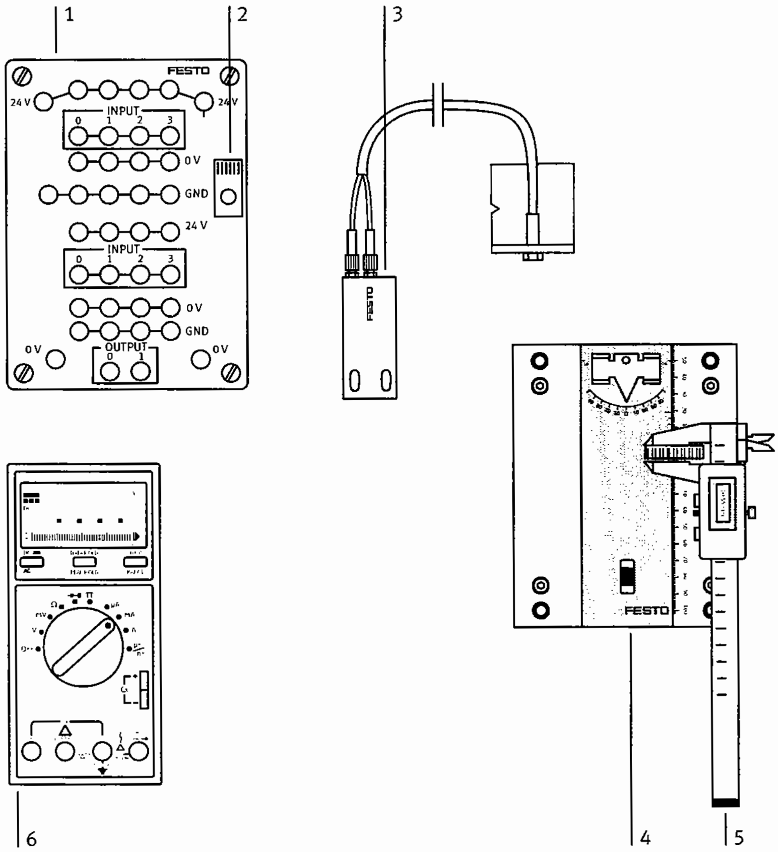


Fig. 7/2: Layout diagram

In order to measure the characteristic curve of current/distance, the analogue diffuse optical sensor must be mounted on the profile plate or Slotted mounting plate. The fibre-optic cable is screwed onto the sensor unit and the front end faces the positioning slide. The Kodak grey card is held by the material retainer of the positioning slide.

To ensure optimum adjustment, make sure that the fibre-optic cable retainer is approximately 6 cm in front of the positioning slide. Moreover, it must be possible for the card and the positioning slide to be moved immediately in front of the fibre-optic aperture. In addition, slide the card in the retainer to the left until the lefthand edge of the card is flush with the fibre-optic retainer. The material retainer must be set at 0 degrees. Set the digital indicator of the vernier caliper at zero, when the surface of the measuring object fully covers the fibre-optic aperture.

Calibrate the sensor with the white side of the Kodak grey card facing the sensor head. Move the Kodak grey card within a distance of 8 mm towards the sensor head. Remove the white cover screw of the sensor setting potentiometer. Set the potentiometer so that the output current measures 4 mA. Replace the cover screw.

Part exercise b)

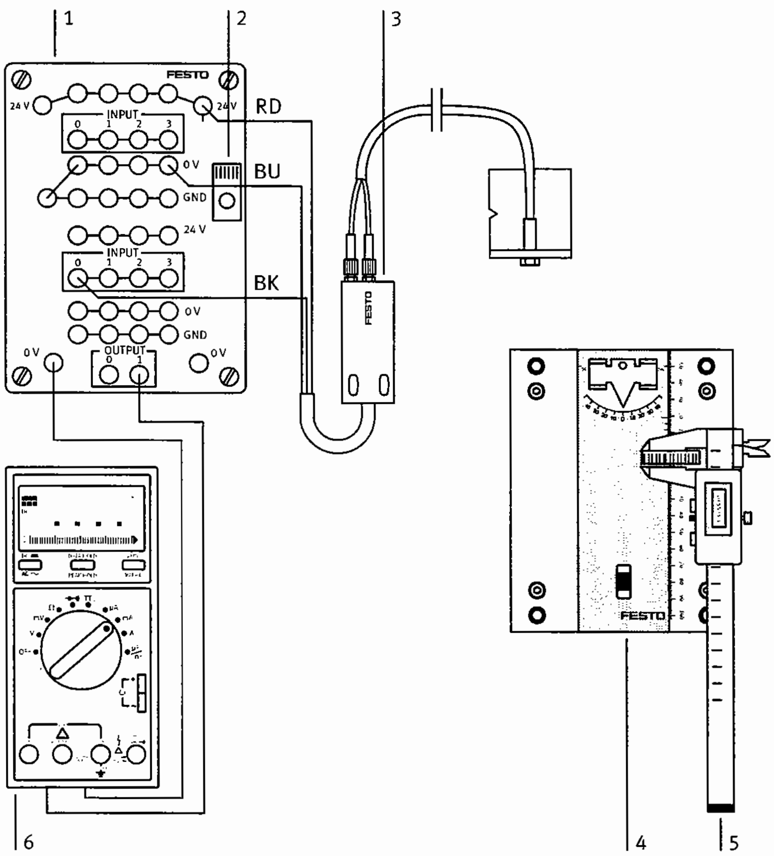


Fig. 7/3: Electrical connection diagram

Note

Please observe the correct setting on the signal switching unit and allocation of the connections, see user notes.

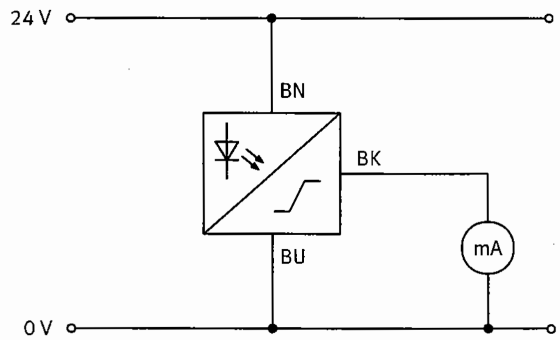


Fig. 7/4: Electrical circuit diagram

Wire up the sensor (3) and the connection unit (1) according to the electrical circuit diagram and then connect the digital multimeter (6). The final step is to connect the power supply to the connection unit. Switch on the power supply and select the mA measuring range of the digital multimeter.

Questions to part exercise c)

What is the value of the current signal when the white surface of the Kodak grey card is directly in front of the fibre-optic aperture? (Round off the current value of the digital indicator of the current measuring device to one digit after the comma.)

____

What is the value of the current signal, when the card is removed from the retainer? (Round off the current value accordingly).

____

Set the zero point on the vernier caliper (5), when the white surface of the card is directly in front of the fibre-optic aperture. Move the positioning slide unit 20.0 mm away from the fibre-optic aperture. (Round off the distance value on the digital indicator of the vernier caliper to one place after the point). Make a note of the current value. Move to 25.0 mm and then back again to 20.0 mm. Has the current value changed?

____________________ / ____________________

____

How does the current signal change, if the card is moved from left to right in front of the sensor? Carefully slide the card with both hands from left to right in the material retainer.

____

____

Put the Kodak grey card with the white surface towards the fibre-optic aperture in the retainer of the positioning slide. Move the positioning slide until the sensor output signal is 10 mA.

Leaving the positioning slide in this position, record the current signal when each sample 3 (steel zinc-coated), 4 (stainless steel), 5 (aluminium), 6 (brass) and 7 (copper) is inserted.
What conclusions do you draw for the application of this sensor in a testing station for springs?

Part exercise d)

Measurement series: Current-distance diagram						
s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)						
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)						

Enter the measured values in the diagram.

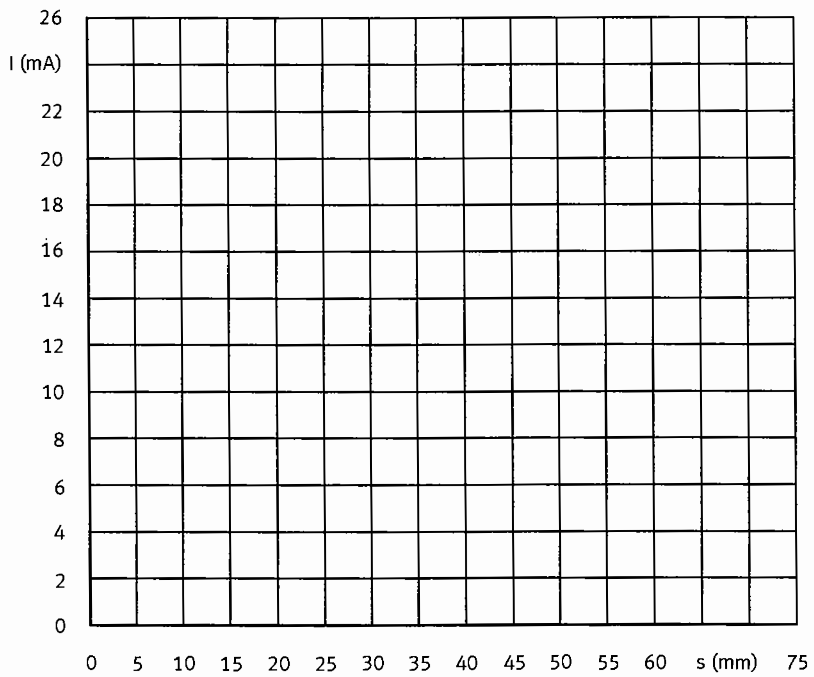


Fig. 7/5: Diagram for part exercise d)

What is the size of the measuring range of the analogue diffuse optical sensor?

____

Measuring material thickness by means of an analogue diffuse optical sensor

Learning content

Distance measurement by means of an analogue diffuse sensor.

Technical knowledge

The optoelectronic diffuse sensor contains a photoelectronic receiver (photodiode or phototransistor) and an infrared LED (IRED). The photoelectronic receiver receives the infrared light which has been emitted by the IRED and reflected by an object and converts it into an electrical current. If the strenght of the light beam arriving at the receiver changes in relation to the distance, then the electrical current also changes. By means of an electronic adjustment of the response characteristic in the sensor itself, a linear correlation between the output signal and the object distance can be achieved within a certain range. The sensing range can be changed by means of a built-in potentiometer.

The sensor is operated as an optical diffuse sensor with a fibre-optic cable. The distance measurement depends on the reflecting power of the object to be measured, i.e. the surface and colour of the object.

By comparison with a reference curve, which has been obtained for a reference object, the distance or the thickness of other similar objects can be determined. The sensor is used in applications where the measurement of variable distances within a range of 8mm to 40mm is required.

Problem description

Flat plastic material in strip form is fed to a fully automatic circular saw which is PLC controlled. Small production runs of plastic blanks are required which frequently vary in thickness between 3mm, 5mm, 8mm, 10mm and 14mm. The plastic material being fed is to be monitored automatically to check that material of the correct thickness is available. Two optical diffuse sensors are to be used for this according to the arrangement illustrated. Identical plastic of the same surface quality is used throughout, thus providing constant reflection characteristics.

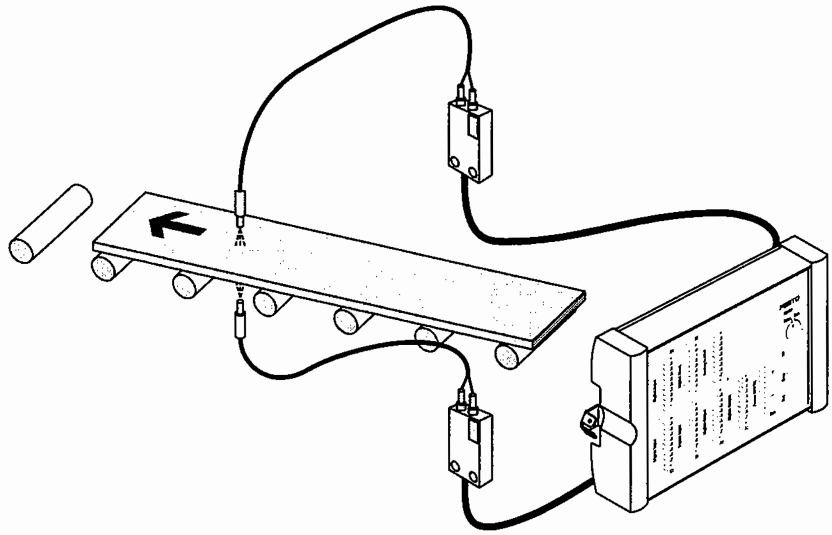


Fig. 8/1: Optical distance sensor for material thickness monitoring

Exercise

a) Mount the analogue diffuse sensor and the positioning slide onto the profile plate and connect the sensor.
b) Record the characteristic curve for the grey plastic plate 23 of the set of test objects, in two part steps:
   1) from 0.0 to 10.0 mm in steps of 1.0 mm.
   2) from 10.0 to 30.0 mm in steps of 2.5 mm.

   Please note that an accuracy of 0.1 mm is sufficient for the vernier caliper and an accuracy of 0.1 mA for the multimeter. Round off the measured values accordingly.
c) Adjust the positioning slide so that the distance between the material holder and the sensor head is 15.0mm. Measure the current values for the remaining grey plastic plates (plates 24 to 27 of the set of test objects) which are of different thicknesses. Carry out the measurements three times and establish the average value.
d) Determine the thickness of the glued on plastic layer 30x30 with the help of the measured values.
e) Measure the thickness of the plastic layers by using the vernier caliper and compare these values with those measured under d).

Practical implementation

The component reference number of the equipment set refers to the layout diagram and applies to all part exercises.

Distance measurement by means of optical sensors
Exercise 8

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Connection unit
2	1	Signal switching unit
3	1	Optical analogue diffuse sensor
4	1	Positioning slide
	1	Set of test objects parts 23-27 (plastic plates)
	1	Set of test objects part 17 Kodak- grey card
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
5	1	Vernier caliper
6	1	Digital multimeter

For the necessary equipment and supply units see page 20.

Part exercise a)

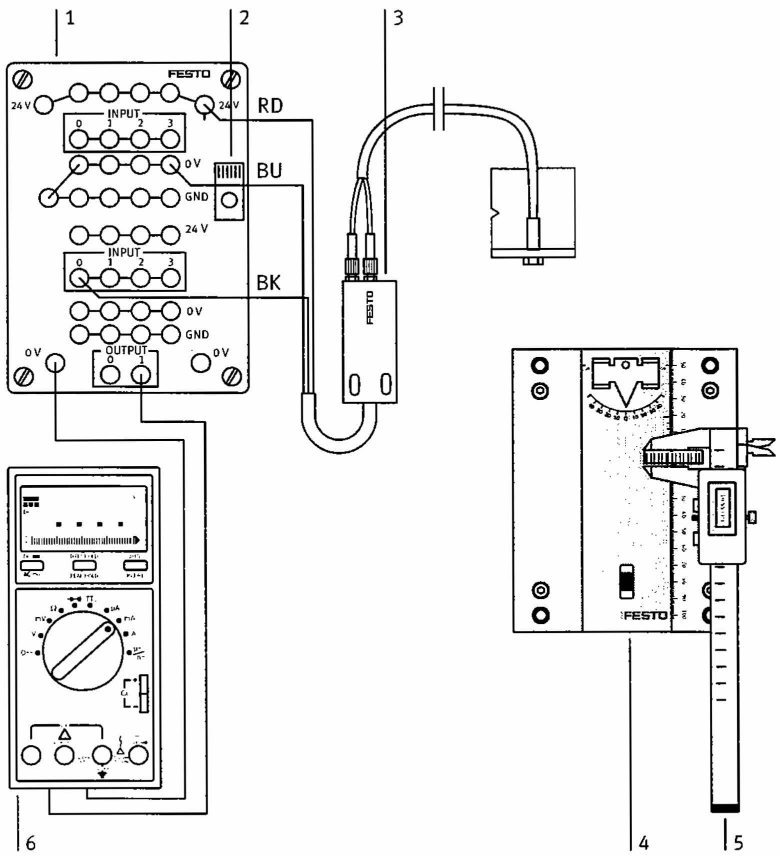


Fig. 8/2: Layout and connection diagram

In order to obtain the measurements for the characteristic curve of current/distance, the analogue diffuse sensor must be mounted on the profile plate. The fibre-optic cable is screwed to the sensor unit with the front end facing the positioning slide. The grey plastic card is to be inserted into the material holder of the positioning slide.

Calibrate the sensor with the white side of the Kodak grey card facing the sensor head. Move the Kodak grey card within a distance of 8 mm towards the sensor head. Remove the white cover screw of the sensor setting potentiometer. Set the potentiometer so that the output current measures 4 mA. Replace the cover screw.

To ensure optimum adjustment, make sure that the fibre-optic cable retainer is positioned approximately 6 cm in front of the positioning slide. Moreover, it must be possible for the card and the positioning slide to be moved directly in front of the fibre-optic aperture. In addition, slide the card in the retainer to the left until the righthand edge of the card is flush with the fibre-optic cable retainer. The retainer should be set at 0 degrees. Set the digitial indicator of the vernier caliper to zero when the surface of the measuring object fully covers the fibre-optic aperture.

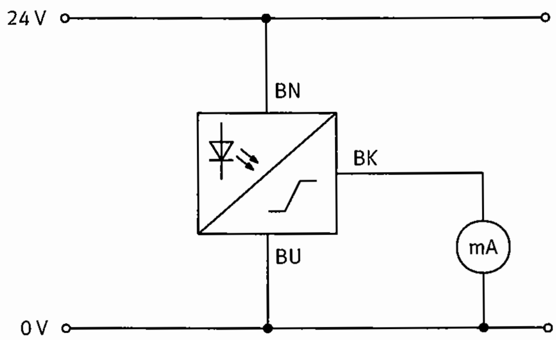


Fig. 8/3: Electrical circuit diagram

Interconnect the sensor (3) with connection unit (1) according to the electrical circuit diagram and then connect the digital multimeter (6). As a final step, the power supply is to be connected to the distribution plate. When the power supply is switched on, select the mA measuring range of the digital multimeter.

Part exercise b)

Measurement series: Current-distance diagram										
s (mm)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
U (V)											
s (mm)	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0			
U (V)											

Enter the measured values in the diagram.

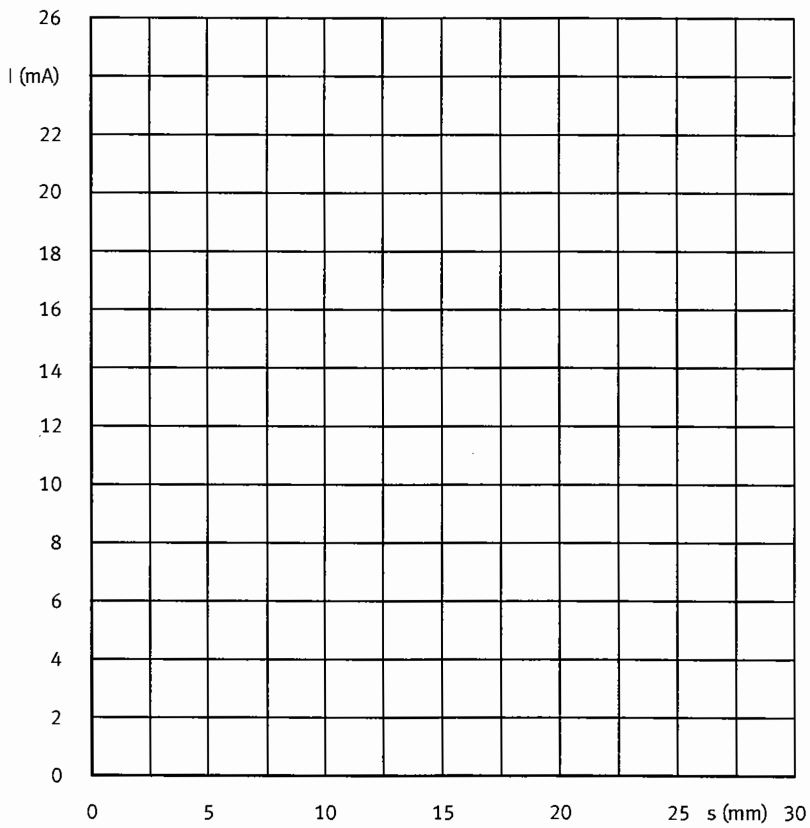


Fig. 8/4: Diagram for part exercise b)

Part exercise c)

Measurement series: Current values for various thicknesses	Current I (mA)	Current I (mA)	Current I (mA)	Average (mA)
Plate 23				
Plate 24				
Plate 25				
Plate 26				
Plate 27				

Part exercise d)

For a particular current value, draw a line parallel to the s axis intersecting the characteristic line. From this point draw a line parallel to the I axis and enter the corresponding distance value in table 8/4. You calculate the thickness by establishing the difference between the distance s read and the distance s of the plate 23.

Measurement series: Thickness measurement	Current I (mA)	Distance s (mm)	Delta s (mm)
Plate 23			
Plate 24			
Plate 25			
Plate 26			
Plate 27			

Part exercise e)

Comparison of measurement	Values measured using vernier caliper (mm)	Values detected using sensor (mm)
Plate 23		
Plate 24		
Plate 25		
Plate 26		
Plate 27		

Question

Why is the use of an analogue sensor appropriate in the case of the problem described?

Determining the effect of material type upon distance measurements using an analogue diffuse optical sensor

Learning content

Distance measurement is dependent on the colour and surface of the object.

Technical knowledge

The optoelectronic diffuse sensor contains a photoelectronic receiver (photodiode or phototransistor) and an infrared LED (IRED). The photoelectronic receiver receives the infrared light which has been emitted by the IRED and reflected by an object and converts it into an electrical current. If the strength of the light beam arriving at the receiver changes in relation to the distance, then the electrical current also changes.
By means of an electronic adjustment of the response characteristic in the sensor itself, a linear correlation between the output signal and the object distance can be achieved within a certain range. The sensing range can be changed by means of a built-in potentiometer.
The sensor is operated as an optical diffuse sensor with a fibre-optic cable. The distance measurement depends on the reflectivity of the object to be measured, i.e. from the surface and colour of the object.
By comparison with a reference curve which has been obtained for a reference object, the distance or thickness of other similar objects can be determined. The sensor is used in applications where the measurement of variable distances within a range of 8mm to 40mm is required.

Problem description

Electronic components such as capacitors, resistors and coils are made in different sizes and colours. Printed circuit boards equipped with electronic components can be checked by means of an analogue diffuse optical sensor. This is an example how the sensor is used in the field of quality control.
Prior to using the sensors, it is often necessary to carry out preliminary tests regarding the response to various shapes and colours of objects.

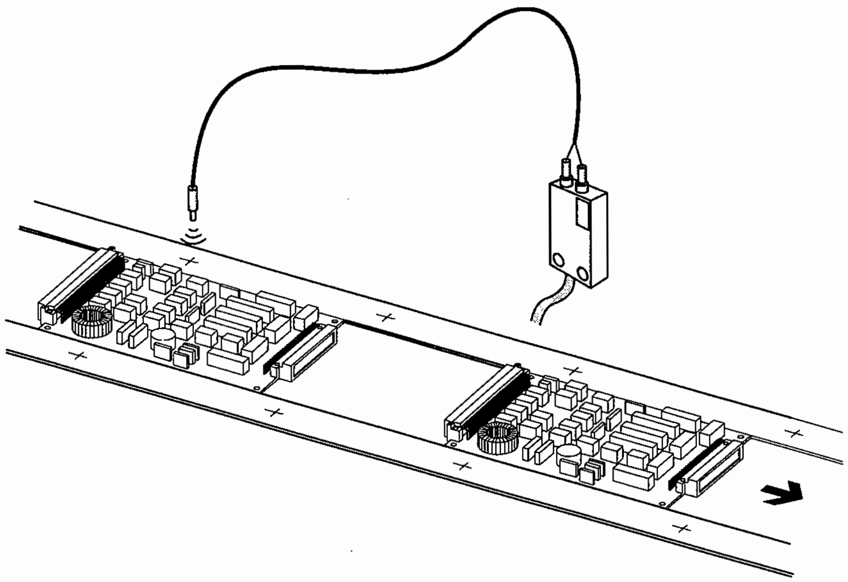


Fig. 9/1: Optical distance sensor used in quality control

Exercise

a) Mount the analogue diffuse optical sensor and the positioning slide onto the profile plate and connect the sensor.
b) Record the characteristic curves for the white and the grey surfaces of the Kodak grey card. Precisely measure the distances from 0.0 mm to 10.0 mm for the grey surface in gaps of 1.0 mm and from 10.0 mm to 55.0 mm in gaps of 5 mm. Then measure the distances from 0.0 mm to 55.0 mm for the white surface in steps of 5 mm. Please note that for part exercise b) toe), an accuracy of 0.1 mm is adequate for the positioning slide and of 0.1 mA for the digital multimeter. Round off the measured values accordingly.
c) Record the characteristic curve for the shiny and matt surface of the red card in gaps of 5.0 mm.
d) Record the characteristic curve for the shiny and matt surface of the blue card in gaps of 5.0 mm.
e) Record the different measuring curves on the same diagram and determine the sensing distance of the sensor for the different materials.

Practical implementation

The component reference number of the equipment set refers to the layout diagram and applies to all part exercises.

Equipment set

Component Ref. No.	Quantity	Description/Designation
1	1	Analogue connection unit
2	1	Signal switching unit
3	1	Analogue optical diffuse sensor
4	1	Positioning slide
	1	Set of test objects Part 17 Kodak grey card Part 19 red card Part 20 blue card 100 mm x 100 mm
	8	Plug-in adapters

Accessories

Component Ref. No.	Quantity	Description/Designation
5	1	Vernier caliper
6	1	Digital multimeter

For the necessary equipment and supply units see page 20.

