Mechatronics

Modules 1 - 8

Fundamentals
Cross-cultural Competencies
Project Management
Fluidics
Electrical Drives and Controls
Mechatronic Components
Mechatronic Systems and Functions
Commissioning, Safety, Troubleshooting
Remote Maintenance, Diagnosis

Trainerguideline

(Concept)

EU-Project Nr 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the Additional Mechatronic Qualification of Skilled Personnel in the Globalized Industrial Production

The Project was developed by the European Union within the action program for vocational education „Leonardo da Vinci“.

Bildung und Kultur

Leonardo da Vinci

www.minos-mechatronic.eu

Mechatronics

Module 1: Fundamentals

Solutions
(concept)

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www.tu-chemnitz.de/mb/WerkzMasch

Bildung und Kultur

Leonardo da Vinci

Teach ware concept working out and proving project partners

- Chemnitz University of Technology, Institute for Machine Tools and Production Processes, Germany – Project Management
- Corvinus University Budapest, Institute for Information Technologies, Hungary
- Stockholm University , Institute for Sociology, Sweden
- Wroclaw University of Technology, Institute for Industrial Engineering and Automation Technologies, Poland
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Teach ware concept:

Manual, exercises and solutions books for

- Module 1: Fundamentals
- Module 2: Cross-cultural Competencies, Projectmanagement
- Module 3: Fluidics
- Module 4: Electrical Drives and Controls
- Module 5: Mechatronic Components
- Module 6: Mechatronic Systems and Functions
- Module 7: Commissioning, Safety, Teleservice
- Module 8: Remote Maintenance, Diagnosis

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1 Technical Mathematics

1.1 Basic arithmetic operations

Exercise 1 *Solve the following exercises. Compute the answers by hand first. After that use the calculator to copmute the answers again.*

$2 \cdot 6 + 7 = 19$

$2 \cdot (6 + 7) = 26$

$4 + 5 \cdot 3 = 19$

$(4 + 5) \cdot 3 = 27$

$(3 \cdot 4) \cdot 2 = 24$

$(9 \cdot 3) + 4 = 31$

$8 + 2 \cdot (3 + 5) = 24$

$5 \cdot (3 + 7) + 4 = 54$

In this exercise, the order of performing of arithmetic operations is very important.

Exercise 2 *Solve the following exercises.*

$8 - 17 = -9$

$7 + (-25) = -18$

$7 - (-25) = 32$

$35 - (-18) - (+12) = 65$

$43 - (+17) + (-13) - (-8) = 21$

The combination of operation symbols and algebraic signs determines whether an addition or a subtraction should be performed.

Exercise 3 *Solve the following exercises.*

$5 - (6 + 7) = 5 - 6 - 7 = - 8$

$5 + (- 6 + 7) = 5 - 6 + 7 = 6$

$- (3 \cdot 4 + 5) = - (12 + 5) = - 12 - 5 = - 17$

$4 \cdot 5 - (8 - 3) = 20 - 8 + 3 = 15$

$- (6 - 2) - (3 \cdot 7) = - 6 + 2 - 21 = - 25$

$(- 5 + 2) \cdot 6 + 7 = - 3 \cdot 6 + 7 = - 18 + 7 = - 11$

Here, the algebraic signs of the elements in brackets must be determined, taking into consideration the order of performing of operations.

Exercise 4 *Solve the following exercises.*

$- 15 \cdot (- 4) = 60$

$8 \cdot (- 3) = - 24$

$16 : (- 4) = - 4$

$- 50 : 5 = - 10$

Pay attention to the algebraic signs of the multiplied and divided values.

Exercise 5 *Solve the following exercises, loosening the brackets.*

$4 (a + b) = 4a + 4b$

$a (8b - 5c) = 8ab - 5ac$

$(x - y) - 5x (2 + y) = x - y - 10x - 5xy = - 9x - y - 5xy$

$$(4x + 5y) \cdot (2a + 3b) = 4x (2a + 3b) + 5y (2a + 3b) = 8ax + 12bx + 10ay + 15by$$

$$(4x + 5y) \cdot (2a - 3b) = 4x (2a - 3b) + 5y (2a - 3b) = 8ax - 12bx + 10ay - 15by$$

$$(4x - 5y) \cdot (2a - 3b) = 4x (2a - 3b) - 5y (2a - 3b) = 8ax - 12bx - 10ay + 15by$$

Pay attention to the algebraic signs when calculating with brackets.