Part exercise a)

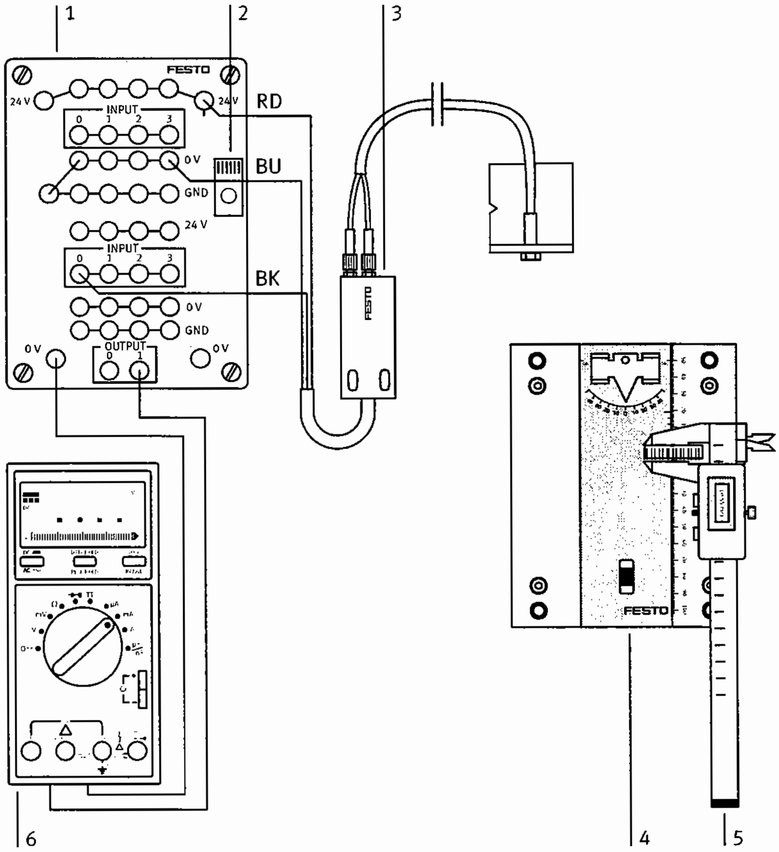


Fig. 9/2: Layout and connection diagram

In order to obtain the measurements for the characteristic curve for current/distance, the analogue diffuse optical sensor needs to be mounted on the profile plate. The fibre-optic cable is screwed to the sensor unit with the front end facing the positioning unit. The Kodak grey card is inserted into the material retainer of the positioning slide unit.

Calibrate the sensor with the white side of the Kodak grey card facing the sensor head. Move the Kodak grey card within a distance of 8 mm towards the sensor head. Remove the white cover screw of the sensor setting potentiometer. Set the potentiometer so that the output current measures 4 mA. Replace the cover screw.

To ensure optimum adjustment, make sure that the fibre-optic cable retainer is approximately 6 cm in front of the positioning slide (4). Moreover, it must be possible for the card and the positioning slide to be moved directly in front of the fibre-optic aperture. In addition, slide the card in the holder to the left until the lefthand edge of the card is flush with the fibre-optic cable retainer. The retainer is to be set at 0 degrees.

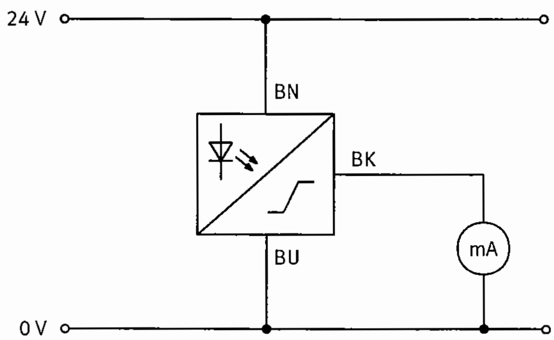


Fig. 9/3: Electrical circuit diagram

Interconnect the sensor (3) with the connection unit (1) according to the electrical circuit diagram. The final step is to connect the power supply to the connection unit. When the power supply has been switched on, select the mA measuring range of the digital multimeter(6).

Part exercise b) **Kodak grey card**

Measurement series: Current-distance diagram of grey surface

s (mm)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
I (mA)										
s (mm)	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)										

Measurement series: Current-distance diagram of white surface

s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)						
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)						

Part exercise c) **Red card**

Measurement series: Current-distance diagram of shiny surface

s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)						
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)						

Measurement series: Current-distance diagram of matt surface

s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)						
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)						

Part exercise d) **Blue card**

Measurement series: Current-distance diagram of shiny surface

s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)						
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)						

Measurement series: Current-distance diagram of matt surface

s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)						
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)						

Part exercise e)

Enter the measured values in the diagram.

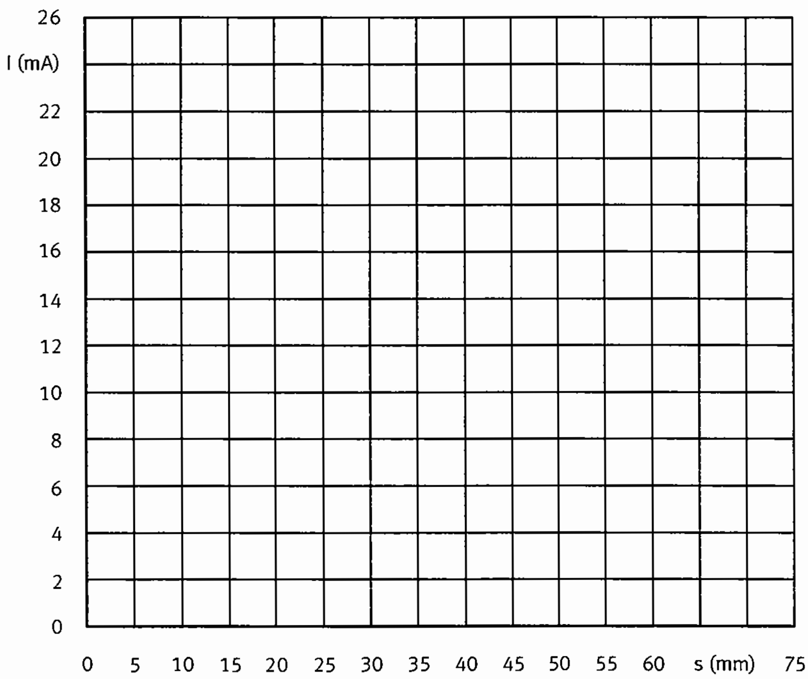


Fig. 9/4: Diagram

Determine the sensing distance of the sensor for the different coloured material surfaces with the help of the diagram.

Detected sensing distances	Surface	Sensing distance in mm
Kodak card	white	
	grey	
Red card	shiny	
	matt	
Blue card	shiny	
	matt	

Questions

Is the characteristic curve of the sensor neutral with regard to colour?

What effect does the nature of the surface have on your measurements?

Section B – Fundamentals

Chapter 1
Inductive distance sensors

1.1 Fundamentals of inductive sensors

Inductive sensors are based on the use of oscillators, their oscillating amplitude being effected by an approaching object. In order to generate sinusoidal oscillation, LC oscillators (consisting of a coil and a capacitor) are used.

The following denote:

L = Coil	Inductance, unit: Henry H	1 H	= 1 Vs/A
C = Capacitor	Capacitance, unit: Farad F	1 F	= 1 As/V

Inductive sensors

Let us consider the LC resonant circuit as applied in an inductive proximity sensor. The coil of an LC oscillator is located in a magnetic half shell core. This oscillator oscillates typically at a frequency in the range of approx. 100 – 1000 kHz. The LC oscillator generates a high frequency electromagnetic alternating field (HF field), which is emitted from the active surface of the sensor.

The amplitude of oscillation decreases or is completely attenuated if a conductive object approaches the half shell core.

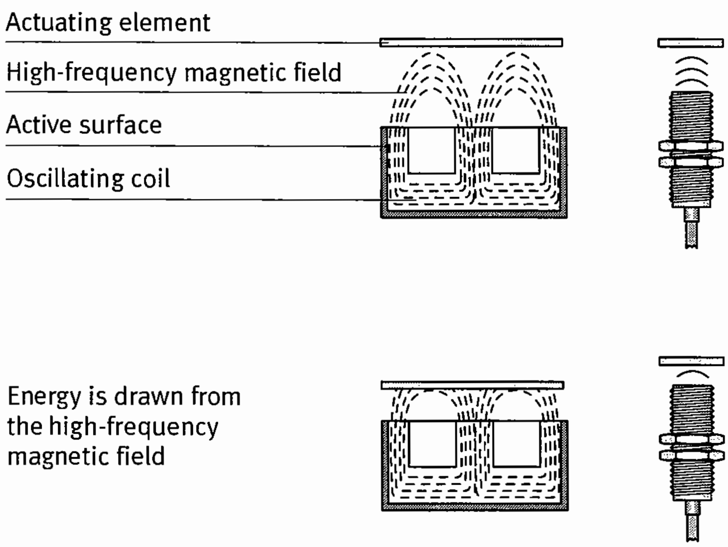


Fig. 1/1: Method of operation of an inductive sensor

Eddy currents

This is due to energy being withdrawn from the magnetic field by the formation of eddy currents as the object approaches. If a piece of metal in a constant magnetic field is moved, this induces eddy currents in this piece of metal. The same happens if stationary metal parts are exposed to magnetically alternating fields.

An inductive sensor operates with a low power consumption of several microwatts and this has three advantages:

- No significant magnetising effect
- The HF field does not cause any interference
- No temperature rise in the object to be sensed.

Binary and analogue inductive position sensors

The basic design of binary and analogue inductive sensors is identical. The main difference is that position sensors have a triggering stage. By means of this triggering stage an input/output threshold is defined. The sensor supplies a binary switching signal (answer YES – NO).

Oscillations

Electrical oscillations can be clearly illustrated by means of mechanical oscillations.

In the case of mechanical spring oscillation, a periodic change between potential and kinetic energy takes place. Analogous to this, electrical and magnetic field energy changes in the case of electromagnetic oscillation.

A comparison of mechanical and electrical quantities is obtained by:

Deflection x	→	Charge q
Load m	→	Inductance L
Friction constant k	→	Resistance R
Spring constant D	→	Reciprocal of capacitance 1/C

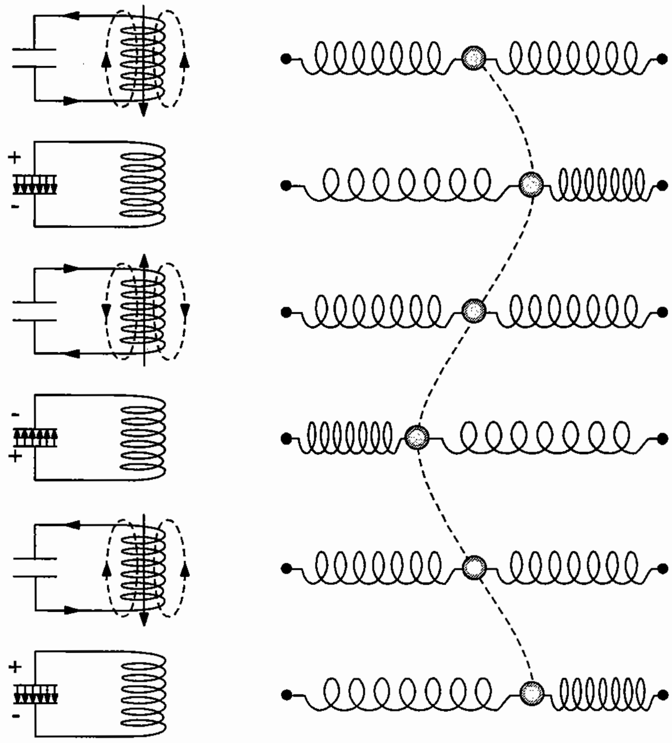


Fig. 1/2: Comparison of mechanical and electrical oscillations

The LC resonant circuit

Electromagnetic oscillations are created in a so-called LC resonant circuit consisting of a coil and a capacitor. Once the capacitor is charged, it discharges via the coil. During this process, current intensity and voltage change periodically.

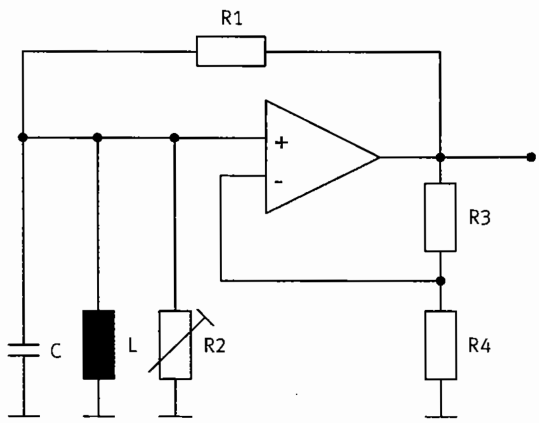


Fig. 1/3: LC resonant circuit

Unattenuated oscillation in this instance can however only be achieved if the resonant circuit has no ohmic resistance. In practice, it is therefore necessary to use an amplifier, which compensates for the attenuation resulting from the resistance. In figure 1/3 an operational amplifier is used for this reason.

In order to establish a value for the frequency of an LC resonant circuit, the time varying charge Q on the capacitor is examined. The following applies in the case of a plate capacitor with capacity C and voltage V:

$$Q = C \cdot V$$

At any given time t, a value q (t) is obtained, which with the capacity C of the capacitor gives the value of the voltage v(t).

The derivation of this charge according to time, dq/dt, determines the current I(t) which flows through the coil with inductance L. The voltage obtained on the capacitor is

$$v_C(t) = \frac{q(t)}{C}$$

and the voltage on the coil

$$v_L = L\frac{di}{dt} = L\frac{d^2q}{dt^2}$$

The equation for oscillation is:

$$v_C + u_L = L\frac{d^2q}{dt^2} + \frac{q}{C} = 0$$

If this equation is divided by L, the result for unattenuated oscillation is:

$$\frac{d^2q}{dt^2} + \frac{q}{LC} = 0$$

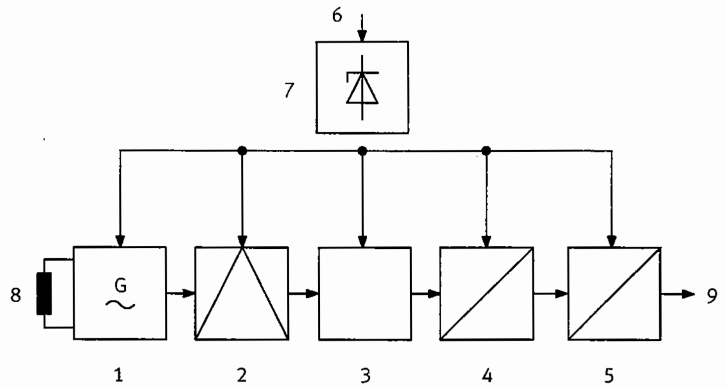
The result for the resonant frequency of the resonant circuit without attenuation is:

$$(\omega)^2 = \frac{1}{LC}$$

Example

For example, if one assumes the values L = 100 µH and C = 10 nF, then the value obtained in respect of resonant frequency is:

Basic circuit of an inductive sensor



1	Oscillator	6	External voltage
2	Demodulator	7	Internal constant voltage supply
3	Amplifier	8	Coil with active zone
4	Linearisation	9	Output: Current or voltage signal
5	Output signal conditioning		

Fig. 1/4: Block diagram of an inductive sensor

1.2 Measuring range and conductivity

The measuring range is dependent on the electrical conductivity of the metal to be detected. The table below indicates the values in respect of the conductivity of different metals and alloys. This simple dependence does not apply in the case of ferromagnetic metals and alloys, where the alternating field is conditioned by ferromagnetism. As an additional effect, high frequency fields cannot penetrate deeply into the conductive material, which results in a lower conductivity.

Conductivity and reduction factors for various materials

Conductor	**Conductivity** $\frac{m}{\Omega mm^2}$	**Reduction factor**
Copper	56.0	0.25 – 0.40
Aluminium	33.0	0.35 – 0.5
Brass	15.0	0.35 – 0.50
Chromium-Nickel	1.00	0.70 – 0.90

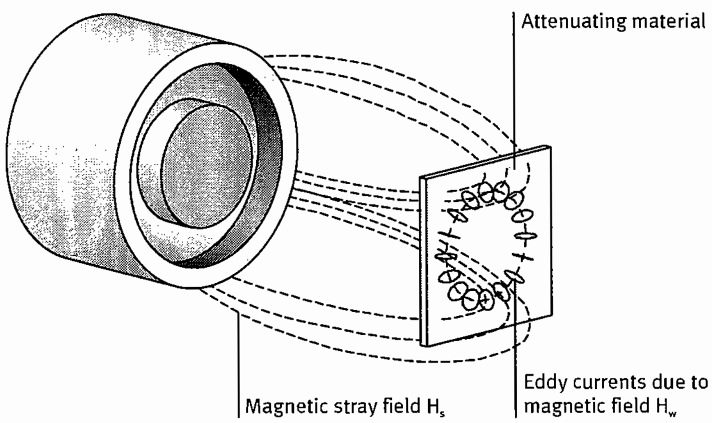


Fig. 1/5: Schematic field pattern with inductive proximity sensors

The field H_W created as a result of the eddy currents acts against the generating field H_S. This effect is described as field displacement. The skin effect has another, however less powerful effect, on the various switching distances of different materials at typical oscillator frequencies. As a rule, the oscillator frequency for inductive proximity sensors is in the range of 300 – 800kHz

Up to now, the dependence of the switching distance of the attenuating material could not be calculated explicitly.

Power dissipation in the attenuating material

Losses are created as a result of eddy currents in a metal plate. Assuming that the depth of penetration of the field is small and that the approaching field does not penetrate the metal plate, the following applies:

$$\frac{\text{power dissipation}}{\text{area}} = H_0{}^2 \sqrt{\frac{\pi f \mu}{\kappa}}$$

H_0 = r.m.s. value of the magnetic field strength of the stray field on the plate surface

$\mu = \mu_0 \cdot \mu_r$ = magnetic permeability

$\mu_0 = 1.257 \cdot 10^{-6} \frac{Vs}{Am}$ = magnetic field constant

μ_r = relative permeability

k = electrical conductivity

f = frequency

Diamagnetism, paramagnetism and ferromagnetism

Materials, which only negligibly reduce the magnetic field of a measuring coil, are described as diamagnetic, i.e. permeability is less than 1. With paramagnetic materials, a slight strengthening of the field occurs, i.e. permeability is higher than 1. Ferromagnetic materials considerably strengthen the magnetic field and as such are given a separate name. Their permeability is considerably higher than 1 and apart from that they depend heavily on pre-treatment of materials.

Paramagnetic materials	Diamagnetic materials	Ferromagnetic materials
Manganese	Zinc	Iron
Chromium	Lead	Cobalt
Aluminium	Copper	Nickel
Platinum	Silver	

Chapter 2
Linear potentiometers

General

With many applications in control technology, information regarding displacement and length has to be detected and transmitted. This information can be obtained by means of incremental or absolute measuring systems.

Incremental measuring systems

The distance between two places can be determined with the help of a map and a pair of dividers by measuring, according to scale, a specific distance with the dividers and establishing how many times this increment goes into the distance between place A and place B. The length of the increment multiplied by the number of steps gives the distance. This measuring system only provides integral multiples of the basic unit.

Absolute measuring systems

If a scale is used instead of dividers, then the distance can be read directly and no counting is required. This is known as an absolute measuring system because the measured variable can be read direct.

2.1 Function description

The simplest form of analogue position sensing is the absolute measurement of a distance travelled by means of a potentiometer. The function of a linear potentiometer is based on the voltage divider principle, whereby the distance travelled is transmitted to a potentiometer, from which the position data can be accessed in the form of an electrical voltage.

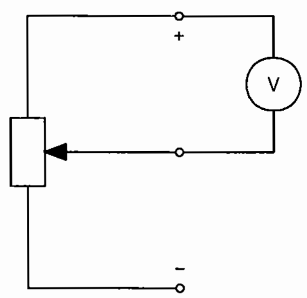


Fig. 2/1: Linear potentiometer

Voltage divider principle

A voltage divider consists of two series-connected resistors R1 and R2, whereby the total voltage V_T is divided into the lesser voltages V_1 and V_2. If no load is connected to the voltage divider, voltage V_2 is described as open circuit voltage.

In order to be able to influence the voltage V_2, a variable resistor is used instead of the two resistors R1 and R2. With this potentiometer, it is possible to set voltage V_2 from 0 to V_T.

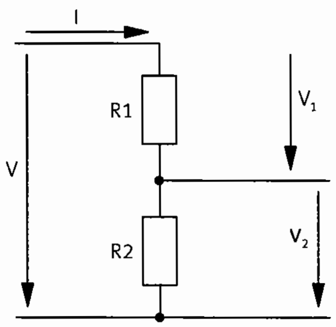


Fig. 2/2: Voltage divider without load

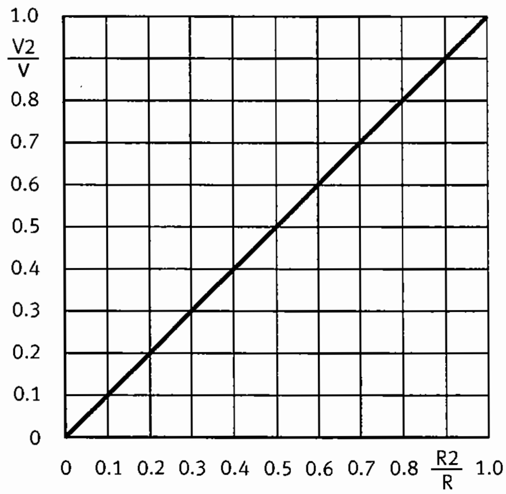


Fig. 2/3: Open circuit voltage (R=R1+R2)

2.2 Voltage measurement

If current is drawn from the voltage divider via a load, this is described as a loaded voltage divider. In this case, the load resistance R_L is parallel to the part resistance R2. The equivalent resistance of this parallel circuit is less than resistance R2, thus reducing the load voltage V_2.

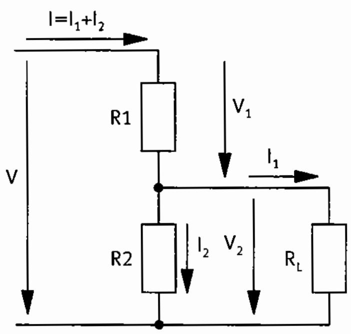


Fig. 2/4: Voltage divider with load

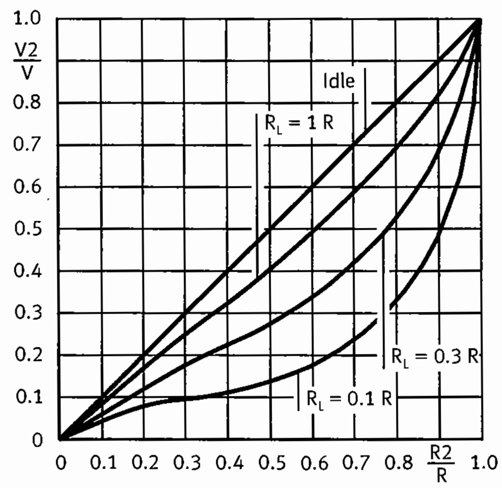


Fig. 2/5: Load voltage (R = R1 + R2)

The greater the load resistance R_L in comparison with part resistance R2, the less the characteristic curve of the load voltage differs from that of the open circuit voltage. In order to achieve this in practice, an impedance converter is connected between the voltage divider and the load. Experience has shown that unsuitable electrical connection with linear potentiometers can cause errors, which are far greater than the specified linearity.

Impedance converter

An impedance converter or voltage follower is used to be able to measure the voltage of the linear potentiometer without load, whereby a non-inverting operational amplifier forms the core of the circuit.

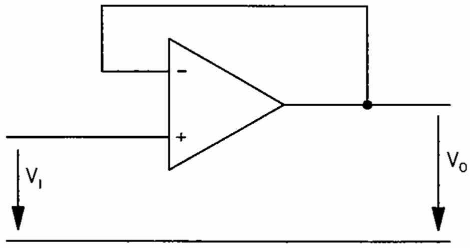


Fig. 2/6: Impedance converter

In the equipment set provided the impedance converter and protective circuit are inserted into the potentiometer cable. The protective circuit is limited to 15 V and protects the potentiometer connection against incorrect polarity.

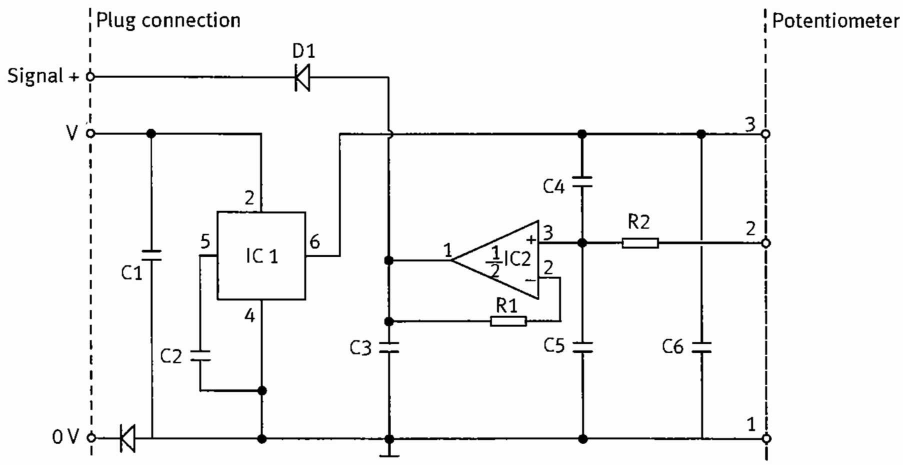


Fig. 2/7: Impedance converter with protective circuit (V = Supply voltage)

2.3 Conductive plastic resistance potentiometers

The resistance part of the linear potentiometer is coated with a conductive plastic resistance layer. On this resistance layer is a sliding contact, where a voltage can be measured, which is proportional to the supply voltage and the slider setting.

The main advantages of this potentiometric displacement sensor are high resolution, reduced linearity difference and reasonable price.

Disadvantages are wear of the resistance layer and sliding contact as well as possible contact defects as a result of dirt or mechanical distortion.

Performance criteria of a linear potentiometer[1]

Linearity error f refers to the maximum difference of the measuring curve of the potentiometer from the ideal straight line. When determining linearity, the output voltage of the potentiometer is compared to an ideal voltage divider.

[1] Source: Performance criteria for conductive plastic potentiometers, E. Gass, Novotechnik

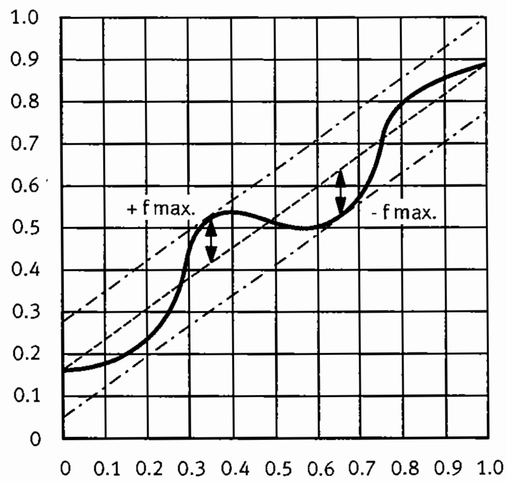


Fig. 2/8: Linearity

Temperature and humidity

One important performance criterium with regard to application is the temperature and humidity coefficient of the voltage divider. This determines the accuracy and stability of the measured value conversion under different environmental conditions.

Measurements which have been carried out on the resistive elements alone show that temperature and relative humidity have only a relatively small effect on the accuracy of linear potentiometers. However, if the resistive elements have not been built into the potentiometer housing sufficiently carefully, these effects can increase several times by a power of ten. It is therefore important to ensure that the plastics substrate can always expand and contract homogenously. However, external effects can be largely eliminated by means of careful construction.

Service life

The maximum number of possible actuations is the criteria for the service life of a potentiometer. The number of actuations possible is determined by the contact reliability, the wear of the resistance and wiper and the change in electrical characteristic values as a result of this.

The unit becomes unserviceable when a marked deterioration in linearity occurs, e.g. by twice the specified value. In the case of large displacement potentiometers, the wiper can become completely worn and inoperative. It is quite possible that this may occur before any other service life criteria such as contact breakage. It is of course possible that mechanical defects such as damaged bearings, axial or radial play may determine the end of the service life of a potentiometer.

Contact behaviour

Contact behaviour is largely influenced by the geometric shape, the contact pressure and by the wiper material.

On the whole, two types of wiper patterns have become predominant: the nib wiper and rake wiper.

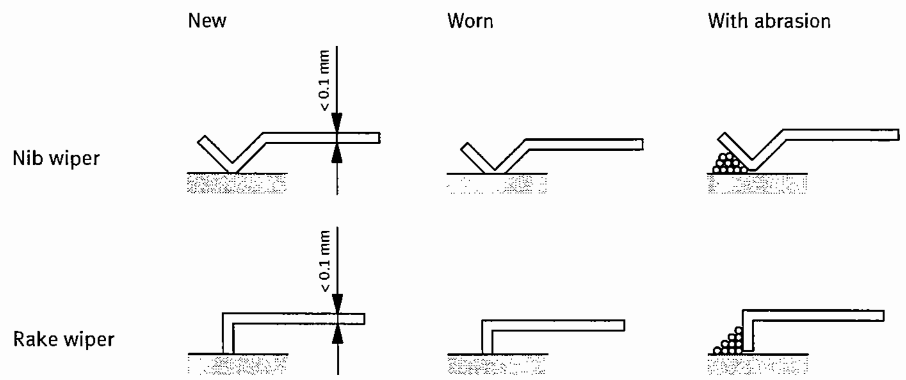


Fig. 2/9: Wiper designs

The rake wiper has three major advantages as opposed to the nib wiper:

- Constant bearing surface in case of wear
- Less floating over worn areas
- Straight line in relation to the contact points running parallel with the potential lines, which are easier to realise.

As a result of these advantages the rake wiper has become more predominant in practical applications.

The wiper pressure of the most common wipers is around 15 mN. As a result of the standard wiper being an undamped spring-loaded system, they are prone to inherent oscillations, which are magnified by any unevenness of the resistance path. Fast actuation leads to contact problems. The wipers are therefore damped. Currently, the most effective solution is the patent-protected cushioning of wiper fingers by using elastomers with good inherent damping.

As with wiper types, just a few standard alloys have proved to be suitable as wiper materials. The following conditions for use must be met:

- Corrosion resistance
- Material hardness
- Good ductility
- Good punching quality in ductile state
- Good spring characteristics

The most widely used wiper material is Paliney 7, which is an alloy consisting of palladium, platinum, gold, cooper, silver and zinc.

Repeatability

Repeatability is a combination of resolution and hysteresis on reversal of movement.

Primarily, there are several decisive factors for resolution, the homogeneity of the resistance layer followed by the geometric design and direction of wiper contact lines.

The hysteresis is determined by mechanical precision, the stiffness of the wiper and the friction value between wiper and resistance layer.

Only the indication of resolution and hysteresis combined provide information regarding repeatability.

As a result of the development of displacement sensors based on conductive plastic, linear potentiometers have gained in significance. They are available in a wide range of designs.

Displacement probes

The special feature of a displacement probe is the preloaded spring, which pushes the feeler into the initial position. As such, the design is suitable for measurements without positive connection between the system of displacement measurement and the object to be measured.

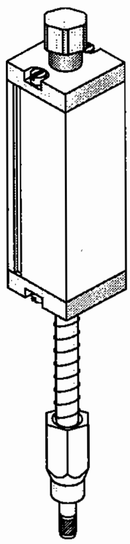


Fig. 2/10: Displacement probe

Piston rod displacement sensors

This is the most widely used design in mechanical engineering and car manufacturing, as well as in robotics and automation. Its distinguishing feature is great robustness and high accuracy. It is constructed using backlash-free spherical couplings permitting greater angular freedom.

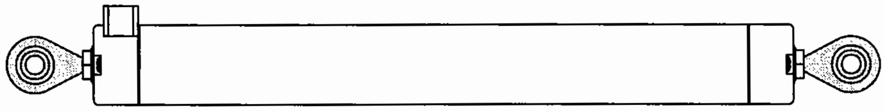


Fig. 2/11: Connecting rod displacement sensor

Rodless displacement sensors

The rodless, longitudinal coupling reduces the installation dimensions, avoids the pumping effect of piston rod displacement sensors and allows greater measuring lengths. A magnetically held steel band provides a sealed covering of the measuring unit.

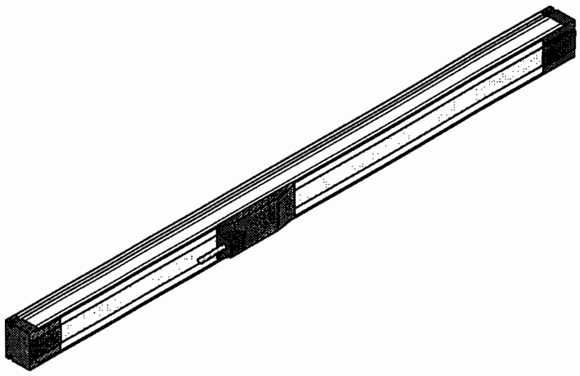


Fig. 2/12: Rodless displacement sensor

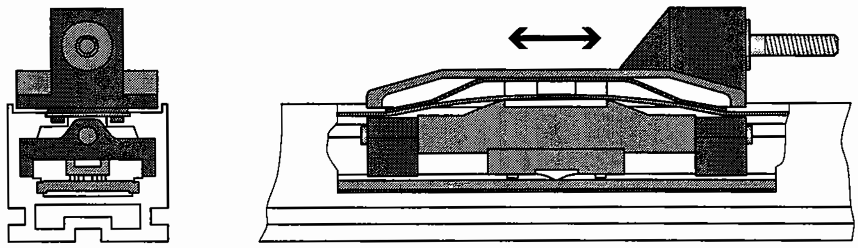


Fig. 2/13: Rodless displacement sensor (sectional view)

Technical data

The data listed below represents the range of parameters of linear potentiometers used in industrial application.

Technical data of conductive plastic potentiometers	
Resistance values	1 – 20 kΩ
Effective working length	5 – 4000 mm
Linearity	±0.01 – ±0.2 %
Resolution	typ. 0.01 mm
Recommended wiper current	<1 μA
Operating speed	<20 m/s
Ambient operating temperature	-30 – 100 °C
Service life	10^6 – 10^8 actuations

2.4 Application

Bottles arriving on a conveyor belt are placed on pallets.

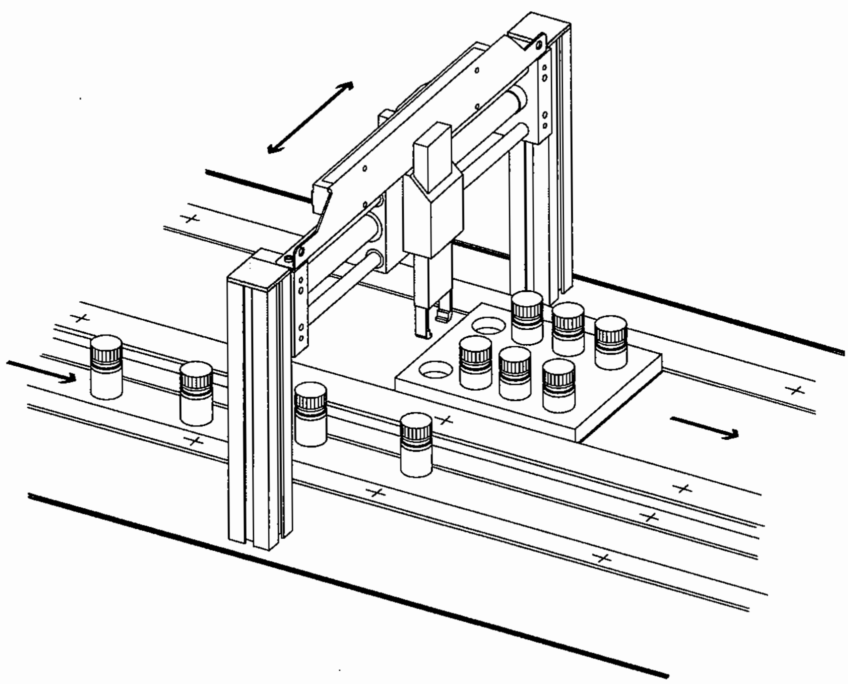


Fig. 2/14: Palettising of small jars

Chapter 3
Ultrasonic sensors

General

In the popular sense, sound is a physical phenomenon perceivable by the ear. This is why initially acoustics were confined to audible sound. Once transmitter and receiver had been developed for non-audible sound, it was then possible to extend the boundaries of acoustics.

Sound is divided into categories according to the generated oscillating frequency:

The different categories of sound	
Audible sound	The lower limit of human perception is 16 Hz, the upper limit fluctuates between 10 kHz and 20 kHz.
Ultrasound	The frequency range above 20 kHz is described as ultrasound.
Infrasound	Oscillations of a frequency below 16 Hz are described as infrasound. This type of sound wave occurs for instance during earth quakes and last for periods ranging from 10 s to 50 s.
Hypersound	The highest frequencies created so far are between 10^{10}Hz and 10^{13}Hz and are known as hypersound. Elastic solid state oscillators cease to vibrate at these frequencies.

3.1 Propagation of sound

The propagation of sound is the result of propagation of mechanical long waves, which manifests itself in a periodic density variation leading to compressions and dilutions in the transmitting medium. The propagation of sound waves is dependent on a transmitting medium, it is not possible in a vacuum. The propagation speed of sound varies according to different media.

The speed of propagation in solid materials can be calculated according to the formula

$$C = \sqrt{\frac{E}{\rho}}$$

E Modulus of elasticity
ρ Density of material

and in liquids according to the formula

$$C = \sqrt{\frac{K}{\rho}}$$

K Modulus of compression
ρ Density of material

in gaseous materials according to the formula

$$C = \sqrt{\frac{p \cdot \kappa}{\rho}} = \sqrt{\kappa \cdot R \cdot T}$$

The speed of propagation c is for instance indicated in m/s.

P Pressure
K Adiabatic exponent
ρ Density of material
R Gas constant
T Temperature

Ultrasonic waves may, because of the short wavelength, be concentrated in the same as light waves. The law of optical geometry "Angle of incidence = angle of reflection" also applies for ultrasonic waves.

The surface texture is of great significance as far as the directed reflection is concerned. If surface roughness is within 1/4 to 1/6 of the sound wavelength, the waves are reflected diffusely, whereas smooth surfaces have a maximum angle of approx. ± 5° to the sound cone. Roughly structured substances, e.g. bulk goods, can be detected up to an angle of approx. ± 45°.

The wavelength is determined by

$$\lambda = \frac{v}{\nu}$$

v Speed of sound
ν frequency

Example

The majority of ultrasonic sensors use an ultrasonic frequency within the range of 30 kHz to 250 kHz. The following value is obtained in respect of sound wavelength, with a sound propagation speed of approx. 340m/s and a frequency of 200 kHz.

$$\lambda = \frac{v}{\nu} = \frac{340 \, m/s}{200 \cdot 10^3 Hz} = 1.7 \cdot 10^{-3} m = 1.7 \, mm$$

The majority of ultrasonic sensors use an ultrasonic frequency within the range of 30 kHz to 250 kHz. The following value is obtained in respect of sound wavelength, with a sound propagation speed of approx. 340 m/s and a frequency of 200 kHz.

Speeds of sound propagation in metres per second

Solid materials (at 20 °C)	v (m/s)
Aluminium	5110
Lead	1200
Iron	5180
Gold	2000
Rubber	54
Cork	500
Copper	3800
Brass	3500
Steel	5100
Fluids (at 20 °C)	v (m/s)
Benzene	1320
Chloroform	1000
Glycerine	1923
Petroleum	1320
Mercury	1415
Carbon tetrachloride	943
Water, distilled	1483
Gases (at 0°C and 101.3 kPa)	v (m/s)
Ammonia	415
Argon	308
Helium	971
Carbon dioxide	258
Carbon monoxide	337
Air	332
Hydrogen	1286

3.2 Ultrasonic emitter

Sound frequency which is above the limit of human hearing (>20kHz) is described as ultrasound. The particular characteristics of ultrasound are the result of the high frequency in conjunction with the short wavelength. These characteristics are adopted mainly when used for the purpose of proximity sensing.

There are three different methods of generating ultrasound:
- mechanical
- magnetic
- electric

In this context, mechanical generation of ultrasound is only of minor importance.

Magnetostriktion

In the case of magnetostrictive sound generation, a phenomenen is utilised which was discovered by J. P .JOULE in the last century. Joule observed, that when a ferromagnetic bar is magnetised, it undergoes a change in length.

With so-called magnetostriction, a magnetisable bar is introduced into the axis of a coil through which an alternating current flows. The bar is then remagnetised in tune with the alternating current frequency, thereby changing its length at the same rate. The relative change in length is within a range of $\frac{\Delta l}{l} \approx 10^{-5}$.

Resonance is achieved when the frequency of the alternating current coincides with the natural mechanical frequency of the bar.

With this method, it is possible to generate highly intensive ultrasonic oscillation of up to 50 kHz, whereby the sound waves are deflected from the end face of the bar. It is not possible to achieve a frequency beyond this, because the coil cannot be remagnetised any faster.

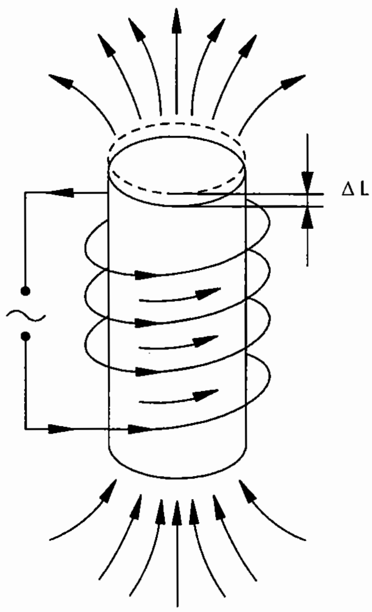


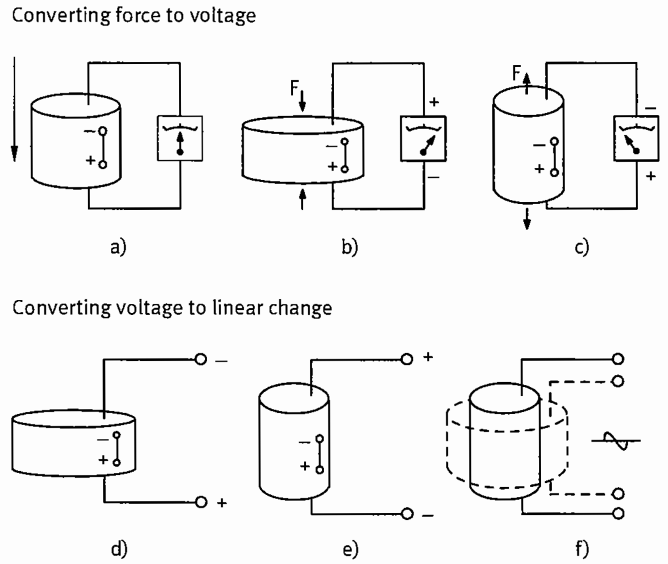
Fig. 3/1: Magnetostriction

Piezoelectric effect

As with magnetostriction, the piezoelectric effect was discovered in the last century. The brothers CURIE observed that in the case of crystals with polar axes, e.g. quartz, an electrical charge occurs at the ends of the polar axes through pressure and expansion.

Conversely, this crystal undergoes mechanical deformations in an electrical field, where the direction coincides with the polar axis. In order to exploit this effect, a section is cut out of the crystal, the two surfaces of which are vertical to the polar axis. This piece of crystal is provided with contacts and these are connected to an alternating voltage. The crystal starts to oscillate. When the frequency of the alternating voltage and natural mechanical frequency coincide, i.e. resonance occurs, oscillation has reached maximum amplitude. With this method, frequencies beyond 100 MHz can be achieved.

Today, instead of previously used quartzes, piezoelectric oxide materials which are marketed under the trade name piezoxide (e.g. by Valvo) are frequently used for the generation of ultrasound. These are materials consisting of lead-zirconate-titanates. Furthermore, piexoelectric plastic film is also used in sensor technology; e.g. in microphones.



a) Unloaded object
b) Compressive stress
c) Tensile stress
d) Direct current, reverse polarity
e) Direct current, same polarity
f) Alternating current, leads to alternating between extending and shortening

Fig. 3/2: Piezoelectric effect (Source: Phillips Components)

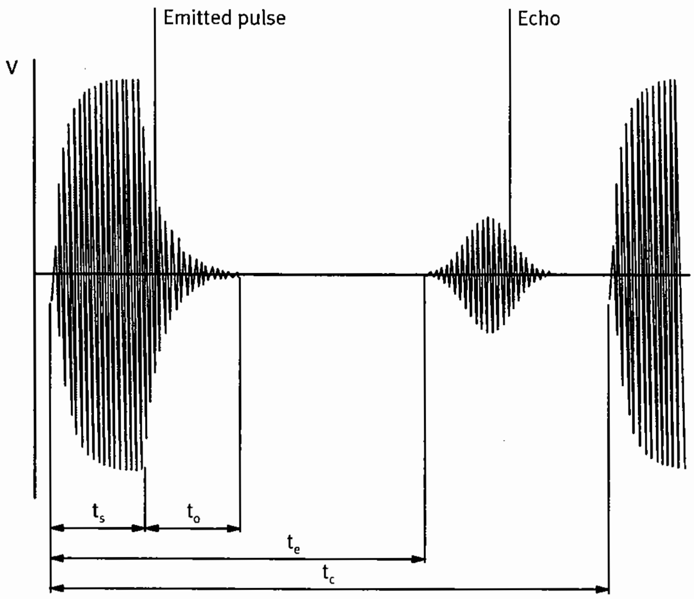
3.3 Ultrasonic receiver

The majority of ultrasonic receivers are based on the reversal of the function principle of the emitter. Built-in control electronics determine the timing of sound generation, emission of the sensor signal, measurement of the echo signal, with the additional task of switching over between emission and receiving operations.

Pulse mode

The pulse mode is used mainly in order to detect the presence of an object and for distance measurement.

This is a typical method whereby pulses of short duration and rise times are generated and emitted. If a reflecting object is within the emission range of a sensor, the sound waves are reflected as echo signals, which arrive at the receiver, after the signal propagation delay. This propagation delay is proportional to the distance between the sensor and the object. The absolute distance from the object is therefore determined by means of time measurement.



t_o = Final oscillation time t_c = Cycle time
t_s = Pulse length t_e = Echo time

Fig. 3/3: Distance measurement by determining run-time of ultrasound

Design of a pulsed ultrasonic sensor

The ultrasonic sensor is divided into the following functional groups:

- Ultrasonic transducer
- Evaluation unit
- Output stage

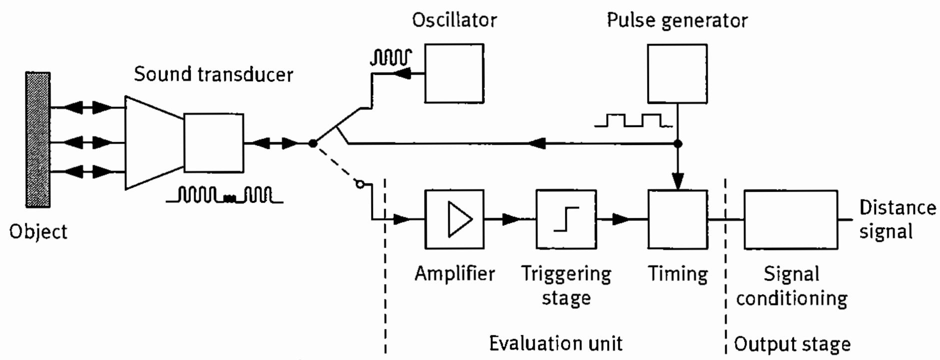


Fig. 3/4: Block diagram of a pulsed ultrasonic sensor

Ultrasonic transducer

In the emitting mode, the ultrasonic transducer is excited by a short voltage pulse. This pulse generates a brief ultrasonic oscillation pulse of a frequency determined by the resonance frequency of the ultrasonic transducer. The ultrasonic transducer is then switched over to the receiving mode and the reflecting ultrasonic waves (echo pulses) are received and evaluated.

Evaluation unit

The evaluation unit first of all checks whether the arriving signal is in fact the echo of the emitted ultrasonic wave. If the signal is recognised as the echo, the propagation time of the sound wave is determined. The propagation time is the time which has passed between the emission of sound and the reception of the echo. The result of this evaluation is passed on to the output stage.

Output stage

The signal which is emitted by the output stage depends on the purpose for which the ultrasonic sensor is used.

If the sensor is used as an ultrasonic proximity sensor, the occurance of a reflected ultrasonic signal is evaluated at the receiver. In this instance, the output signal merely indicates whether an object is present or not.

If the sensor is used as an ultrasonic distance sensor, then the propagation time of the sound is calculated and an electrical signal is available via the output unit, which corresponds to the distance between sensor and object.

Operating conditions for ultrasonic sensors

With ultrasonic sensors it is possible to detect solid, liquid, granular and powdery substances.

According to the surface roughness of an object, the range of a sensor can on the one hand be reduced as a result of diffuse back scatter, but on the other hand the sensor no longer needs to be aligned with the object at a precise right angle in order to obtain reflection.

The colour of an object does not affect sensor behaviour.
No object must be present within the so-called local part of the sensor's sound field, as this may lead to error pulses at the output of the proximity sensor. For example, an ultrasonic proximity sensor with a transducer diameter of D = 15 mm and a transmission frequency of 200 kHz has a local field range of approx. 130 mm.

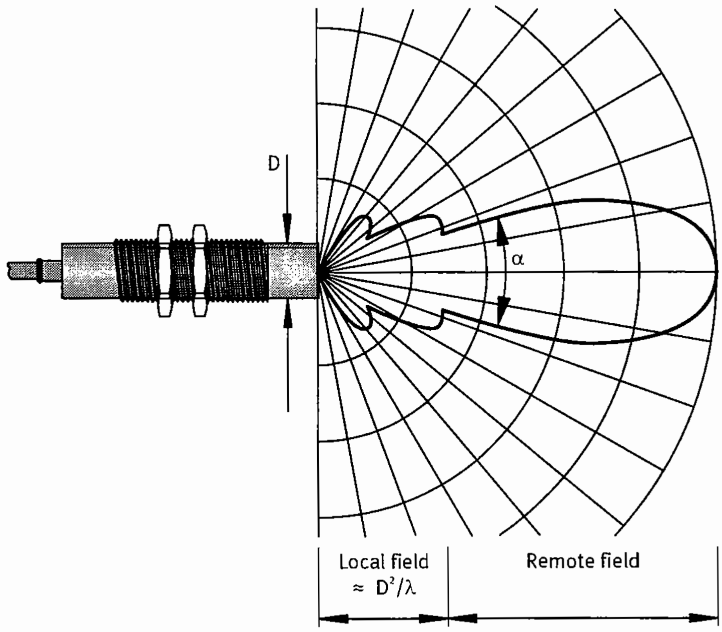


Fig. 3/5: Field of an ultrasonic sensor

The speed of sound varies slightly according to temperature (0.18 %/C). Ultrasonic sensors are therefore temperature dependent. In the case of very hot applications such as molten metal baths, this effect is very pronounced and it is not possible to achieve a reliable echo signal.

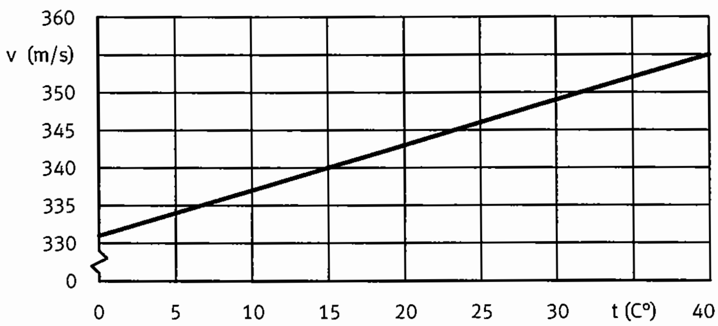


Fig. 3/6: Change of speed of sound in dry air with respect to temperature

Moreover, the speed of sound through air depends on air humidity. The speed of sound between dry and moist air varies by approximately 0.5 % at 20 °C.

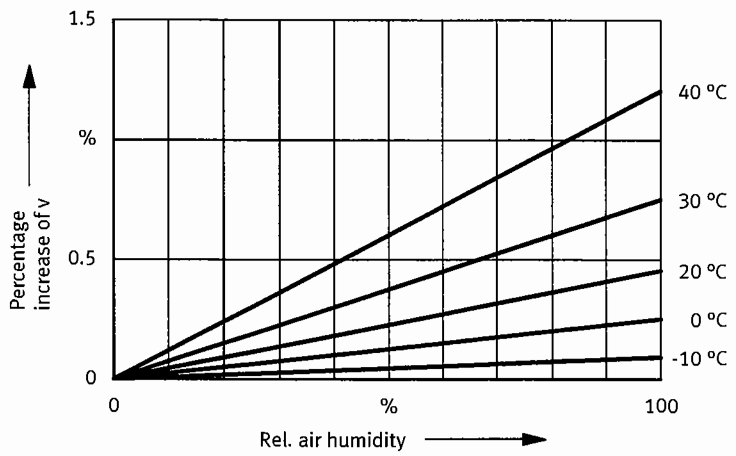
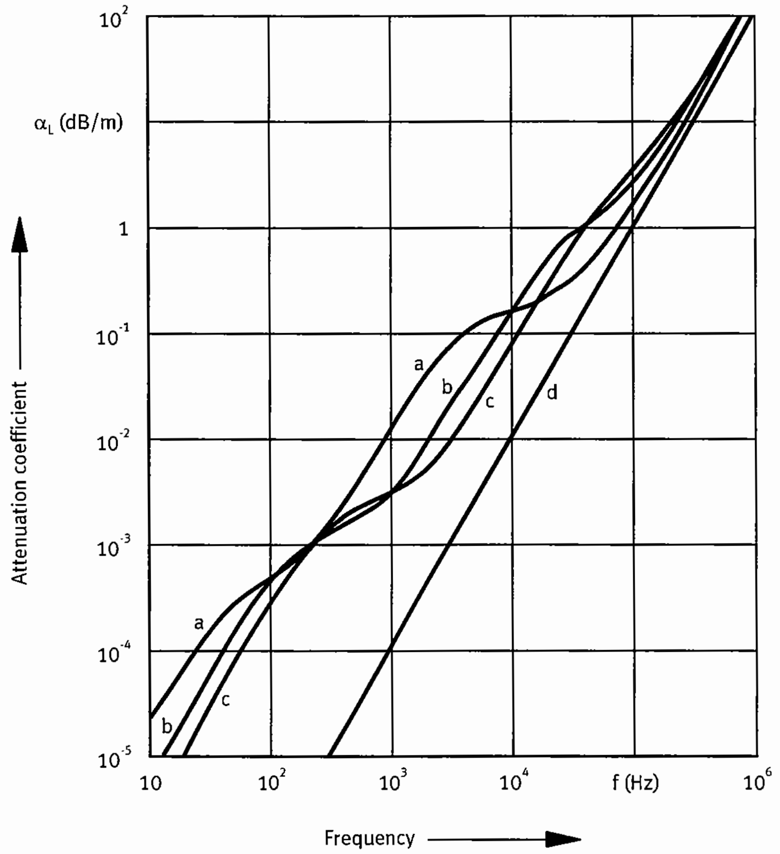


Fig. 3/7: Percentage change of speed of sound in air with respect to air humidity

When selecting ultrasonic sensors, the frequency of the emitter should be observed. Fig. 3/8 illustrates the losses in attenuation in relation to frequency and air humidity.



Air temperature 20 °C

a) Relative air humidity 10 %

b) Relative air humidity 40 %

c) Relative air humidity 80 %

d) Theoretic attenuation on the basis of normal absorption:
The linear attenuation is proportional to the square of the sound frequency

Fig. 3/8: Attenuation of ultrasonic waves in relation to frequency and air humidity

3.4 Designs

Ultrasonic sensors are basically divided into

- square designs and
- cylindrical designs

Both designs are available with one or two sound transducers.

Separate sound transducers

In the case of a design with two sound transducers, one transducer element is used as an emitter and the other as a receiver. This results in a small dead zone in front of the sensor (≤50 mm),

$$\alpha = C\frac{\lambda}{D}$$

λ = wave length, D = aperture, K= constant

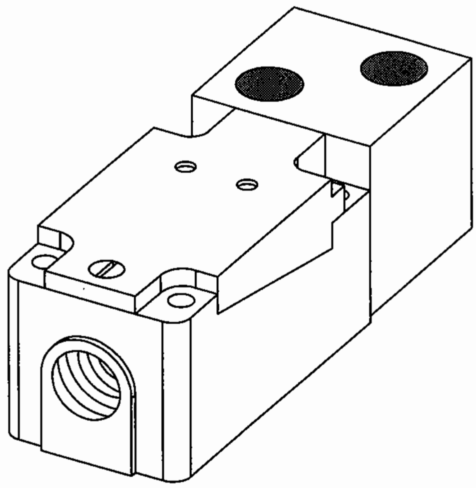


Fig. 3/9: Square designed ultrasonic sensor with two ultrasonic transducers

Sound transducer with a single transducer element

This type operates with a single transducer element, which is used alternately as an emitter and a receiver. This means a greater dead zone due to the decaying transient oscillation after emission of an ultrasonic pulse (<250 mm).

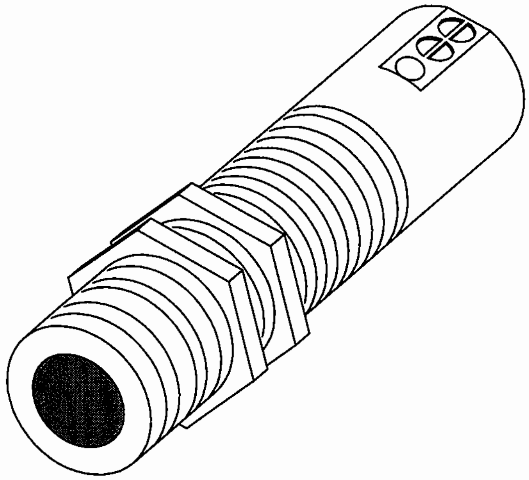


Fig. 3/10: Barrel-shaped design with a single sound transducer

Technical data

The data shown below is typical for analogue ultrasonic sensors in industrial applications.

Typical data for ultrasonic sensors	
Operating voltage	20 – 30 V DC
Max. range	0,5 – 10 m
Inaccuracy, Non-linearity	<0,5 – 5 %
Resolution	0,1 – 2 mm
Response time	20 – 500 ms
Object material	any, with the exception of sound absorbing materials
Analogue output	typ.: 0 – 10 V or 4 – 20 mA
Ambient operating temperature	-10 – 70 °C
Susceptibility to dirt	moderate
Service life	long
Ultrasonic frequency	30 – 220 kHz
Protection class to DIN 40 050	typical IP 65

3.5 Applications

Ultrasonic sensors are used in a wide range of industrial production and handing processes. The following illustrations provide a small selection of typical areas of application.

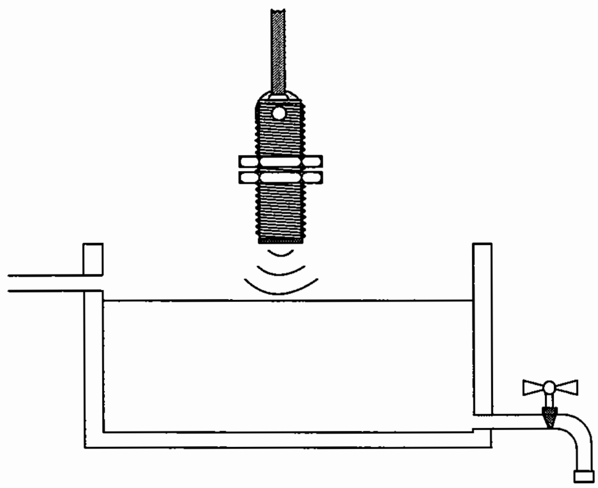


Fig. 3/11: Sensing liquid levels

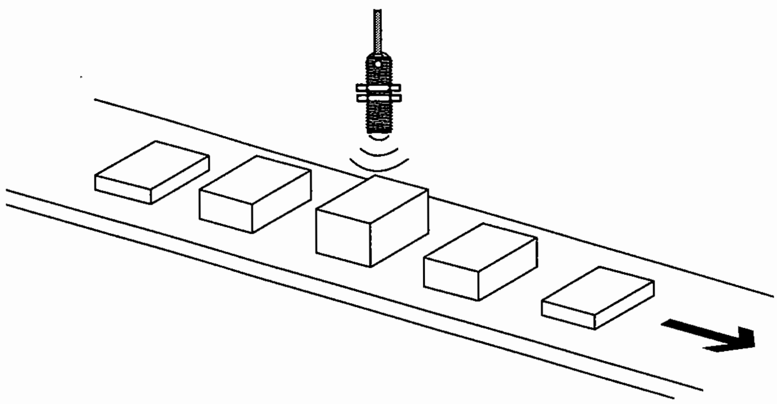


Fig. 3/12: Sorting parts according to heights

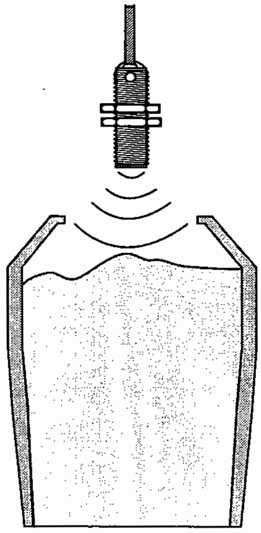


Fig. 3/13: Monitoring of filling level in silos

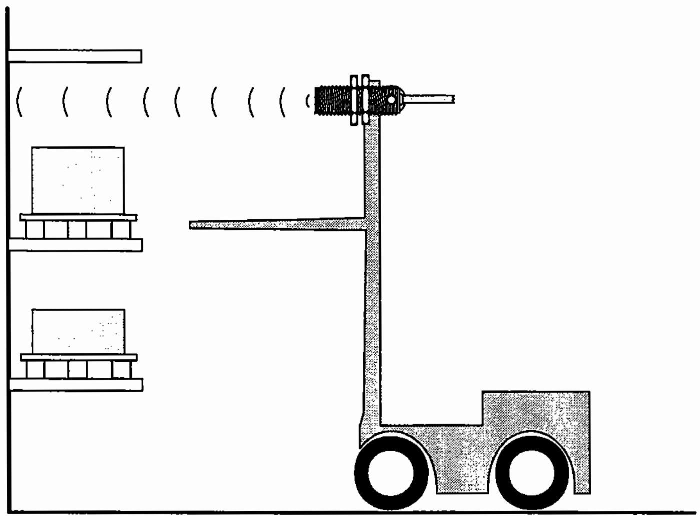


Fig. 3/14: Control of lifting vehicles

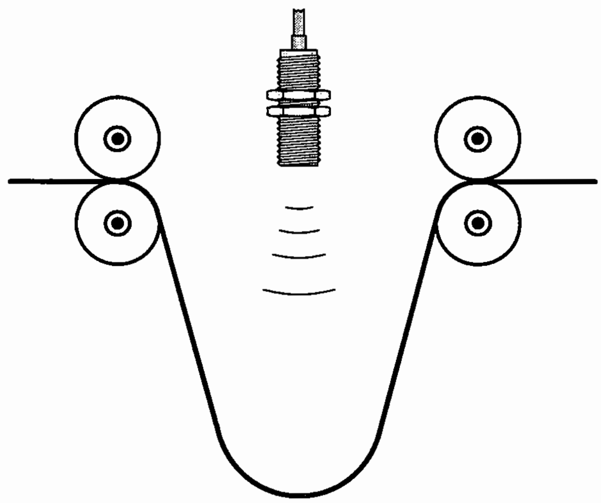


Fig. 3/15: Tension monitoring

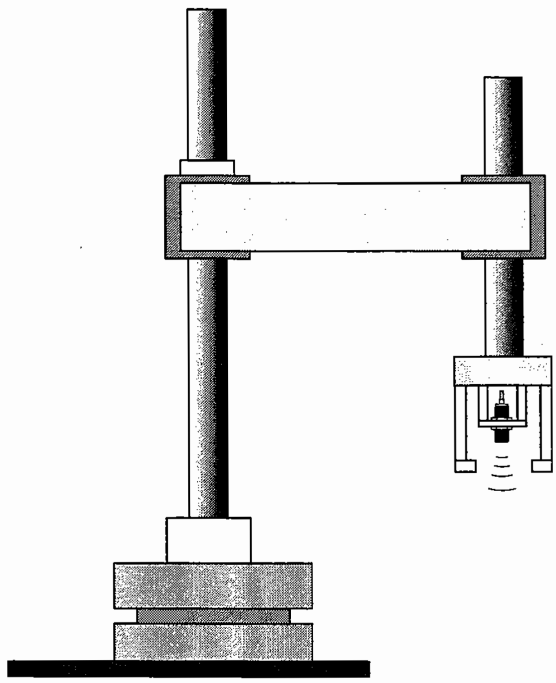


Fig. 3/16: Monitoring gripping devices on industrial robots

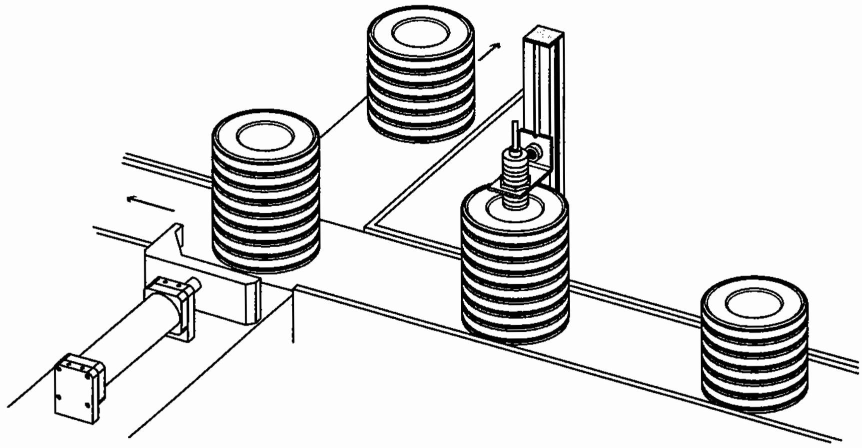


Fig. 3/17: Sorting according to stack height

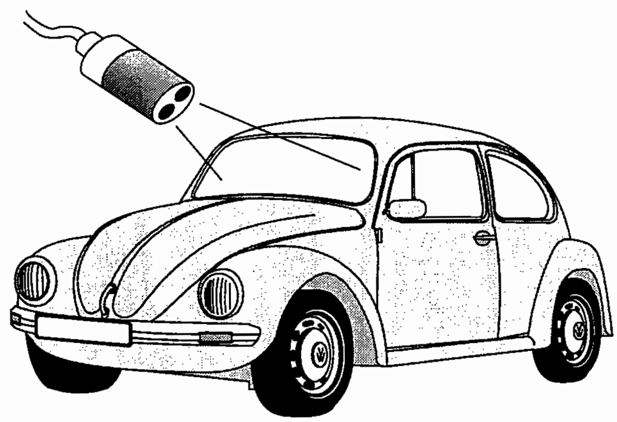


Fig. 3/18: Detecting car windscreens

Chapter 4
Optical sensors

4.1 Photoelectric components

In optoelectronic sensors, photoelectric emitting components are used to create light emission and photoelectric receiving components to receive light emission.

The most commonly used emitter components are luminescent diodes, which are also known as LEDs (light emitting diodes). For special applications, laser diodes are also used.

Photodiodes and phototransistors are generally used as receiving components. In addition to these, photoresistors are also of some importance, e.g. for photoelectric exposure meters.

Luminescent diodes

Luminescent diodes (LEDs) are semiconductor diodes, which emit light beams when an electrical current passes in forward direction. Depending on the composition of the semiconductor material, light beams of varying wavelength are created, see the table below.

Typical materials and wavelengths of luminescent diodes, data in nm

Material	Colour	Wavelength
Gallium arsenide	red	950
Gallium aluminium	red	880
Gallium aluminium	red	660
Gallium arsenide	red	660
Gallium arsenide	red	635
Gallium arsenide	yellow	590
Gallium phosphide	green	565

Luminenscent diodes in the infrared and red spectral range are mainly used in sensors, because these adapt well to the sensitivity of photodiodes when receiving light emissions.

Luminescent diodes represent a relatively small spectral range of the emitted light, which is generally between 30 nm to 140 nm half-value width, see fig.4/1.

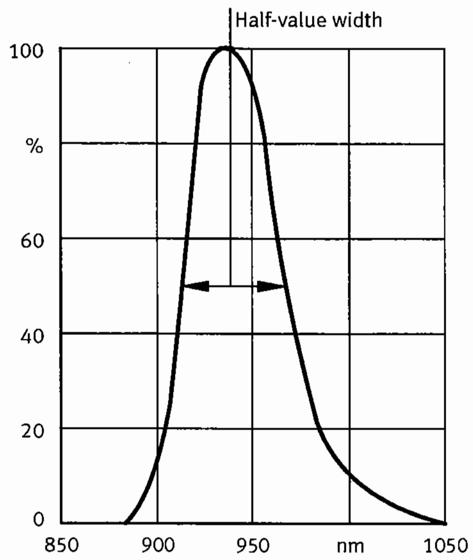


Fig. 4/1: Emission spectrum of a GaAs LED

Luminescent diodes have a current voltage characteristic in the forward direction which is characterised by a steep increase in current as from a particular threshold of the voltage, see fig. 4/2.

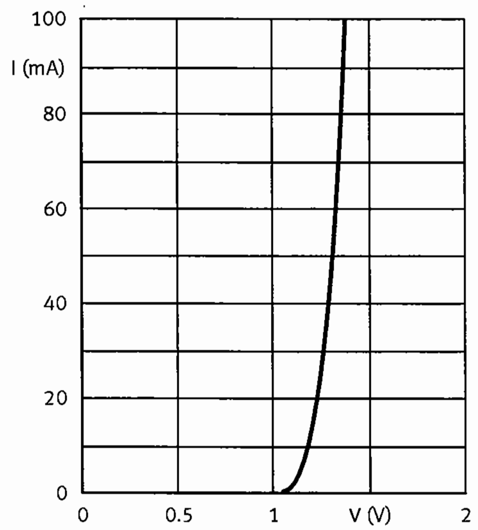


Fig. 4/2: Characteristic current-voltage curve of a GaAs-LED

The stabilised setting of the forward current is achieved with the help of a series resistor as per fig.4/3.

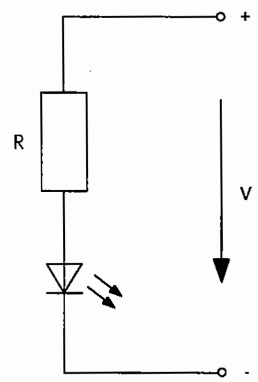


Fig. 4/3: Function of an LED with series resistor

Luminescent diodes are available mass produced in small plastic or metal housings with two connections (housing types such as TO18, TO46 or 5 mm LED housing). To concentrate the light emission in a narrow angle of emission, a glass or plastic lens is often built into the housing. When mounting luminescent diodes in sensor housings, separate optical lenses are generally connected in series.

Photodiodes

Photodiodes are semi-conductor components which are based on single-crystalline silicone or germanium. They are constructed in the same way as ordinary semiconductor diodes, however the barrier layer is very closely arranged underneath the crystal surface. If the diode is exposed to light emission, then the photons penetrating the crystal (quantum of the optical radiation) are absorbed and electrical charge carrier pairs are created. This effect is known as the photoelectric effect. The charge carrier pairs are separated in the barrier layer and an electrical current is created, i.e. the photocurrent.

Photodiodes are basically divided into the following types:

- PN photodiodes
- PIN photodiodes
- Schottky photodiodes
- Avalanche photodiodes

PN photodiodes have two differently doped areas in the crystal material, the so-called P-area and N-area, which are separated by a thin barrier layer. (Doping refers to the process of integrating atoms from other materials, e.g. of boron or gallium into the crystal material. By means of doping it is possible to influence the conductivity of a semiconductor).

With PIN photodiodes the P-area and the N-area is separated by a relatively wide layer of intrinsically conductive semiconductor material (I = intrinsic). This creates a layer of low insulating capacity and a fast switching time of the PIN photodiode.

PN-silicone and PIN silicone photodiodes are the most widely used types of photodiodes.

Schottky photodiodes are named after the Schottky effect and renowned for their excellent sensitivity in the ultraviolet spectral range.

Silicone avalanche diodes are based on the avalanche effect in barrier layer semiconductors. They operate at a high reverse voltage and are suitable for the detection of very small light emissions with reduced reaction times.

The typical spectral sensitivity (responsivity) within a silicone photodiode is shown in fig. 4.4. One important characteristic is the maximum value of spectral sensitivity, which for silicone photodiodes can range between approx. 600 nm and 1000 nm, depending on type.

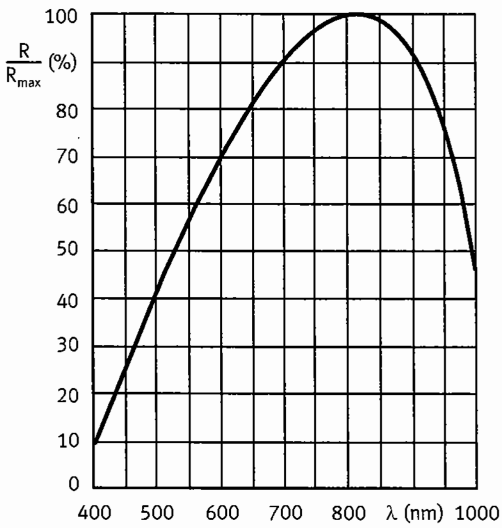


Fig. 4/4: Relative spectral responsivity R/R_{max} of a silicon photodiode (λ = wavelength)

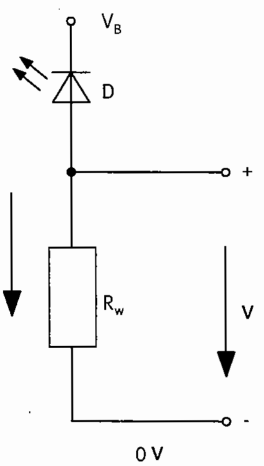
The sensitivity of silicone photodiodes in the spectral maximum is typically at 0.5 A/W, i.e. at a received light emission power of 1 mW for instance, a photocurrent of 0.5 mA is generated.

Responsivity R of a photodiode is the quotient of the photocurrent I and the light emission power P, which impinges on the photodiode:

$$R = \frac{I}{P}$$

Seen from the electrical mode of operation, differentiation is made between biased voltage operation and short circuit operation of a photodiode.

In biased voltage operation as shown in fig. 4/5, the photodiode operates at a reverse voltage which typically is within a maximum range of 10 V to 100 V.

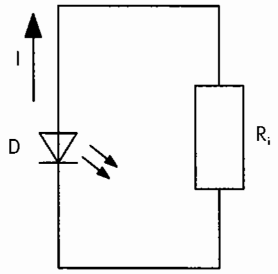


V_B = Bias voltage
D = Photodiode
R_w = Working resistance
I = Photoelectric current

Fig. 4/5: Switching of a photodiode in bias voltage operation.

For this, the reverse current I of the photodiode is within a certain range proportional to the light emission power, which the photodiode receives. By means of this circuit, it is possible to achieve very fast reaction times by using PIN photodiodes, which can be in the order of 1 ns. An important application is, for instance, fast optical data transmission via fibre-optic cables.

If the photodiode is operated according to fig. 4/6, it is on the assumption that the internal impedance R_i of the load connected to the photodiode is so small that there is practically short-circuit operation.



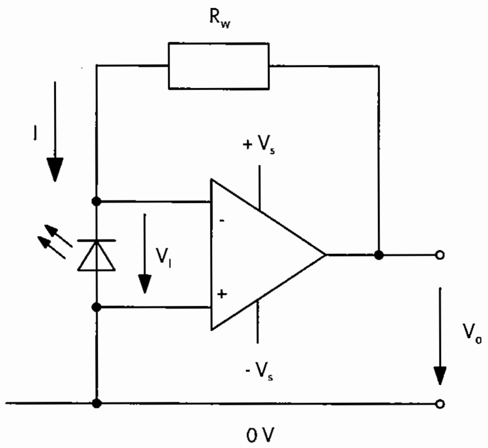
I = Photoelectric current
R_i = Internal impedance

Fig. 4/6: Switching of a photodiode in short-circuit operation

No additional electrical voltage is required, the photodiode acts as a power source during exposure to light emission in exactly the same way as solar cells.

Performance of the short circuit current $I = I_s$ is proportional to the light emission power over several decades. Linearity is possible over 10 decades, whereby there are limits due to the noise of the photodiode and the maximum permissible photocurrent. This linear performance is frequently used in measuring and sensor technology.

In practice, a circuit with an operational amplifier as in fig. 4/7 is used, whereby use is made of the fact that the input voltage Vi is very small with regard to the output voltage V_o, because the amplification factor of the operational amplifier is very large.



$+V_s$, $-V_s$ = Supply voltages of operational amplifier
R_w = Working resistance

Fig. 4/7: Short-circuit operation of a photodiode with operational amplifier

If G_0 is the open-loop gain of the operational amplifier, then the effective resistance R_L, at which the photodiode operates is $R_L = R_w/G_o$. For most operational amplifiers $G_0 \approx 10_5$. In this way, a virtually ideal short circuit operation is available even in the case of relatively great values of the working resistance R_w.

Because the photocurrent flows almost entirely via the feedback resistor R_w due to the small input current of the operational amplifier, the following applies for the output voltage:

$$V_o = R_w \cdot I$$

Phototransistors

In the case of a phototransistor the collector-base diode is designed as a photodiode. The remaining characteristics correspond to a normal transistor. The method of operation of a phototransistor can be illustrated as shown in fig. 4/8 by combining a single photodiode and a transistor.

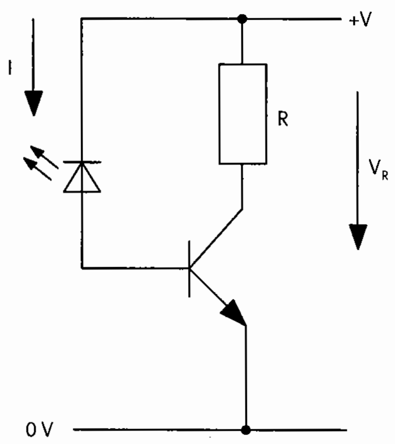


Fig. 4/8: Equivalent circuit diagram illustrating a phototransistor

During exposure to light emission, a photocurrent I is created, which forms the base current of the transistor. If the transistor has a current amplification B (e.g. B = 100), then this creates a collector current $I_c = B \cdot I$ and a drop in voltage $V_R = B \cdot R \cdot I$.

The sensitivity of the phototransistor is therefore greater than that of a photodiode by factor B. Phototransistors, however, do not possess equally good linearity between exposure to light emission power and photocurrent. For analogue sensors, linearity is an important criteria. On the other hand, linearity is unimportant for switching sensors and phototransistors are therefore often used as receiver elements in light barriers and other optical proximity sensors.

Compared with photodiodes, phototransistors have longer switching times, which are however adequate for optical proximity sensors.

Photoresistors

Photoresistors are passive components, which change their electrical resistance under the effect of light beams. They usually consist of semiconductor crystals. Insulators can also change their electrical resistance under the influence of light, optical radiation, e.g. cadmium sulphide. In the case of semiconductors, they operate without a barrier layer and therefore independent of current direction. Photoresistors exist for various spectral ranges from visible light to the infrared range with a wavelength of 10 m for example.

Photoresistors in cadmium sulphide have found widespread use, e.g. as exposure meters in photography, for lighting control or as automatic flame guards.

With a cadmium sulphide photoresistor, its resistance R is in the initial approach reverse proportional to the exposure to light emission E. Without exposure, cadmium sulphide is non-conductive.

This dependence can be illustrated within a limited section by means of the relationship $R = C \cdot E^{-y}$ whereby y and C are constants.

When used in sensors and measuring devices, this non-linear dependence is a disadvantage, which is why, generally, photodiodes are used for accurate analogue measurement. On the other hand, in the case of wavelengths greater than 2 mm in the infrared range, where no photodiodes are available, photoresistors are predominant, e.g. in materials such as lead sulphide, lead selenide, indium antimonide, indium arsenide or mercury-cadmium-telluride. Photoresistors of this type can, as a rule, only be used with additional cooling. Applications can be found for example in thermography (recording of heat images which are based on the various degrees of heat radiation from different objects, i.e. heat images of the earth taken from aircraft).

4.2 Analogue optical diffuse sensor

Analogue diffuse optical sensors can be used to carry out distance measurements. Because the sensor is sensitive to the reflective behaviour of surfaces, it can also be used for the detection of contours and patterns.

The analogue diffuse optical sensor used in the equipment set of function package FP1120 consists of three main parts, the emitter, the receiver and the signal processing electronics. The emitter is an infrared light diode and the receiver a photodiode, which is active in the infrared range. By using a dual fibre-optic cable, the sensor unit can be freely mounted in the proximity of the object to be measured. The infrared light is emitted by the emitter and reflected back to the receiver by the object to be detected. Sensing distance is within a range of 8 to 40 mm.

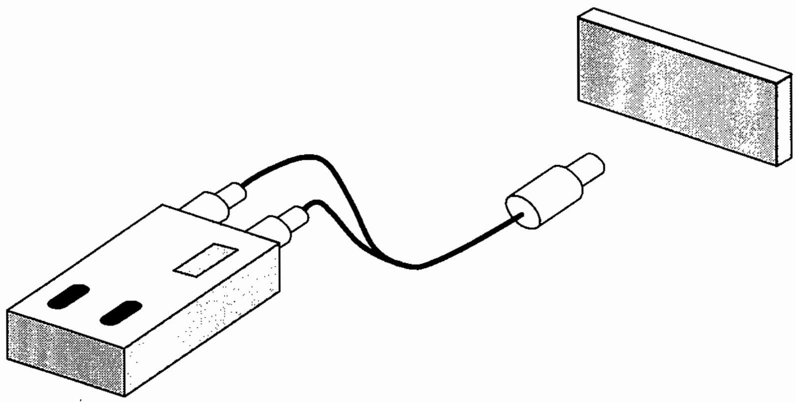
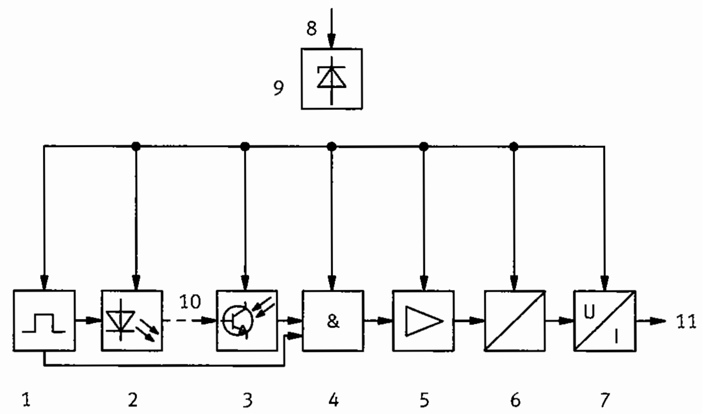


Fig. 4/9: Analogue optical diffuse sensor

The advantages of diffuse sensors lie in those applications, which require reduced installation costs and easy adjustment. Moreover, small objects and any optically rough surfaces can be detected.

Because less light emission is reflected back to the receiver by an object which is at a greater distance than one which is nearer, there is no linear correlation between the distance and the receiver signal but, conversely, the received signal decreases as distance increases. Nevertheless, in order to maintain an increasing characteristic curve within a certain operating range, the diffuse optical sensor has built-in electronics for linearisation.

The sensor electronics correspond to the following block diagram:



1	Oscillator	6	Linearisation
2	Photoelectric sensor	7	Voltage / Current converter
3	Photoelectric receiver	8	External voltage
4	Logic operation	9	Internal constant voltage supply
5	Amplifier	10	Optical distance
		11	Output current signal

Fig. 4/10: Block diagram of analogue optical diffuse sensor

In order to prevent interference during signal reception, an oscillator circuit is built in. The emitted light beam is modulated with a frequency of 1 kHz and the receiver is linked to this frequency accordingly by means of an AND gate. Then the signal is amplified and transformed to achieve a linear sensing characteristic. The output stage supplies a current intensity within a nominal range of 4 mA to 20 mA.

4.3
Applications

Analogue diffuse optical sensors are used in quality control and in any applications, where a sensing distance of 3 to 40 mm is required. One advantage of the analogue sensor is that it can be connected to the analogue input of a PLC.

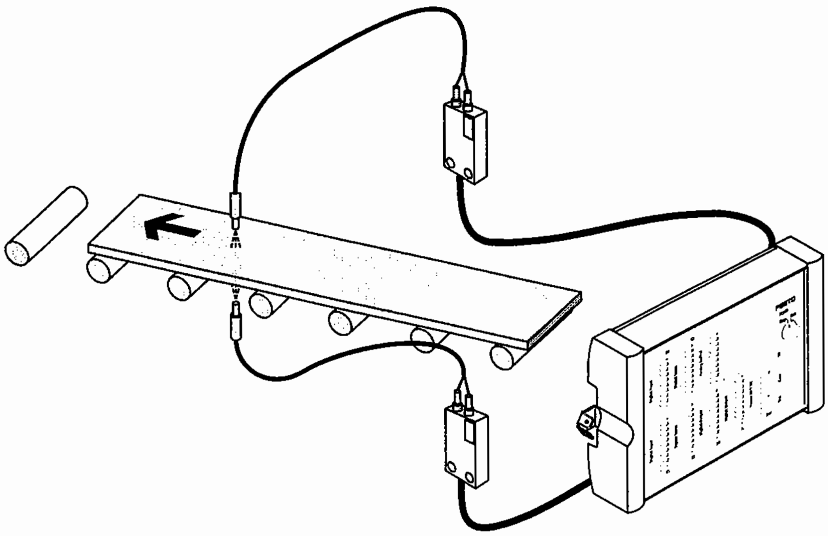


Fig. 4/11: Packaging

Fig. 4/11 illustrates a sample application in packaging. Distance measurement by means of an analogue sensor signals that a cardboard box is not closed properly. The processing of the sensor signal then causes the piston rod of a cylinder to extend and the carton is pushed off the conveyor belt. This task could possibly also be solved by means of binary optoelectronic sensors, e.g. with a diffuse optical sensor. In contrast with this, the analogue optical sensor is also able to ascertain the even surface of the two lid halves or the omission of sticky tape. If the two lid halves are not provided with sticky tape, then the analogue optical sensor detects the gap where the two lid halves meet, provided that the lids are of same colour tone and unprinted.

Another sample application is detecting label inscriptions. A number of black letters amount to a certain grey scale value with a characteristic degree of reflection. The sensor can be set as a reference value in respect of the intensity of the received light beam. If there is a deviation from this value, then the label is incorrectly printed.

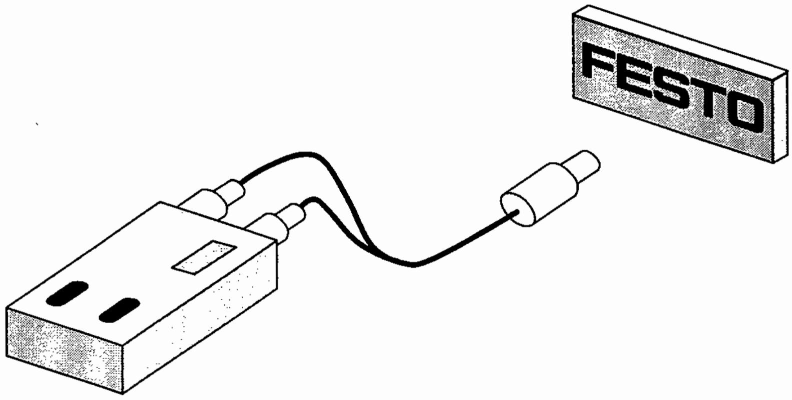


Fig. 4/12: Checking of printed labels

An interesting sample application is the use of analogue diffuse optical sensors for the purpose of assembly. Because of its sensitivity, it can be used for contour sensing or for checking the correctly aligned feeding of parts.

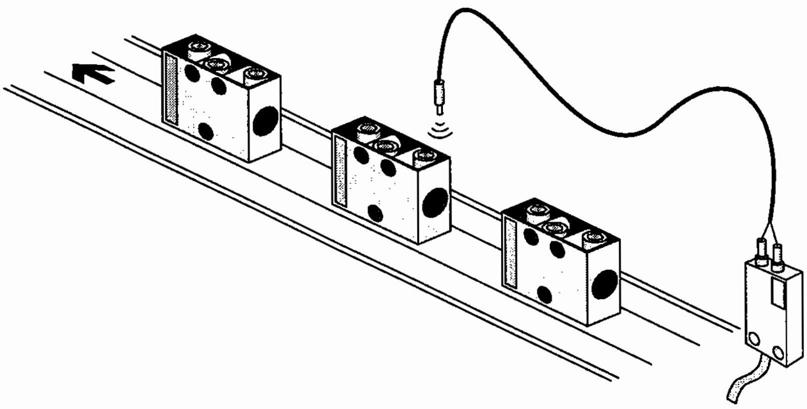


Fig. 4/13: Assembly

Assembled parts moving underneath a sensor produce a characteristic current-time graph.

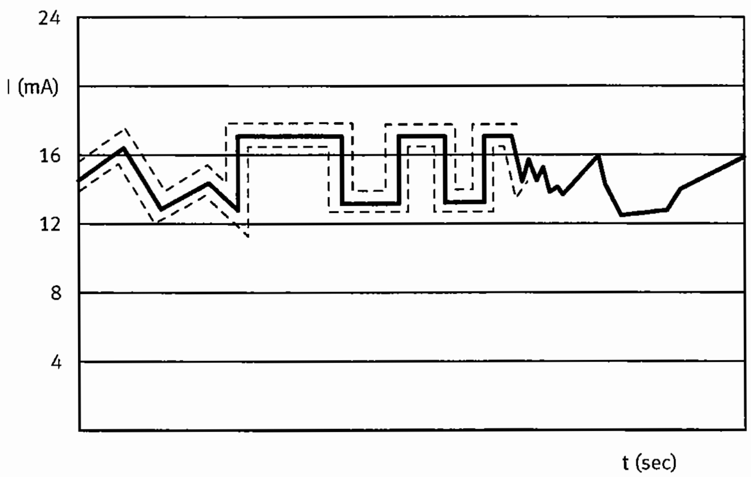


Fig. 4/14: Current-time graph

This pattern can be used as a reference by a programmable logic controller and compared with the parts to be checked. Deviations from the required pattern are indicated by that part of the graph which is outside the dotted line outlining the tolerance band shown in fig. 4/14.

Chapter 5
Incremental capacitive displacement measurement

5.1 Method of measurement

The attachable measuring slide provided in the equipment set of function package FP1120 is an incremental capacitive sensor for linear measurement; the acquisition of measured data is based on the principle of a differential capacitor. In order to achieve a wide sensing range, the electrodes are made up of parallel strip shaped plates which are arranged in a comb-like manner to form a scale. Strip electrodes are built into the reading head to form the two counter-electrodes. These counter electrodes are activated via electronic switches. Further switching of the electrodes during movement of the reading head takes place when the measured voltage has reached a certain value. Within this range, a certain linear correlation exists between the measured voltage and the displacement to be measured. The indexing signal is simultaneously passed to a counter. If the dimensions of the electrodes are known, the number of counted pulses provides a gauge of how often the linear range of the measured voltage has been travelled. The counter value and the actual level of the measured voltage provide the value of the total displacement path. The measured value is indicated via a digital display.

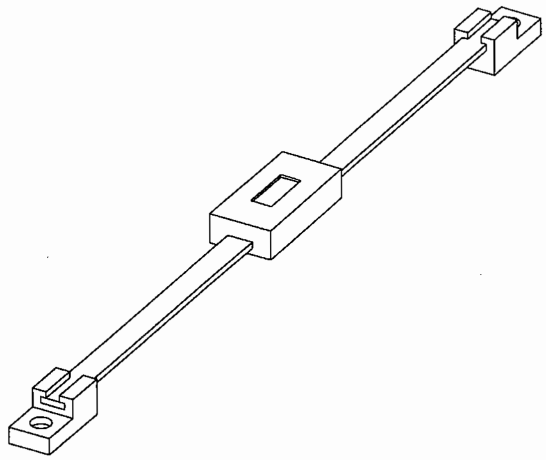


Fig. 5/1: Attachable measuring slide

Section C – Solutions

Distance measurement by means of inductive sensors
Solution 1

Determining the characteristic curve of an analogue inductive sensor

Part exercise a)

Measurement series 1								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)	0.3	0.3	0.3	0.3	2.6	6.4	10.8	15.2
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)	19.1	22.3	22.3	22.3	22.3	22.3	22.3	22.3

Part exercise b)

Measurement series 2								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)	0.2	0.2	0.2	0.2	2.6	6.4	10.8	15.2
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)	19.1	22.3	22.3	22.3	22.3	22.3	22.3	22.3

Measurement series 3								
Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)	0.2	0.2	0.2	0.2	2.6	6.4	10.8	15.2
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)	19.1	22.3	22.3	22.3	22.3	22.3	22.3	22.3

Part exercise c)

Measurement series 4

Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)	0.2	0.2	0.2	0.2	2.6	6.4	10.8	15.2
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)	19.1	22.3	22.3	22.3	22.3	22.3	22.3	22.3

Measurement series 5

Distance s (mm)	0	1	2	3	4	5	6	7
Output current I (mA)	0.2	0.2	0.2	0.2	2.6	6.4	10.8	15.2
Distance s (mm)	8	9	10	11	12	13	14	15
Output current I (mA)	19.1	22.3	22.3	22.3	22.3	22.3	22.3	22.3

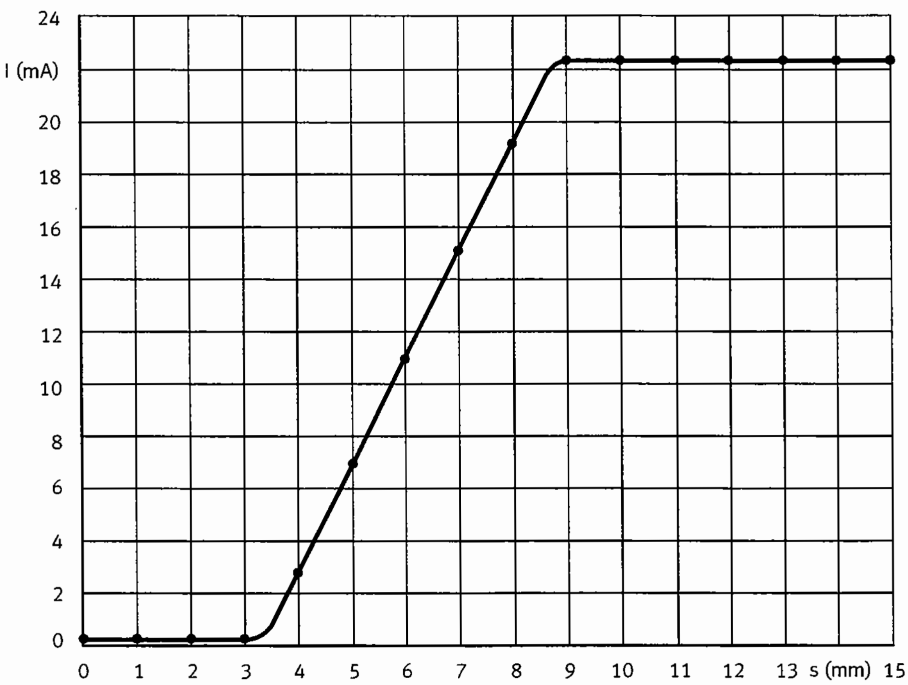


Fig. 1/6: Typical characteristic curve of an inductive sensor

Distance measurement by means of inductive sensors
Solution 1

Questions

From what distance s_0 does the range of measurements start?

$s_0 = 3.3$ mm

From what distance do you obtain a linear correlation between the object distance and the output signal of the sensor?

The linear range of the sensor is between 3.5 mm and 8.7 mm.

Calculate the conversion factor R for steel (S 235 JR)

$$R = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} = \frac{19.1\,\text{mA} - 2.5\,\text{mA}}{8\text{mm} - 4\text{mm}} = \frac{16.5\,\text{mA}}{4\text{mm}} = 4.1\frac{\text{mA}}{\text{mm}}$$

You have examined the inductive distance sensor. Is the sensor suitable for measuring the thickness of steel discs? What is the degree of accuracy?

The thickness measurement as outlined in the problem description is a relative measurement, which means that the thickness of the discs is measured in relation to a standard disc. From the line equation

$$s = 0.24\frac{\text{mm}}{\text{mA}} \cdot I + 3.5\,\text{mm}$$

it can be seen that a 1 mA output current change corresponds to a thickness change of 0.24 mm can be resolved. If an appropriate distance is selected between the standard disc and the sensor, a measuring range of ± 2 mm can be reliably detected.

Distance measurement by means of inductive sensors
Solution 2

Effect of the object to be measured on the output signal of an analogue inductive sensor

Part exercise a)

Measuring object: Stainless steel										
Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)	0.1	0.1	0.1	1.6	5.4	9.9	14.3	18.4	21.6	22.5
Measurement series 2 Output current I (mA)	0.1	0.1	0.1	1.8	5.6	10.1	14.6	18.5	21.6	22.6
Mean value Output current I (mA)	0.1	0.1	0.1	1.7	5.5	10.0	14.5	18.5	21.6	22.6

Measuring object: Aluminium										
Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)	2.4	7.2	13.1	18.7	22.6	22.6	22.6	22.6	22.6	22.6
Measurement series 2 Output current I (mA)	2.4	7.1	13.1	18.8	22.6	22.6	22.6	22.6	22.6	22.6
Mean value Output current I (mA)	2.4	7.2	13.1	18.8	22.6	22.6	22.6	22.6	22.6	22.6

Measuring object: Brass										
Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)	0.8	5.2	10.5	16.1	21.2	22.6	22.6	22.6	22.6	22.6
Measurement series 2 Output current I (mA)	0.8	5.2	10.6	16.3	21.2	22.6	22.6	22.6	22.6	22.6
Mean value Output current I (mA)	0.8	5.2	10.6	16.2	21.2	22.6	22.6	22.6	22.6	22.6

Measuring object: Copper										
Distance s (mm)	0	1	2	3	4	5	6	7	8	9
Measurement series 1 Output current I (mA)	4.2	9.5	15.6	21.1	22.6	22.6	22.6	22.6	22.6	22.6
Measurement series 2 Output current I (mA)	4.2	9.5	15.7	21.1	22.6	22.6	22.6	22.6	22.6	22.6
Mean value Output current I (mA)	4.2	9.5	15.7	21.1	22.6	22.6	22.6	22.6	22.6	22.6

Question

Which materials are particularly easy to differentiate?

Steel and copper, steel and aluminium, steel and brass are particularly easy to distinguish.

Part exercise b)

Test condition: Distance of sensor to measuring object 3 mm

Test size	**Output current I (mA)**			
Steel S 235 JR	Measured value 1	Measured value 2	Measured value 3	Mean value
Part 11: 30 x 30	0.2	0.2	0.2	0.2
Part 12: 25 x 25	0.2	0.2	0.2	0.2
Part 13: 20 x 20	0.2	0.2	0.2	0.2
Part 14: 15 x 15	2.0	2.2	1.8	2.0
Part 15: 10 x 10	11.4	11.2	11.3	11.3
Part 16: 5 x 5	22.0	22.1	22.2	22.1

Test condition: Distance of sensor to measuring object 4 mm

Test size	**Output current I (mA)**			
Steel S 235 JR	Measured value 1	Measured value 2	Measured value 3	Mean value
Part 11: 30 x 30	0.3	0.5	0.4	0.4
Part 12: 25 x 25	1.1	1.0	0.9	1.0
Part 13: 20 x 20	1.5	1.4	1.6	1.5
Part 14: 15 x 15	4.5	4.7	4.6	4.6
Part 15: 10 x 10	13.5	14.5	14.0	14.0
Part 16: 5 x 5	22.3	22.3	22.3	22.3

Question

f you transfer the result to the initial problem description given, is it then possible to differentiate between the metal rings (flat seals) on the basis of the above results as regards the effect of the material type and size?

The flat seals can be detected, if the diameters vary by mm. The shape of the object also has some relevance.

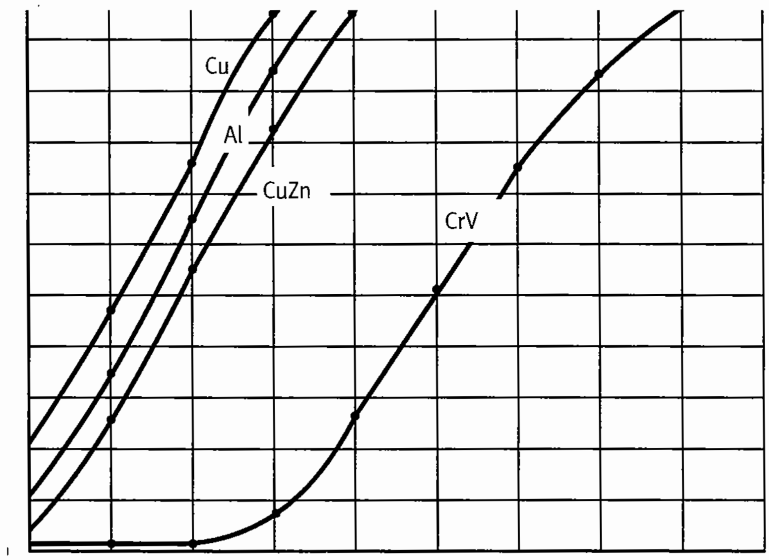


Fig. 2/6: Diagram for part exercise a)

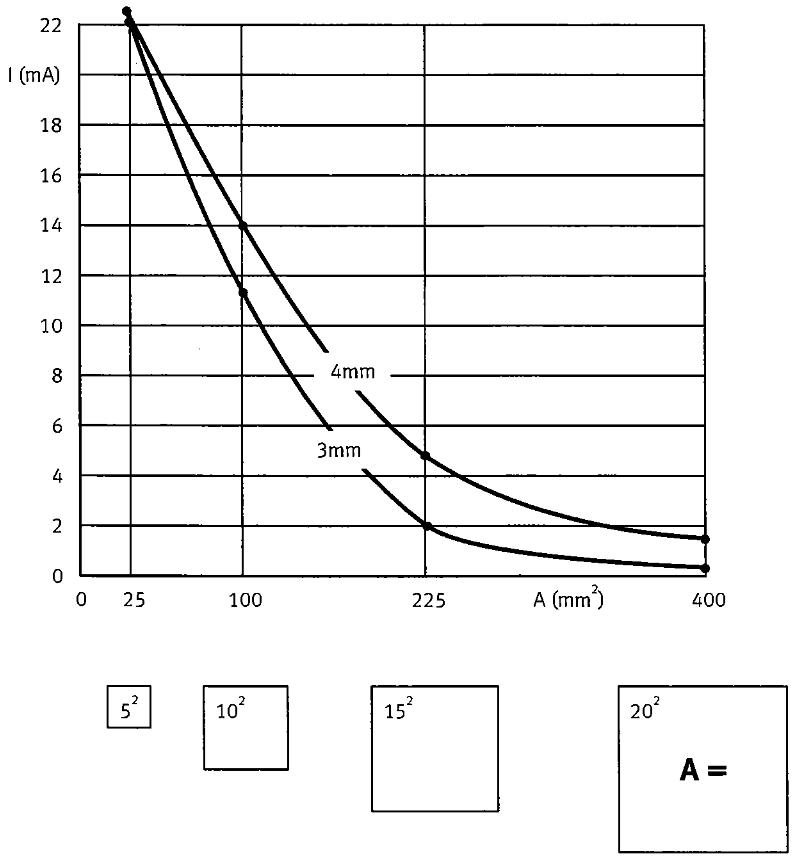


Fig. 2/7: Diagram for part exercise b)

Distance measurement by means of inductive sensors
Exercise 3

Measuring the deflection of flat material

Part exercise a)

Measurement series									
Distance s (mm)	0	0.5	1	1.5	2	2.5	3	3.5	4.0
Output current I (mA)	1.6	3.8	6.4	9.0	11.3	13.9	16.8	19.3	21.6

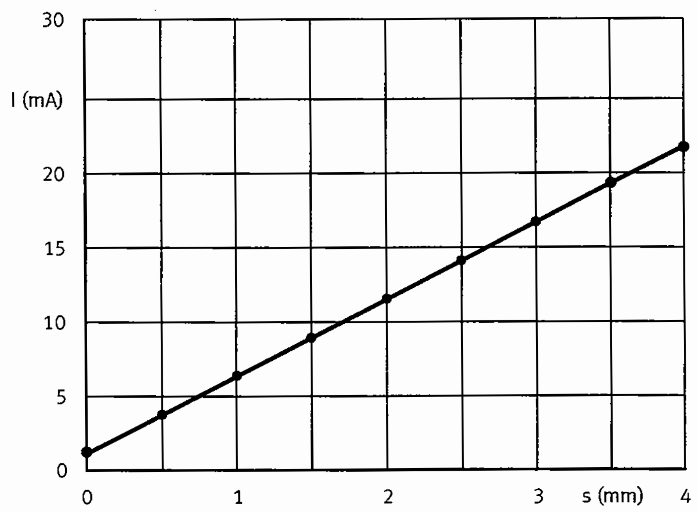


Fig. 3/8: Diagram for part exercise a)

Question

Calculate the conversion factor R:

$$R = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} = \frac{(21.6 - 1.6)\,mA}{4mm} = 5\frac{mA}{mm}$$

Part exercise b)

Measurement series							
Load m (g)	0	10	20	50	100	200	500
Output current I (mA)	9.3	9.4	9.5	9.6	9.8	10.3	11.6

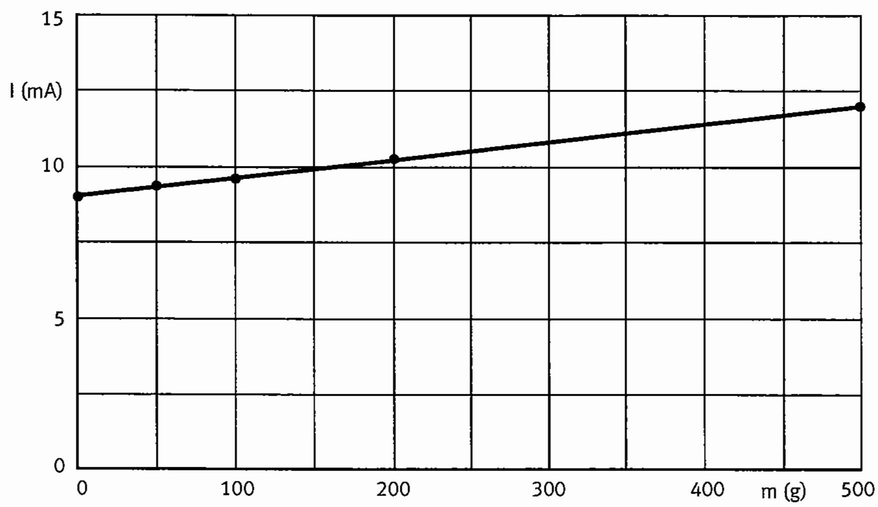


Fig. 3/9: Diagram for part exercise b)

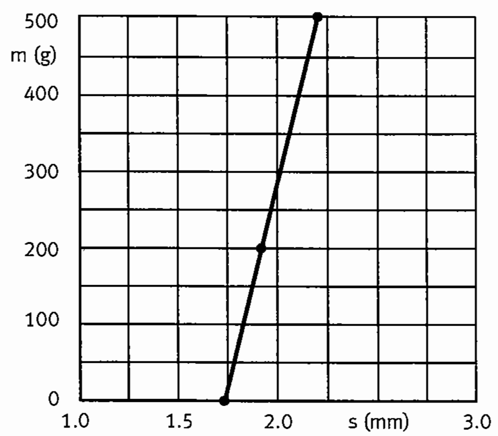


Fig. 3/10: Load-displacement diagram

Question

Which requirements must be fulfilled with regard to transport devices in order to determine the comparable surface contours of the tins?

The tins must pass underneath the sensor without vibration in order to achieve a constant reproducible profile. The transport device must provide a steady support for the tins to prevent them from tipping and to ensure that they are always detected in the same position by the sensor.

Determining the eccentricity of a rotating disc

Part exercise a)

Measurement series									
Distance s (mm)	1	2	3	4	5	6	7	8	9
Output current I (mA)	0.2	0.2	0.8	4.4	8.4	13.0	16.8	20.8	22.3

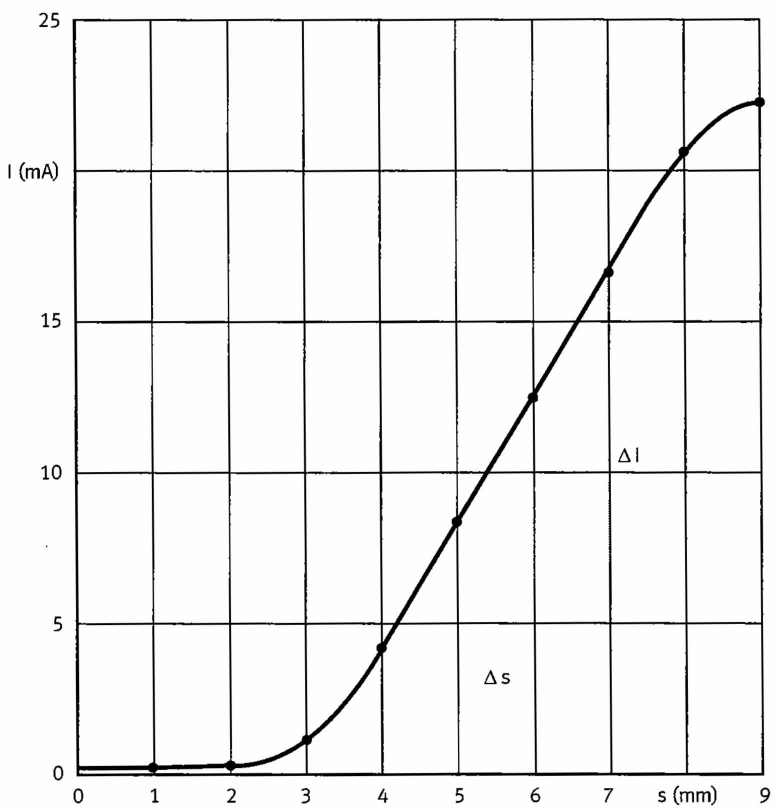


Fig. 4/11: Diagram for part exercise a)

Calculate the conversion factor R_a

$$R_a = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} = \frac{16.8mA - 4.4mA}{7mm - 4mm} = \frac{12.4mA}{3mm}$$

$$R_a = 4.13 \frac{mA}{mm}$$

Part exercise b)

Measurement series									
Distance s (mm)	1	2	3	4	5	6	7	8	9
Output current I (mA)	1.7	5.8	10.1	14.9	19.3	22.3	22.3	22.3	22.3

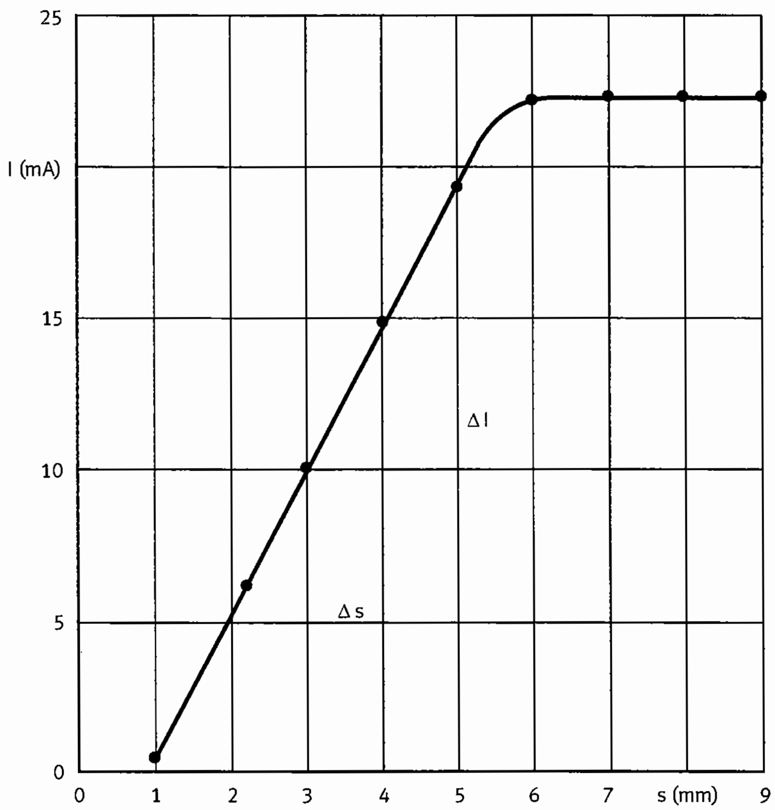


Fig. 4/12: Diagram for part exercise b)

Calculate the conversion factor R_r

$$R_r = \frac{\Delta I}{\Delta s} = \frac{I_2 - I_1}{s_2 - s_1} = \frac{19.3mA - 5.8mA}{5mm - 2mm} = \frac{13.5mA}{3mm}$$

$$R_r = 4.5\frac{mA}{mm}$$

Part exercise c)

Output current in respect of measurement of axial eccentricity	**1**	**2**	**3**
Output current I_{max} in mA	13.4	13.4	13.4
Output current I_{min} in mA	12.5	12.5	12.5
Difference of output current ΔI_a in mA	0.9	0.9	0.9
Mean value of difference in output current ΔI_{am} in mA			0.9

Axial eccentricity $$s_a = \Delta I_{am} \cdot \frac{1}{R_a} = 0.9\text{mA} \cdot 0.242 \frac{\text{mm}}{\text{mA}}$$
$$s_a = 0.22\,\text{mm}$$

Part exercise d)

Output current in respect of measurement of radial eccentricity	**1**	**2**	**3**
Output current I_{max} in mA	4.6	4.6	4.6
Output current I_{min} in mA	3.8	3.8	3.8
Difference of output current ΔI_r in mA	0.8	0.8	0.8
Mean value of difference in output current ΔI_{rm} in mA			0.8

Radial eccentricity $$s_r = \Delta I_{rm} \cdot \frac{1}{R_r} = 0.8\text{mA} \cdot 0.222 \frac{\text{mm}}{\text{mA}}$$
$$s_r = 0.18\,\text{mm}$$

Note

The measured data may vary as the axial and radial eccentricity greatly depend on how precisely the disc was attached to the motor shaft with the locking screw.

Part exercise e)

Measurement with dial gauge	Maximum value	Minimum value	Difference
Axial eccentricity s_a in mm			
Radial eccentricity s_r in mm			

Questions

Is the sensor suitable for these measurements?

The tolerance limit of 0.05 mm specified in the problem description requires a resolution of the sensor output signal of approximately 0.2 mA. This resolution is possible with the sensor.

Up to what speed can measuring be carried out?

Due to the fact that the maximum measurement frequency is 80Hz, measurement up to a speed of $\frac{1}{2} \cdot 4800 \frac{1}{\text{min}}$ is possible with this sensor. The factor $\frac{1}{2}$ stems from the fact that two measurements are required per rotation.

Position detection on a spindle drive unit by means of a linear potentiometer

Questions regarding part exercise d)

Which physical value does the linear potentiometer provide?

Voltage

What should be taken into account with a standard linear potentiometer with regard to short circuit protection of the output?
By what method is short circuit protection achieved in the case of the linear potentiometer used?

If, in the case of a standard linear potentiometer, the wiper output is accidently connected to the power supply, then the resistance layer may become damaged near the end position of the potentiometer due to overloading. In the case of the potentiometer used here, a protective circuit has been built into the supply cable.

Let the spindle drive unit travel alternately towards the left or the right whilst observing the multimeter. How does the reading change?

Spindle drive unit moves towards the left: Voltage drops
Spindle drive unit moves towards the right: Voltage increases

---

Part exercise f)

Measurement series											
s (mm)	0	10	20	30	40	50	60	70	80	90	100
U (V)	2.0	2.1	2.6	2.9	3.3	3.6	3.9	4.2	4.4	4.8	5.2
s (mm)	110	120	130	140	150	160	170	180	190	200	210
U (V)	5.5	5.7	6.1	6.5	6.8	7.1	7.4	7.8	8.2	8.5	8.8

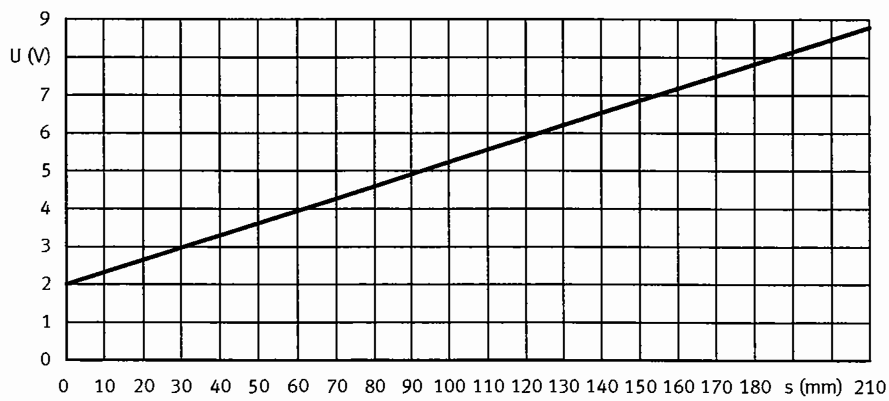


Fig. 5/8: Diagram for part exercise f)

Position detection on a spindle drive unit by means of an ultrasonic sensor

Questions to part exercise c)

What is the physical value generated by an ultrasonic sensor?

Current intensity in amps or milliamps

What measuring range must be set on the multimeter?

Milliamps

Move the spindle drive unit alternately towards the left or the right whilst observing the multimeter. How is the reading affected?

When travelling to the left, the value displayed on the digital multimeter decreases.
When travelling to the right, the value displayed on the digital multimeter increases.

Why does the signal output of the ultrasonic sensor indicate a current value and not a voltage value?

The type of output signal is dependent on the internal processing electronics. Designs of ultrasonic sensors are available with current output, with voltage output or with both options (selectable). The current output type is frequently used, because it is considerably more insensitive to interference than the voltage type.

Part exercise d)

Measurement series: With reflector width of 60 mm											
s (mm)	0	10	20	30	40	50	60	70	80	90	100
I (mA)	10.77	11.02	11.35	11.66	11.98	12.29	12.61	12.93	13.30	13.69	13.88
s (mm)	110	120	130	140	150	160	170	180	190	200	210
I (mA)	14.20	14.52	14.96	15.28	15.48	15.79	16.10	16.41	16.85	17.30	17.63

Measurement series: With reflector width of 40 mm											
s (mm)	0	10	20	30	40	50	60	70	80	90	100
I (mA)	10.76	11.03	11.35	11.63	11.95	12.26	12.67	12.92	13.34	13.64	13.87
s (mm)	110	120	130	140	150	160	170	180	190	200	210
I (mA)	14.19	14.52	14.96	15.27	15.49	15.80	16.15	16.60	16.93	17.22	17.50

Measurement series: With reflector width of 20 mm											
s (mm)	0	10	20	30	40	50	60	70	80	90	100
I (mA)	10.78	11.09	11.54	11.77	12.17	12.62	12.82	13.13	13.43	14.00	14.20
s (mm)	110	120	130	140	150	160	170	180	190	200	210
I (mA)	14.52	14.84	15.15	15.60	16.05	16.34	16.38	16.61	16.89	24.61	24.61

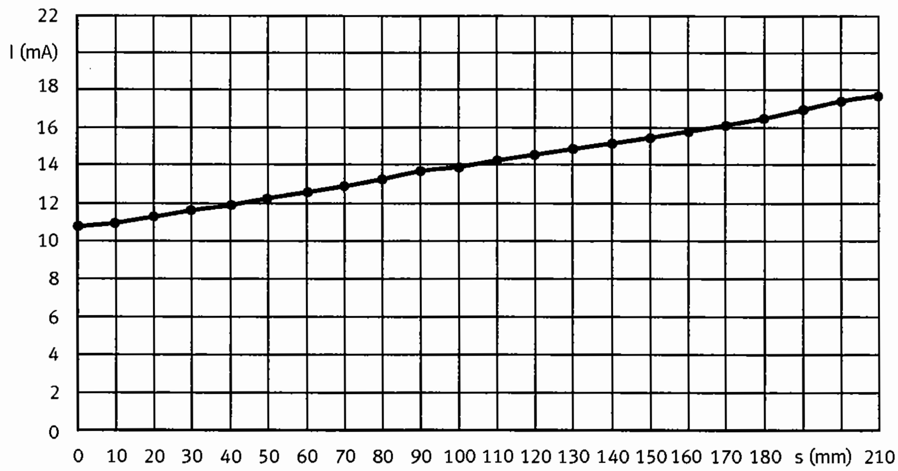


Fig. 6/6: Resulting curve using 60 mm reflector, part exercise d

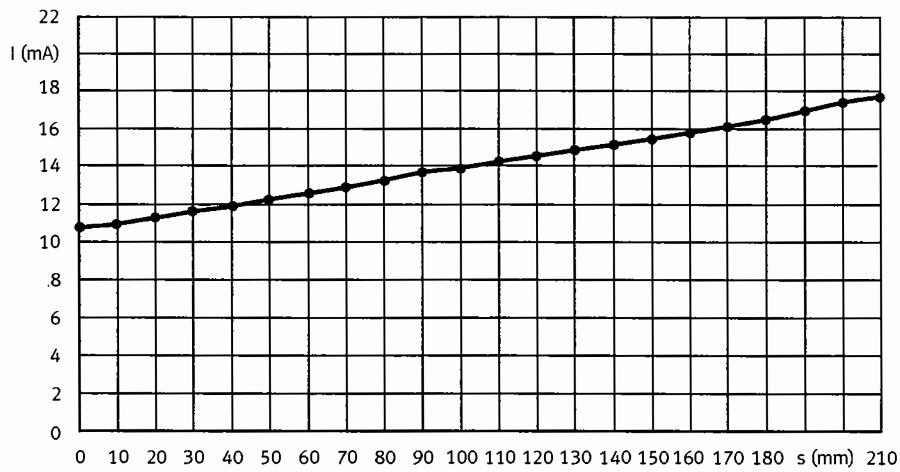


Fig. 6/7: Resulting curve using 40 mm reflector, part exercise d

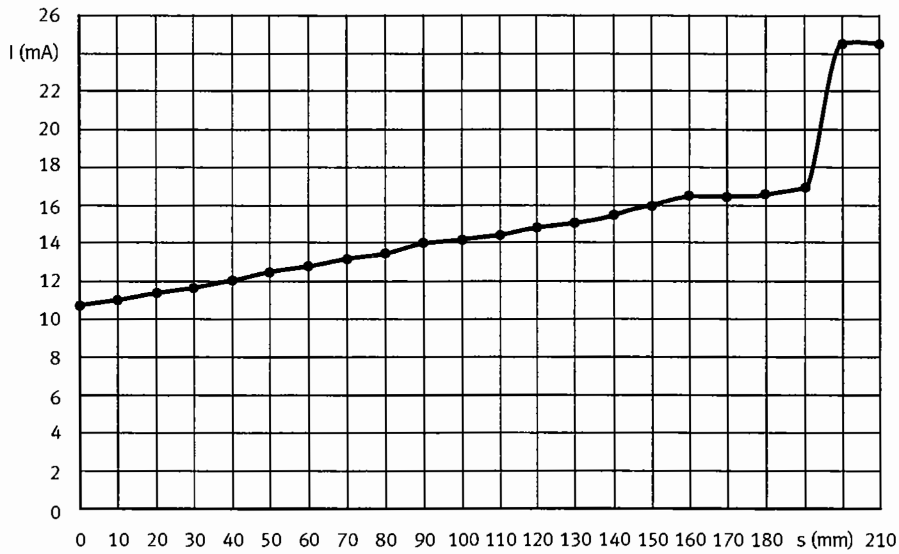


Fig. 6/8: Resulting curve using 20 mm reflector, part exercise d

Questions to part exercise e)

Describe what you have observed on the multimeter.

Turn the reflector in the direction of the sensor:	Current value decreases
Turn the reflector away from the sensor:	Current value increases

---

If a specific angle is exceeded when the reflector is turned, the indicated current increases abruptly. What angle needs to be exceeded in order for this reaction to occur?

$\alpha > 3^\circ$

Substantiate your observations.

After an angle of more than 3°, the deflection of the ultrasonic wave is so great that the echo signal can no longer be detected by the receiver. The ultrasound is reflected past the receiver by the reflector.

Is it possible to solve the task described in the problem description by means of the ultrasonic sensor provided?

As can be seen from the diagrams, the ultrasonic sensor can be used to distinguish car wheel rims.

What requirements need to be fulfilled in order to detect a definite profile of the wheel rims?

In order to detect a wheel rim profile, the wheel rims must be positioned vertical to the sensor and the conveyor speed must be constant. Otherwise, only part of the profile shape can be detected. Signal failure due to reflection is to be expected.

Distance measurement by means of optical sensors
Exercise 7

Determining the characteristic curve of an analogue diffuse optical sensor

Questions on part c)

What is the value of the current signal when the white surface of the Kodak grey card is directly in front of the fibre-optic aperture? (Round off the current value of the digital indicator of the current measuring device to one digit after the comma.)

3.7 mA to 3.8 mA

Note

With this arrangement you have measured the offset signal of the analogue diffuse optical sensor. This value is also the minimum output current of the sensor.

What is the value of the current signal, when the card is removed from the retainer? (Round off the current value accordingly).

24.2 mA to 24.4 mA

Note

This value is the maximum output current of the sensor

Set the zero point on the vernier caliper (5), when the white surface of the card is directly in front of the fibre-optic aperture. Move the positioning slide unit 20.0 mm away from the fibre-optic aperture. (Round off the distance value on the digital indicator of the vernier caliper to one place after the point). Make a note of the current value. Move to 25.0 mm and then back again to 20.0 mm. Has the current value changed?

18.2 mA / 18.6 mA
yes

Note

The current values can vary, in which case the difference is caused by the play which exists between the slide and guide of the positioning slide. This is why a series of measurements must be conducted travelling in the same direction in order to obtain reproducible measuring values.

How does the current signal change, if the card is moved from left to right in front of the sensor? Carefully slide the card with both hands from left to right in the material retainer.

The current signal increases

Note: The emitter illuminates a circular area on the object to be measured and the receiver reacts to the intensity of the reflected light. If the emitted light beam misses the object to be measured, the current value increases despite the fact that the distance does not change.

Put the Kodak grey card with the white surface towards the fibre-optic aperture in the retainer of the positioning slide. Move the positioning slide until the sensor output signal is 10 mA.

Leaving the positioning slide in this position, record the current signal when each sample 3 (steel zinc-coated), 4 (stainless steel), 5 (aluminium), 6 (brass) and 7 (copper) is inserted.
What conclusions do you draw for the application of this sensor in a testing station for springs?

The results show that before testing of different spring materials, a calibration of the spring constant is necessary. The reflex sensor output signal depends on the finish given to parts during their production e.g. painted, burnished, etc.

Part exercise d)

Measurement series: Current-distance diagram						
s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)	3.7	3.8	5.6	8.2	10.6	13.1
	3.7	3.8	5.7	8.2	10.7	131
	3.7	3.8	5.7	8.2	10.6	13.1
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	15.5	18.1	20.8	23.1	23.9	24.0
	15.6	18.1	20.7	23.2	24.0	24.0
	15.5	18.0	20.7	23.2	24.0	24.1

Fig. 7/5: Current-distance diagram

What is the size of the measuring range of the analogue diffuse optical sensor?

approx. 7 mm – 45 mm

Note: The measuring range can be read from the linear range of the characteristic curve.

Measuring material thickness by means of an analogue diffuse optical sensor

Part exercise b)

Measurement series: Current-distance diagram											
s (mm)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
U (V)	8.2	3.7	3.8	5.1	6.6	7.9	9.2	10.7	12.0	13.3	14.8
s (mm)	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0			
U (V)	17.9	21.1	23.4	23.9	24.0	24.0	24.1	24.1			

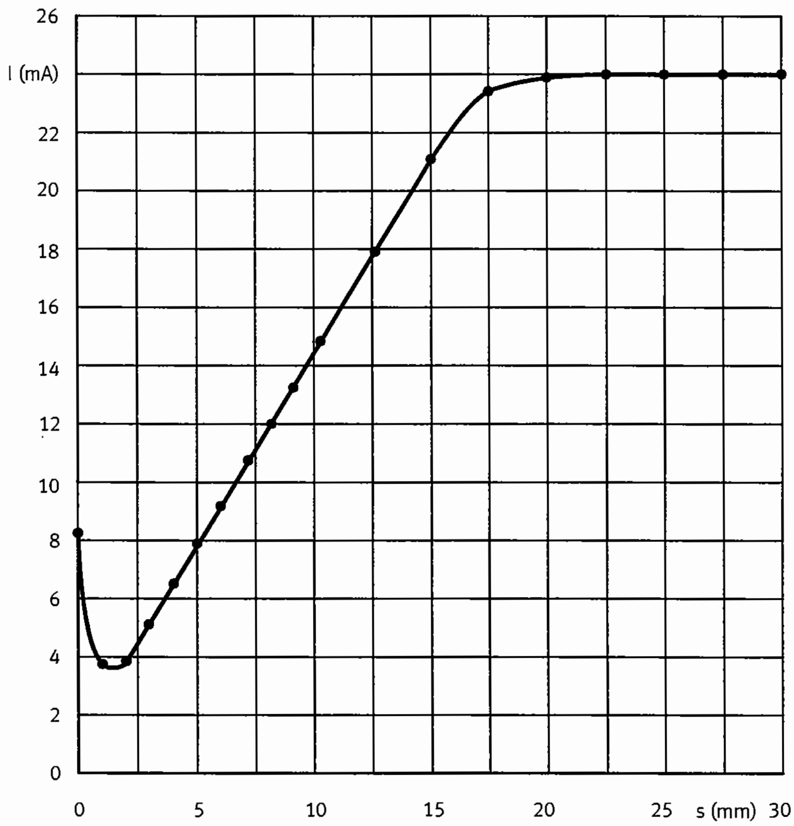


Fig. 8/4: Current-distance diagram

Part exercise c)

Measurement series: Current values for various thicknesses				
	Current I (mA)	Current I (mA)	Current I (mA)	Average (mA)
Plate 23	21.0	21.0	21.0	21.0
Plate 24	19.3	19.3	19.6	19.4
Plate 25	17.7	17.7	18.6	18.0
Plate 26	13.0	13.2	13.8	13.3
Plate 27	10.6	10.8	11.5	10.9

Part exercise d)

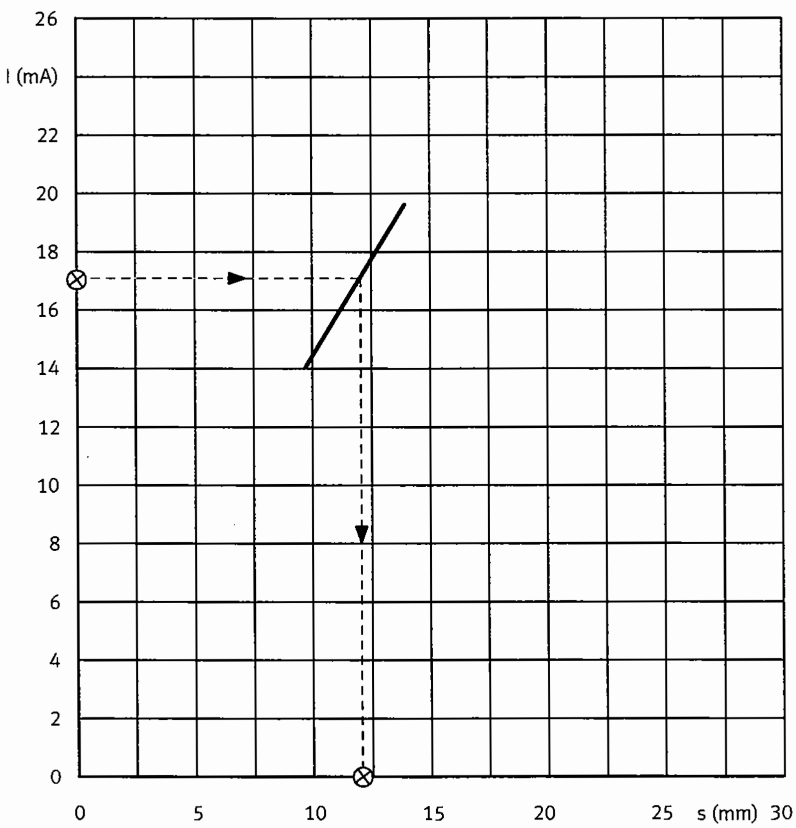


Fig. 8/5: Diagram I = f(s)

Measurement series: Thickness measurement

	Current I (mA)	Distance s (mm)	Delta s (mm)
Plate 23	21.0	15.0	0
Plate 24	18.4	13.8	1.2
Plate 25	16.8	11.5	3.5
Plate 26	13.3	9.0	6.0
Plate 27	10.9	7.0	8.0

Part exercise e)

Comparison of measurement

	Values measured using vernier caliper (mm)	Values detected using sensor (mm)
Plate 23	0.0	0.0
Plate 24	1.4	1.2
Plate 25	3.3	3.5
Plate 26	6.1	6.0
Plate 27	8.3	8.0

Question

Why is the use of an analogue sensor appropriate in the case of the problem described?

By using analogue sensors, the variations in thickness of the plastic plates can be measured quite easily. A change in the material thickness requires only a reaction in the PLC program. It is not necessary to change the mechanical assembly, thus reducing machine down-times. For plastic plates with different material characteristics, it is recommendable to use analogue ultrasonic sensors rather than the analogue diffuse optical sensor used here.

Determining the effect of material type upon distance measurements using an analogue diffuse optical sensor

Part exercise b)

Kodak grey card

Measurement series: Current-distance diagram of grey surface

s (mm)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
I (mA)	5.6	3.7	3.72	4.2	5.2	6.0	6.9	7.6	8.3	9.2
	6.1	3.7	3.7	4.2	5.2	6.0	6.9	7.6	8.4	9.1
	6.3	7.7	3.7	4.3	5.1	6.0	6.9	7.8	8.5	9.2
s (mm)	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	10.0	14.3	18.3	22.1	23.9	24.1	24.2	24.2	24.2	24.3
	10.1	14.3	18.4	22.1	23.9	24.2	24.2	24.3	24.2	24.3
	10.0	14.3	18.3	22.1	23.9	24.1	24.2	24.2	24.2	24.3

Measurement series: Current-distance diagram of white surface

s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)	3.7	3.7	5.6	8.2	10.6	13.1
	3.7	3.8	5.7	8.2	10.7	13.1
	3.7	3.8	5.7	8.2	10.6	13.1
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	15.5	18.1	20.8	23.1	23.8	24.2
	15.6	18.1	20.7	23.2	23.9	24.2
	15.5	18.0	20.7	23.2	23.9	24.2

Part exercise c) **Red card**

Measurement series: Current-distance diagram of shiny surface						
s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)	3.7	3.7	6.4	9.4	12.2	15.1
	3.7	3.8	6.5	9.5	12.3	15.2
	3.7	3.8	6.6	9.6	12.4	15.3
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	17.9	20.9	23.4	24.1	24.2	24.3
	18.0	20.9	23.4	24.0	24.1	24.3
	18.1	21.0	23.4	24.0	24.1	24.3

Measurement series: Current-distance diagram of matt surface						
s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)	3.7	3.8	6.8	9.8	12.7	15.7
	3.7	3.8	6.8	9.8	12.8	15.6
	3.7	3.8	6.8	9.8	12.3	15.7
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	18.5	21.4	23.5	24.1	24.2	24.3
	18.5	21.5	23.6	24.1	24.2	24.3
	18.6	21.5	23.6	24.1	24.2	24.3

Part exercise d) **Blue card**

Measurement series: Current-distance diagram of shiny surface						
s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)	3.7	4.5	8.67	12.5	16.1	19.7
	3.7	4.5	8.7	12.7	16.3	19.8
	3.7	4.5	8.7	12.7	16.3	19.9
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	23.2	24.1	24.1	24.2	24.2	24.3
	23.2	24.1	24.2	24.2	24.2	24.3
	23.2	24.1	24.2	24.2	24.2	24.3

Measurement series: Current-distance diagram of matt surface						
s (mm)	0.0	5.0	10.0	15.0	20.0	25.0
I (mA)	3.7	4.3	8.9	12.0	16.6	20.2
	3.7	4.3	9.1	13.0	16.8	20.4
	3.7	4.3	9.1	13.0	16.8	20.3
s (mm)	30.0	35.0	40.0	45.0	50.0	55.0
I (mA)	23.3	24.1	24.2	24.3	24.3	24.3
	23.4	24.1	24.2	24.3	24.3	24.3
	23.4	24.1	24.2	24.3	24.3	24.3

Questions

Is the characteristic curve of the sensor neutral with regard to colour?

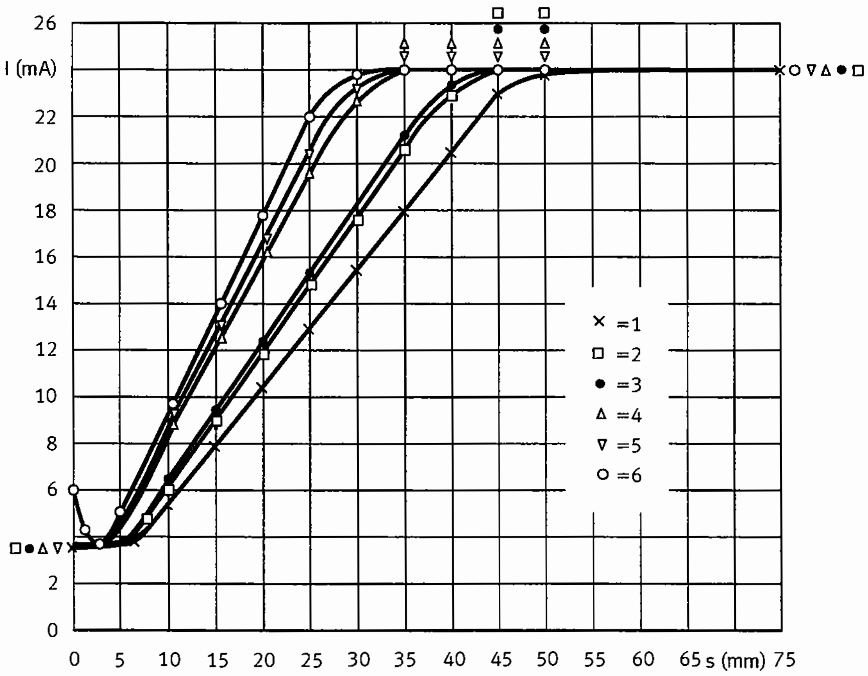
The ideal characteristic curve should not display any deviations with different colours. The measurement does however illustrate that the sensor cannot undertake measurement independent of colour?

What effect does the nature of the surface have on your measurements?

The characteristic curves for matt and shiny surface are very close together and cannot be distinguished if taking into account a certain measuring error.

Part exercise e)

Enter the measured values in the diagram.



1	Kodak card	white side
2	Red card	shiny side
3	Red card	matt side
4	Blue card	shiny side
5	Blue card	matt side
6	Kodak card	grey side

Fig. 9/4: Diagram

Determine the sensing distance of the sensor for the different coloured material surfaces with the help of the diagram.

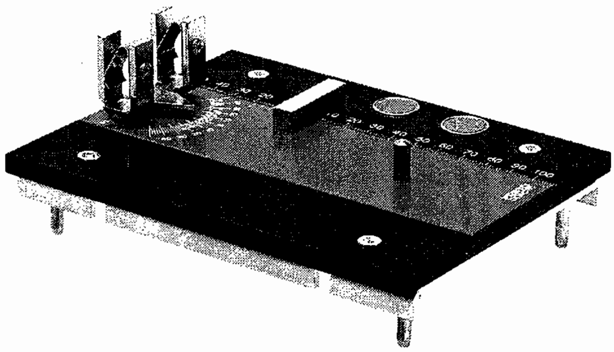
Detected sensing distances

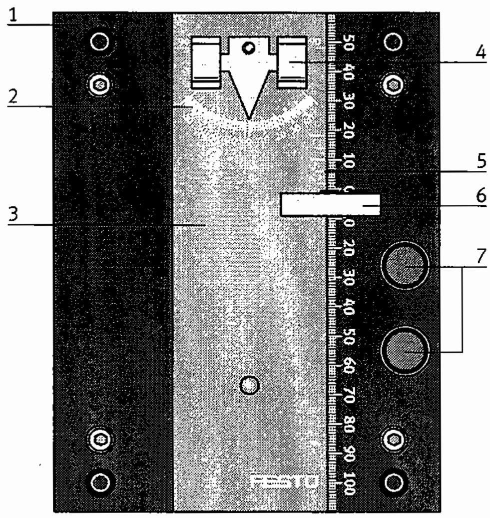
	Surface	Sensing distance in mm
Kodak card	white	7.5 – 45.0
	grey	5.0 – 25.0
Red card	shiny	7.5 – 40.0
	matt	7.5 – 40.0
Blue card	shiny	5.0 – 27.5
	matt	5.0 – 27.5

Part D – Data sheets

034094

Positioning slide





1	Base plate	5	Vernier
2	Angular position scale	6	Stop for vernier caliper
3	Sliding plate	7	Retaining magnets for vernier caliper
4	Rotatable material retainer		

Design

The positioning slide consists of a plug-in base plate with four locating pins, a sliding plate and a rotatable material retainer. Attachment of this unit to the profile plate requires 4 plug-in adapters (Order no. 323971).

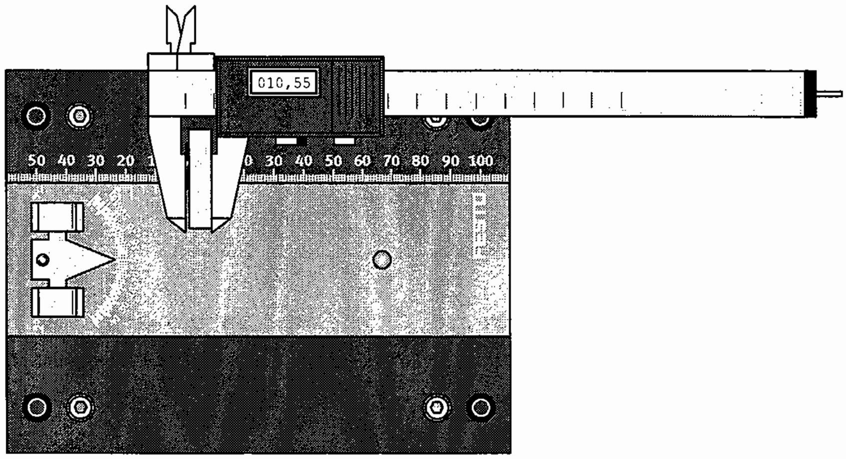
034094

Positioning slide

Function

The positioning slide is used for carrying out the measurements which determine the switching distances and sensing ranges of different types of proximity sensors. For this, various test materials are held in the spring loaded retainer and then moved towards the proximity sensor along a central axis. A graduated scale on the sliding plate indicates the distance between the proximity sensor and object. The material retainer can be rotated, an angular scale for reading the rotary angle is marked on the sliding plate.

A vernier caliper can be fitted to the positioning slide by means of magnetic retainers. This increases the accuracy of measurement and simplifies the procedure for measuring hysteresis. When mounting the vernier caliper, the slide unit of the positioning slide is set to "0". The two pointers are moved apart by approximately 10 mm. The vernier caliper is placed parallel to the base plate flush with the edge in such a way, that the front pointer rests against the stop for the vernier caliper. The two retaining magnets retain the caliper body to the base plate of the positioning slide.



Note

When using a vernier caliper for digital reading of measurements, the sliding plate supporting the test object is moved up to the proximity sensor, and the reading is set to "0". This provides a simple method of zero setting.

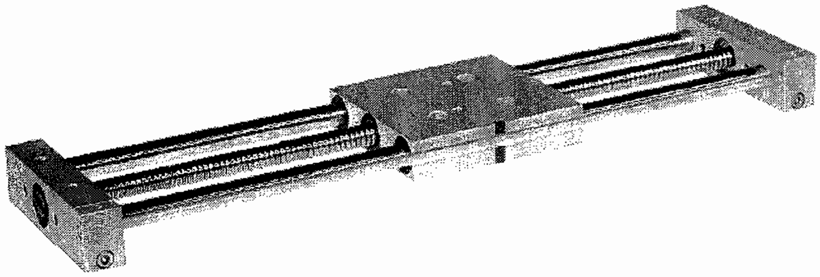
Avoid bringing objects sensitive to magnetic influence near the positioning slide.

Technical data

Mechanics	
Slide travel	150 mm
Graduation	1 mm
Angular scale	90°
Graduation	2°
Vernier scale	0.2 mm
Max. clamping thickness	5 mm
Retaining force of stop magnets	each 5 N
Retaining force of retaining magnets	each 60 N
Max. operational temperature of magnets	+150 °C
Materials	Steel, zinc coated (base plate) Plastic (sliding plate, side pieces) Aluminium (stop) Samarium cobalt (magnets)
Weight	0.81 kg

080824

Spindle drive unit, ball screw



Design

In conjunction with the gear motor (Order no. 080828) or the stepper motor (Order no. 080830) the spindle drive unit can be used for single axis motions. It is electrically actuated by means of a programmable logic controller, an input/output module or a motor control unit (Order no. 162249).

Function

The spindle drive unit is of conventional construction with a drive spindle and two guide rods. The sliding carriage is bearing mounted and has an attachment hole pattern to suit the Festo Didactic Handling System. The drive spindle is mounted in ball bearings and has a drive coupling at one end which matches with the drive motor. The opposite end of the spindle can be fitted with a distance ring, which enables an encoder to be attached. A rod is mounted to one of the longitudinal sides of the slide unit for attachment of proximity switches which are activated by a magnet fixed to the slide.

Note

The unit can be attached to the profile plate by using an adapter (Order No. 150519).

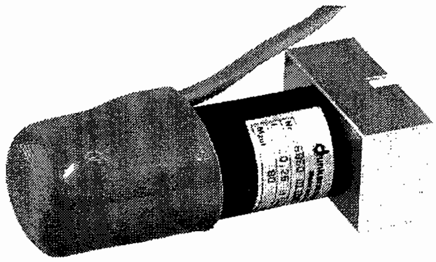
Technical data

Mechanics	
Max. carriage displacement	260 mm
Attachment hole pattern	top: 4 x Ø 5.3 (40 x 40 mm), with a counterbore on both sides for socket head screws M5 2 x Ø 5.1 (36 x 15 mm) at the sides: 2 x M5 (36 x 15 mm)
Overall dimensions	approx. 110 x 420 x 30 mm
Guide rod diameter	12 mm
Lead of the spindle	3 mm

 Subject to change

080828

Geared motor



Design

The gear motor drives the transfer slide unit (Order no. 080824) and, in conjunction with the mounting kit DE (Order no. 150539), it can be used as a rotary unit.

Function

It comprises a DC motor with drive, a mounting flange and mounting screws. The electrical connection is established by means of a cable which is 2 m in length.

Note

The polarity of the applied voltage is critical for satisfactory operation. The plugs connected to the cable are colour coded:

Operating voltage: Positive pole plug: red — cable: brown
Negative pole plug: blue

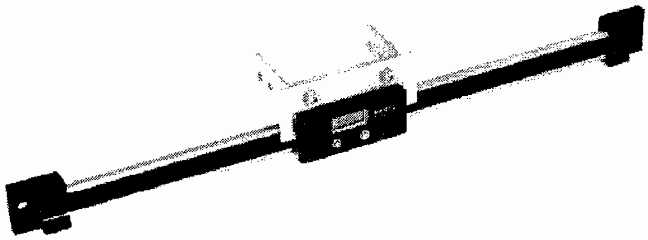
Technical data

Electrical, Mechanics	
Nominal voltage	24 V
Nominal current	0.3 A
Output rating	3.31 W
Nominal speed	158 r.p.m
Motor starting torque	60.75 Ncm
Nominal torque	19 Ncm
Materials	End cover (Plastic) Housing (Steel)
Connection	Cable with 4 mm safety connector plugs
Weight	340 g

 Subject to change

150536

Mountable vernier caliper



Design

The measuring slide attachment with digital display can be attached to the positioning slide (Order No. 080824) by means of the mounting kit (Order No. 150540). The driver represents the connection between the positioning slide and the measuring slide and is used to move the sensing head to detect the displacement of the slide.

Function

The measuring slide is a capacitive device for linear measurement; the acquisition of measured values is based on the principle of a differential capacitor. In order to achieve a wide sensing range, the electrodes are made up of parallel strip shaped plates which are arranged in a comb-like manner to form a scale. Strip electrodes are built into the reading head to form the two counterelectrodes.

These counter electrodes are activated via electronic switches. Further switching of the electrodes during movement of the reading head takes place when the measured voltage has reached a certain value. Within this range, a certain linear correlation exists between the measured voltage and the displacement to be measured. The indexing signal is simultaneously passed to a counter. If the dimensions of the electrodes are known, the number of counted pulses provides a gauge of how often the linear range of the measured voltage has been travelled. The counter value and the actual level of the measured voltage provide the value of the total displacement path. The measured value is indicated via a digital display.

Note

Power supply: One 1.5 V battery, 155 mAh (e.g.: Varta V357, IEC standard: SR44). Service life of battery approx. 12 months.

Required battery replacement is signalled by means of a flashing indicator. The battery can be replaced by unscrewing the four screws on the indicator side and removing the housing. (Fit the new battery with the positive pole uppermost!).

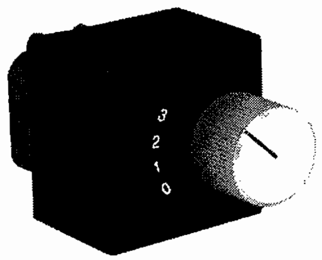
150536

Mountable vernier caliper

Technical data

Electrical, Mechanics	
Measuring path	286 mm
Measuring accuracy	±0.03 mm
Resolution and repeat accuracy	≤0.01 mm
Wiper accuracy	<1.5 m/s
Power consumption	1.5 mW
Ambient operating temperature	0 – +40 °C
Storage temperature	-20 – +70 °C
Weight	350 g

Signal switching unit



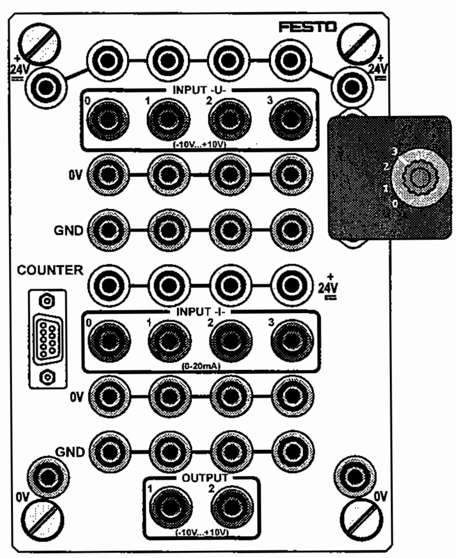
Design

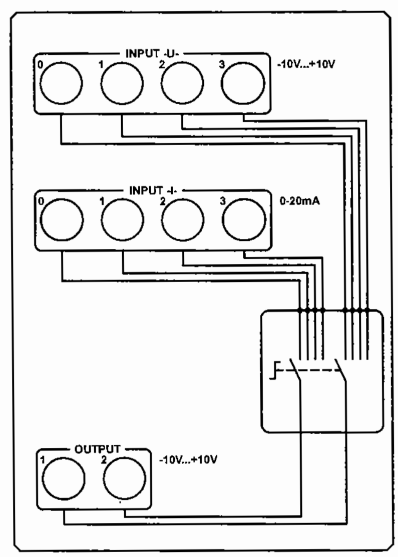
This signal switching unit consists of a rotary switch and a micro-ribbon connection plug moulded into a plastic housing. It can only be used in conjunction with connection unit, analog (Order No. 162247).

Function

The signal switching unit is plugged into the 14-pin micro-ribbon socket of the connection unit. The connection unit is used as a signal distributor.

The signal switching unit consists of a 2-pin rotary switch with 4 switching positions. The signals of analogue voltage inputs 0 to 3 of the connection unit are connected to OUTPUT 0 via the signal switching unit. The signals of the analogue current inputs 0 to 3 of the connection unit are connected to OUTPUT 1 via the switching unit. By means of the changeover function, the signal of the two inputs bearing the same number, e.g. VI0 and II0, are switched to the corresponding outputs for each switching position. The respective output signals can be detected by means of a measuring device.





Block circuit diagram for the switching unit and connection unit, analog

 Subject to change

150538

Signal switching unit

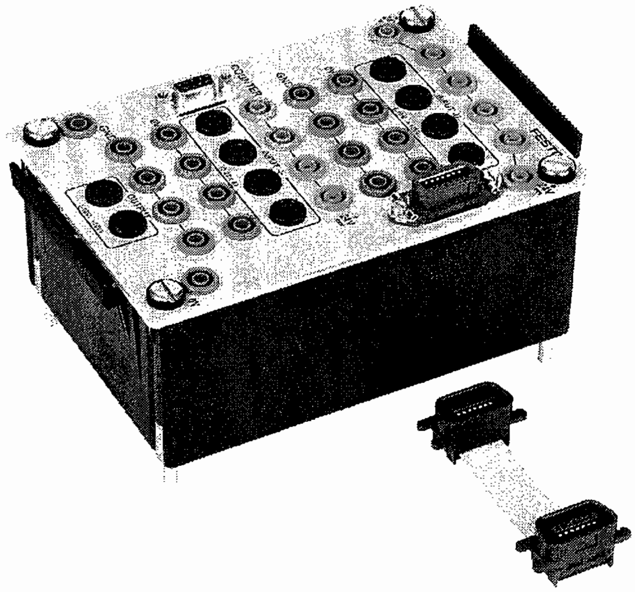
Switch setting	**Inputs**	**Outputs**
0	INPUT 0, voltage INPUT 0, current	OUTPUT 0 OUTPUT 1
1	INPUT 1, voltage INPUT 1, current	OUTPUT 0 OUTPUT 1
2	INPUT 2, voltage INPUT 2, current	OUTPUT 0 OUTPUT 1
3	INPUT 3, voltage INPUT 3, current	OUTPUT 0 OUTPUT 1

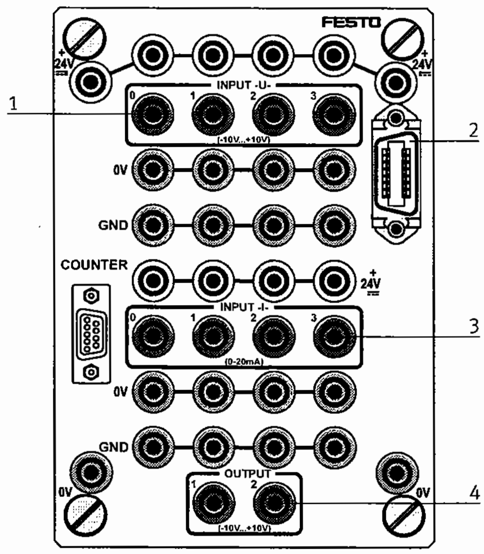
Allocation of switch settings of the signal switching unit to the inputs of the connection unit, analog

Technical data

Electrical	
Switching capacity	Max. 0.4 VA
Switching voltage	Max. 28 V
Service life, electrical	10^4 cycles
Conductance	<50 mΩ
Insulation resistance	>100 MΩ
Voltage requirement	>500 V AC
Ambient operating temperature	-25 – +85 °C
Connection	Micro-ribbon connector, 14-pole
Weight	58 g

Connection unit, analog





1 Analogue voltage inputs VI0...VI3
2 Connection signal switching unit
3 Analogue current inputs II0...II3
4 Analogue outputs VO0 - VO1

Design

The connection unit, analog is mounted in a single housing with connector sockets for assembly on a panel or assembly board. Attachment on profile plate requires 4 plug-in adapters (Order No. 323571).

Included in delivery is a ribbon cable which is not needed for this application. The analogue inputs and outputs are accessible via 4 mm safety connectors.

Function

The Festo Didactic power pack provides a 24 V power supply for the connection units.

The analogue current inputs (II0...II3), the analogue voltage inputs (VI0...VI03), the analogue voltage outputs (VO0, VO1) and the analogue ground signal (GND) are all accessible via 4 mm safety connectors.

All inputs and outputs (4 mm safety connectors) of the connection unit are designed with a protective circuit against reverse polarity

If the 24 V socket is connected with the sockets for the analogue voltage output, this may damage the fuses built into the connection unit. In this case, open the connection unit and replace the damaged fuse with a new fuse.

The analogue voltage outputs (VO0, VO1) are short-circuit proof which means that the built-in fuses cannot be damaged!

Note

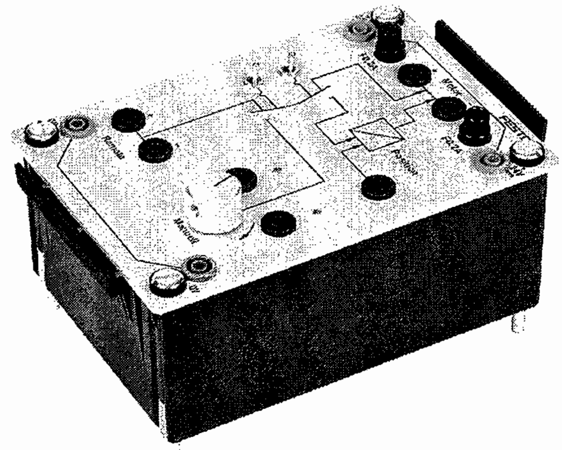
If 2, 3 or 4 sensors are connected to the current inputs (II0...II3), GND must be connected to 0 V, otherwise the currents add up.

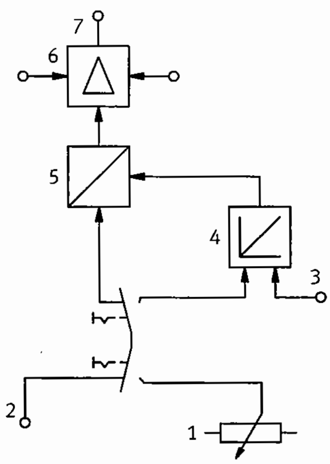
Technical data

Electrical		
Permissible operating voltage	24 V DC	
Perm. voltage fluctuations	22 – 27 V DC	
Analogue voltage inputs INPUT V	Range Input resistance Reference	-10 – +10 V (max. ±30 V) 200 kΩ GND
Analogue current inputs INPUT I	Range Input voltage Reference	0 – 20 mA (max. -4 – +24 mA) max. ±30 V GND
Analogue outputs	Voltage Current Reference	-10 – +10 V, Short circuit protected max. ±30 V fuse protected max. 20 mA GND

162249

Motor control unit





1 Rotary potentiometer for manual setting
2 Remote input for setpoint input via PLC
3 Actual value of position (of displacement sensor)
4 P-loop controller
5 Converter
6 Amplifier with proximity sensor inputs
7 Motor connection

Design

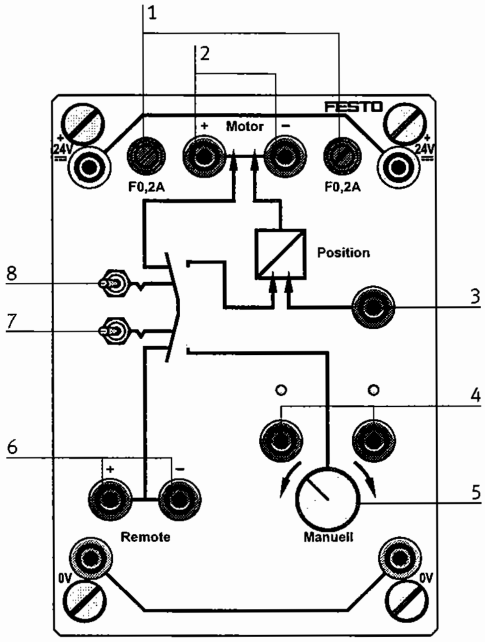
The motor controller is installed in a housing with 4 locating pins and consists of inputs and outputs which permit the control of speed and direction of a gear motor (Order No. 080828). In addition, two inputs are available for proximity sensors.

Note

The motor controller can be mounted on a profile plate by using four adapters (Order No. 323571)

162249

Motor control unit



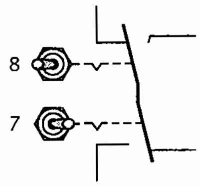
1 Fuses
2 Motor output
3 Position input
4 Proximity sensor inputs
5 Rotary knob for potentiometer to control speed and direction
6 Connection of external voltage for motor
7 Toggle switch remote/manual
8 Toggle switch direct/controller

Function

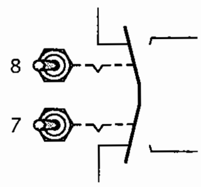
With the motor controller, the speed and direction of the gear motor (Order No. 080828) can be controlled. The motor output of the motor controller is adapted to the gear motor. Either anti-clockwise or clockwise operation is possible depending on the polarity of the motor voltage.

If the gear motor is mounted on to a transfer slide unit (Order No. 080824), then the position of the transfer slide unit can be infinitely adjusted with the help of the motor controller. The position of the transfer slide unit can be adjusted in four different ways depending on whether the adjustment is made manually or via a PLC. In the case of adjustable position setting, a displacement sensor will be required to detect the actual position of the transfer slide unit.

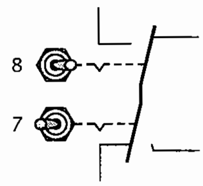
Modes of operation depending on toggle switch setting



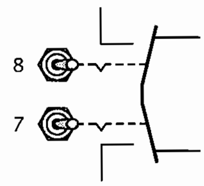
- Manual setting of motor voltage by means of rotary potentiometer.
- Direct control of motor, without closed loop control. A specific transfer slide position can be reached by way of a corrective readjustment of the rotary potentiometer.



- Control of motor via a PLC.
- Closed loop control can be effected via the PLC in conjunction with a displacement sensor. Connection of displacement sensor to the PLC.



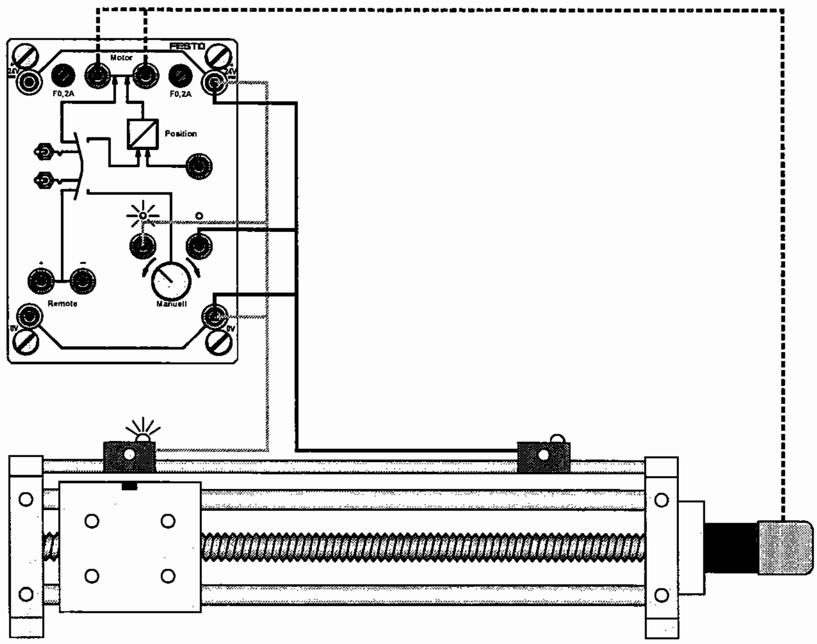
- Setpoint adjustment is effected by means of PLC via 'remote' input .
- Position control via P-controller of the motor controller in conjunction with a displacement sensor. Connection of displacement sensor to 'Position' socket.



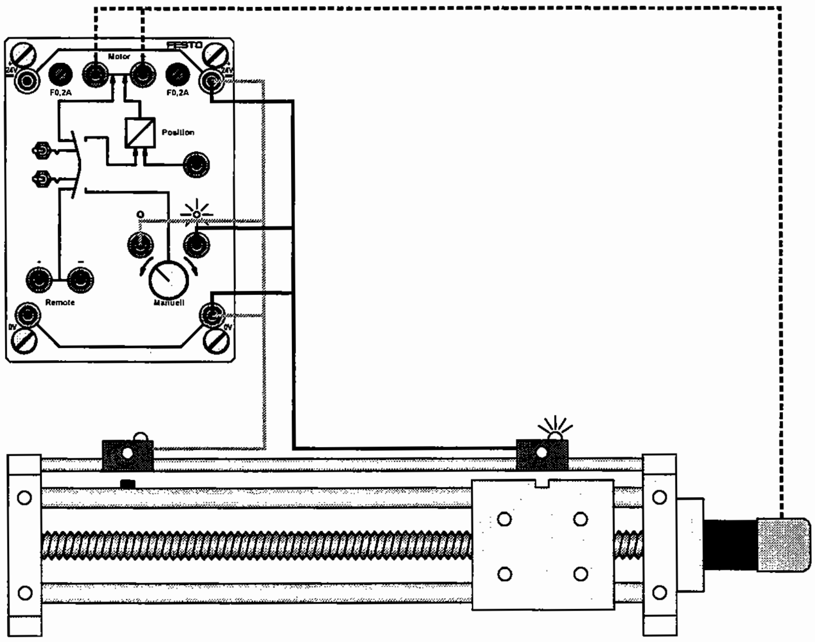
- Manual setpoint adjustment by means of rotary potentiometer.
- Position control via P-controller of motor control in conjunction with a displacement sensor. Connection of displacement sensor to 'Position' socket.

Proximity sensor inputs

With proximity sensor inputs, it is possible to interrupt either direction of rotation of the connected motor.



With the anti-clockwise movement interrupted, movement is only possible in clockwise direction. (A slight voltage reversal is applied to the motor, which may result in the slide slowly withdrawing out of the response range of the proximity sensor).



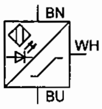
With the clockwise movement interrupted, movement is only possible in the anti-clockwise direction. (A slight voltage reversal is applied to the motor, which may result in the slide slowly withdrawing out of the response range of the proximity sensor).

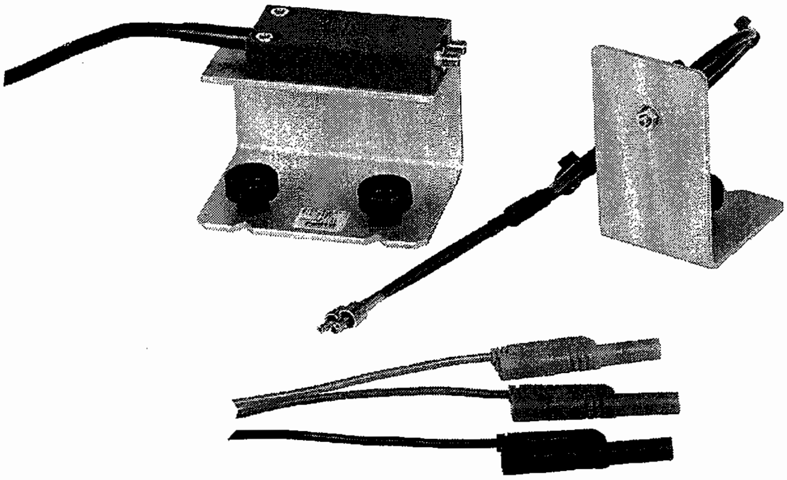
Technical data

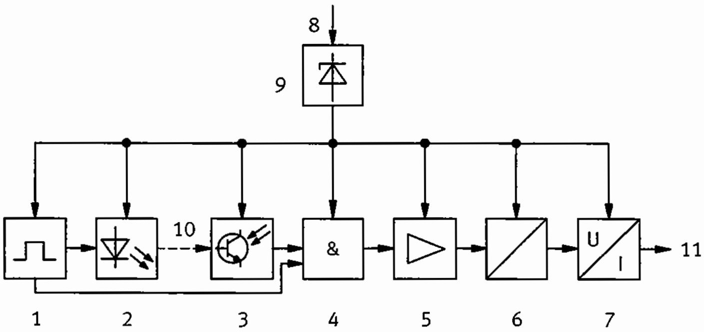
Electrical	
Voltage supply	24 V DC
Motor output	±20 V DC/300 mA
Remote input	±10 V DC
Position input	0 – 24 V DC
Proximity sensor inputs	24 V DC/30 mA
Positioning accuracy	±5 %
Weight	510 g

167051

Analog-optical distance sensor







1	Oscillator	6	Linearisation
2	Photoelectric emitter	7	Voltage/Current converter
3	Photoelectric receiver	8	External voltage
4	Logic operation	9	Internal constant voltage supply
5	Amplifier	10	Optical distance
		11	Output: Current signal

Design

The optoelectronic diffuse reflective sensor and the associated fibre-optics are mounted on two separate aluminium brackets. Assembly on to the profile plate is by means of T-head nuts and knurled screws.

 Subject to change

167051

Analog-optical distance sensor

Function

The optoelectronic diffuse sensor contains a photoelectronic receiver (photodiode or phototransistor) and an infrared LED (IRED). The photoelectric receiver receives the infrared light which has been emitted by the IRED luminescent diode and reflected by an object and converts this into an electrical current. If the light emission strength at the receiver changes in relation to distance, then the electrical current also changes. On the basis of an electronic adjustment made within the proportional range of the response characteristic, a linear relationship exists between the output signal and the distance of the object. The sensing range can be changed by means of the built-in potentiometer.

Note

Prior to operation, note the polarity of the applied voltage. The plugs attached to the connection cable are colour coded as follows:

Operating voltage:	Positive pole plug: red	cables: brown
	Negative pole plug: blue	
Analogue output signal:	Current plug: black	

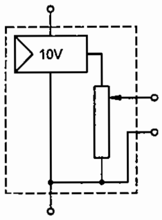
The sensor is protected against reverse polarity.

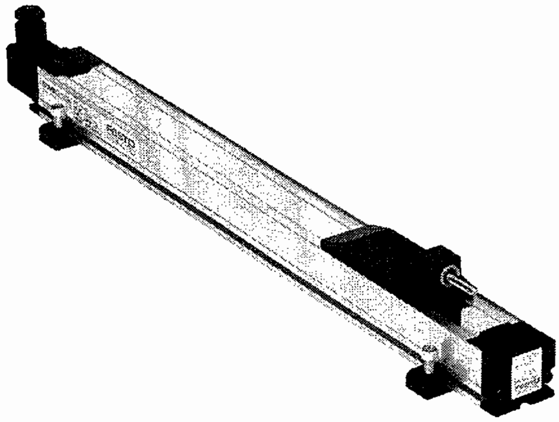
The sensor output supplies a load-independent current and is operated in the short-circuit mode. Ideally, the output load resistor is $R_L = 0\ \Omega$.

Technical data

Electrical, Sensorial	
Permissible operating voltage	10 – 30 V DC
Current consumption (without load)	<50 mA
Current output	4 – 20 mA
Max. load resistance	900 Ω
Measuring range with fibre-optic cable (adjustable via potentiometer)	8 – 40 mm
Response time	<1 ms
Ambient operating temperature	−20 – +70 °C
Linearity error	<5 % full scale deflection
Reproducibility	≤0.2 mm
Reverse polarity protection	yes
Material (housing)	plastic
Protection class	IP65
Weight	340 g
Connection	Cable with 4 mm safety connector plugs

Linear potentiometer





Design

The linear potentiometer can be mounted on to the transfer slide unit (Order No. 080824) by using the mounting kit (Order No. 150540). Electrical connection is established via the cable provided (Order No. 376574), which contains an impedance converter for reverse polarity protection and signal adaption.

Function

The linear potentiometer is constructed in the form of an internal rodless sliding potentiometer with in-line coupling which is housed in an aluminium profile housing. This sliding potentiometer is used to tap a voltage which is proportional to the connected supply voltage and the wiper position. The resistance surface consists of a conductive plastic layer which, compared to the wirewound potentiometer, has the advantage of higher resolution and longer service life.

Note

Prior to operation, note the polarity of the connected voltage. The plugs attached to the connection cable are colour coded as follows:

Operating voltage:	Positive pole plug: red
	Negative pole plug: blue
Analogue output signal:	Voltage plug: black

The sensor is protected against reverse polarity and short circuit by means of the cable provided (Order No. 376574).

177465

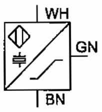
Linear potentiometer

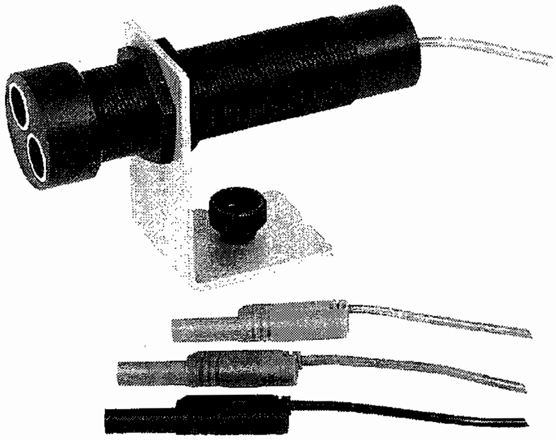
Technical data

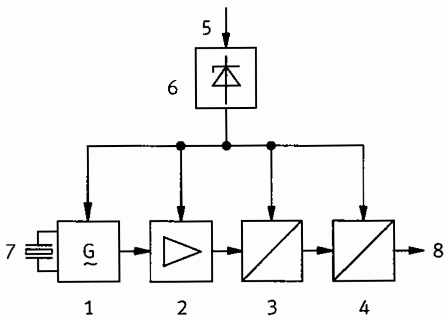
Electrical, Mechanics	
Permissible operating voltage[1]	13 – 30 V DC
Potentiometer resistance	5 kΩ
Resistance tolerance	±20 %
Recommended wiper current	≤1 µA
Electrical pick-up length	304 mm
Output voltage[1]	0 – 10 V DC
Ambient operating temperature[1]	-30 – +70 °C
Max. linearity error	±0.07 % full scale deflection
Resolution and reproducibility	≤0.01 mm
Reverse polarity protection	yes
Insulation resistance (Potentiometer)	<100 MΩ at 500 V DC, 1 bar
Dielectric strength (Potentiometer)	500 V_{eff} at 50 Hz, 1 min, 1 bar
Positioning speed	±10 m/s
Adjustment acceleration	±200 m/s2
Actuating force (horizontal)	<1 N
Max. number of actuations	10^8
Material (housing)	Aluminium
Weight	720 g
Connection (via cable Order No. 376574)	Cable with 4 mm safety connector plugs

[1] Applicable for potentiometer including impendance converter

Analog ultrasonic distance sensor







1	Oscillator	5	External voltage
2	Amplifier	6	Internal constant voltage supply
3	Evaluation unit	7	Ultrasonic transducer
4	Output signal conditioning	8	Output: Current signal

Design

The ultrasonic sensor is mounted on an aluminium bracket. Assembly is effected by means of a T-head nut and a knurled screw.

Function

The operational principle of an ultrasonic sensor is based on the generation of acoustic waves and their detection when reflected by an object. Normally, atmospheric air serves as a carrier of the ultrasonic waves.

A transducer is actuated briefly and emits an ultrasonic pulse, which is inaudible to the human ear. After emission, the ultrasonic pulse is reflected by an object within the range of the sensor and reflected back to the receiver. The transit time of the ultrasonic pulse is subsequently electronically evaluated. Within a defined range, the output signal is proportional to the signal transit time of the ultrasonic pulse.

Analog ultrasonic distance sensor

The object to be detected can be made of a wide range of materials. Shape and colour or material type, whether it be solid, liquid or powder form, has little or no effect on detection. Objects of a smooth, even surface must be aligned vertically to the ultrasonic emission.

Note

Prior to operation, note the polarity of the connected voltage. Connecting cables and plugs are identified by colour coding as follows:

Operating voltage:	Positive pole plug: red	cable: white
	Negative pole plug: blue	cable: brown
Analogue output signal:	Current plug: black	cable: green

The sensor is protected against reverse polarity.

The sensor output supplies a load-independent current and is operated in short-circuit mode. Ideally, the output load resistor is $R_L = 0\ \Omega$.

Technical data

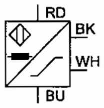
Electrical, Sensorial	
Permissible operating voltage	24 V DC
Current consumption (without load)	<35 mA
Load resistor	<400 Ω
Current output	6 – 20 mA
Measuring range	150 – 500 mm
Ambient operating temperature	-20 – +75 °C
Temperature drift	0.1 %/°C
Linearity error	0.2 % full scale deflection
Measuring clock frequency	40 Hz
Acceptance angle of sound cone	ca. 5°
Reverse polarity protection	yes
Protection class	IP 65
Materials (housing)	plastic
Weight	250 g
Connection	Cable with 4 mm safety connector plug

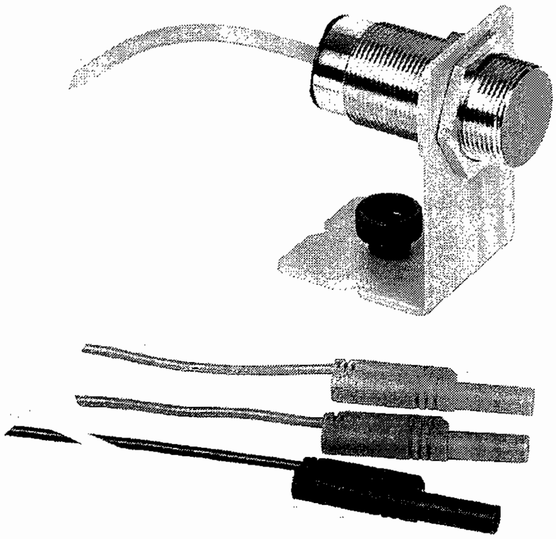
Note

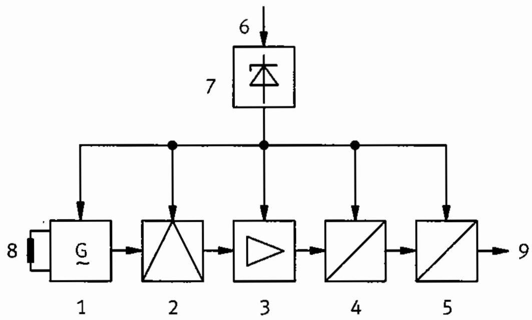
The sound-reflecting surface must have a minimum size dictated by the shape of the sonic pulse and the distance from the sensor.

184117

Analog inductive distance sensor







1	Oscillator	6	External voltage
2	Demodulator	7	Internal constant voltage supply
3	Amplifier	8	Coil with active zone
4	Linearisation	9	Output: Current or voltage signal
5	Output signal conditioning		

Design

The analogue inductive sensor is mounted on an aluminium bracket. Assembly on to the profile plate is effected by means of a T-head nut and a knurled screw.

Function

The analogue inductive sensor contains an oscillator circuit, which consists of a parallel resonant circuit with coil and capacitor as well as an amplifier. The electromagnetic field is directed outwardly by means of a ferrite shell core.

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Analog inductive distance sensor

If an electrically conductive material is introduced into the active zone of the stray field, eddy currents are induced into the material according to the laws of inductance, which attenuate oscillation. Attenuation of the oscillator varies according to the conductivity, permeability, dimensions and proximity of the conductive object. The output signal, within a defined range, is proportional to the distance between workpiece and sensor if the workpiece material and dimensions remain unchanged.

Note

Prior to operation, note the polarity of the applied voltage. The plugs attached to the connection cable are colour coded as follows:

Operating voltage:	Positive pole plug: red	cables brown
	Negative pole plug: blue	
Analogue output signals:	Voltage plug: black	
	Current plug: white	

The sensor is protected against reverse polarity and short circuit.

Technical data

Electrical, Sensorial	
Permissible operating voltage	15 – 30 V DC
Current consumption (without load)	≤8 mA
Voltage output	0 – 10 V
Load resistance	≤4.7 kΩ
Current output	0 – 20 mA
Load resistance	≤500 Ω
Measuring range	3 – 8 mm
Max. switching frequency	80 Hz
Ambient operating temperature	-10 – +70 °C
Temperature error	±5 % full scale deflection
Linearity error	±3 % full scale deflection
Reproducibility	≤2 % full scale deflection
Protection class (DIN 40 050)	IP 67
Reverse polarity and short circuit protection	yes
Material	Housing CuZn, chromium plated
Weight	260 g
Connection	Cable with 4 mm safety connector plugs

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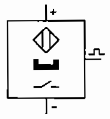
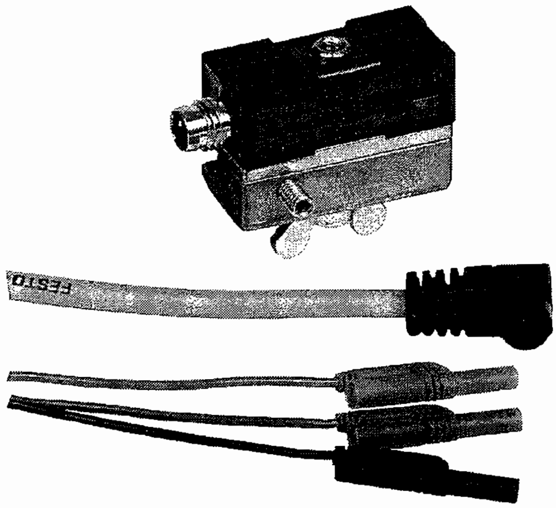
Proximity sensors, non-contact, inductive-magnetic





Design

The inductive magnetic proximity sensor comprises the sensor itself and mounting elements. Electrical connection is established via a plug, for which a socket and cable are enclosed.

Function

This contactless proximity sensor emits an electrical signal with the approach of a magnetic field (e.g. permanent magnet on a cylinder piston). By means of a defined magnetic field strength (permanent magnet) a signal is generated via an integrated circuit. The proximity sensor contains an oscillating coil with a ferromagnetic screen. With the approach of a magnetic field part of the screen is saturated, thereby causing a change in the oscillator current. This change in oscillator current is converted into an output signal. Switching of the load is with respect to the negative pole of the supply voltage. By using the enclosed mounting parts, the switch can be attached to the Duo-rail or the mounting rod (tie rod) of a cylinder suitable for contactless sensing. The active surface of the switch must face and also be in contact with the cylinder barrel. This surface is marked in yellow. If the piston of the cylinder moves under the active surface, then the switch is actuated. An LED indicates the switching status.

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Proximity sensors, non-contact, inductive-magnetic

Note

Prior to operation, note the polarity of the connected voltage. The plugs connected to the cable are colour coded as follows:

Operating voltage: Positive pole plug: red
Negative pole plug: blue

Output signal: plug: black
(PNP output, load connected to negative supply voltage)

The sensor is protected against reverse polarity, overload and short circuit.

Technical data

Electrical	
Power supply	10 – 30 V DC
Switching current	max. 200 mA
Switching capacity	6 W
Overcurrent trip	min. 250 mA
Switching accuracy	±0.1 mm
Connection	Plug socket for cable with plug