1.2 Calculation with fractions

Exercise 6 *Reduce the following fractions as much as possible, without calculating their values.*

$$\frac{4}{12} = \frac{1}{3}$$

$$\frac{3 \cdot 4}{24} = \frac{3 \cdot 1}{6} = \frac{1}{2}$$

$$\frac{9 \cdot 4 \cdot 5}{15 \cdot 8 \cdot 3} = \frac{3 \cdot 2 \cdot 1}{3 \cdot 4 \cdot 1} = \frac{1 \cdot 1 \cdot 1}{1 \cdot 2 \cdot 1} = \frac{1}{2}$$

$$\frac{27 \cdot 3 \cdot 8}{2 \cdot 6 \cdot 9} = \frac{3 \cdot 1 \cdot 4}{1 \cdot 2 \cdot 1} = \frac{3 \cdot 1 \cdot 2}{1 \cdot 1 \cdot 1} = \frac{6}{1}$$

First of all the possibility of reducing must be tested. The reducing of fractions before calculating their values results smaller values which are easy to handle with.

Exercise 7 *Calculate the following fractions. Reduce the fractions as much as possible, without calculating their values.*

$$\frac{2}{3} + \frac{5}{6} = \frac{2 \cdot 2}{3 \cdot 2} + \frac{5}{6} = \frac{4}{6} + \frac{5}{6} = \frac{9}{6} = \frac{3}{2}$$

$$\frac{1}{5} + \frac{13}{10} = \frac{1 \cdot 2}{5 \cdot 2} + \frac{13}{10} = \frac{2}{10} + \frac{13}{10} = \frac{15}{10} = \frac{3}{2}$$

$$\frac{4}{12} + \frac{3}{4} = \frac{4}{12} + \frac{3 \cdot 3}{4 \cdot 3} = \frac{4}{12} + \frac{9}{12} = \frac{13}{12}$$

$$\frac{7}{8} - \frac{1}{4} = \frac{7}{8} - \frac{1 \cdot 2}{4 \cdot 2} = \frac{7}{8} - \frac{2}{8} = \frac{5}{8}$$

A common denominator must be found before adding or subtracting. The result can be calculated after increasing of one or both of the fractions. Finally, the resulting fraction must be reduced as much as possible.

Exercise 8 *Calculate the following fractions.*

$$\frac{2}{3}\cdot\frac{15}{6}=\frac{2}{1}\cdot\frac{5}{6}=\frac{1}{1}\cdot\frac{5}{3}=\frac{5}{3}$$

$$\frac{4}{21}\cdot\frac{28}{8}=\frac{1}{21}\cdot\frac{28}{2}=\frac{1}{3}\cdot\frac{4}{2}=\frac{1}{3}\cdot\frac{2}{1}=\frac{2}{3}$$

$$\frac{11}{4}\cdot\frac{3}{13}=\frac{33}{52}$$

$$\frac{16}{8}\cdot\left(\frac{5}{4}+\frac{1}{3}\right)=\frac{16}{8}\cdot\left(\frac{15}{12}+\frac{4}{12}\right)=\frac{16}{8}\cdot\frac{19}{12}=\frac{4}{8}\cdot\frac{19}{3}=\frac{1}{2}\cdot\frac{19}{3}=\frac{19}{6}$$

Before calculating test if reducing is possible. In the last exercise it is also possible to multiply the value outside the brackets by each of the values inside the brackets before calculating of the sum. The result is of course the same.

Exercise 9 *Calculate the following fractions.*

$$\frac{4}{5}:\frac{6}{12}=\frac{4}{5}\cdot\frac{12}{6}=\frac{4}{5}\cdot\frac{2}{1}=\frac{8}{5}$$

$$\frac{3}{11}:\frac{21}{7}=\frac{3}{11}\cdot\frac{7}{21}=\frac{3}{11}\cdot\frac{1}{3}=\frac{1}{11}$$

$$\frac{17}{5}:\frac{7}{2}=\frac{17}{5}\cdot\frac{2}{7}=\frac{34}{35}$$

$$\frac{3}{7}:\left(\frac{5}{6}-\frac{1}{3}\right)=\frac{3}{7}:\left(\frac{5}{6}-\frac{2}{6}\right)=\frac{3}{7}:\frac{3}{6}=\frac{3}{7}\cdot\frac{6}{3}=\frac{6}{7}$$

Before calculating the fractions should be reduced if possible. In the last exercise the value inside the brackets must be calculated before performing of division.

1.3 Higher arithmetic operations

Exercise 10 *Calculate the following powers.*

$3^2 = 9$

$5^3 = 125$

$2^4 = 16$

$4^3 = 64$

$2^{-3} = 1/2^3 = 1/8 = 0{,}125$

$5^{-2} = 1/5^2 = 1/25 = 0{,}04$

Simple powers can be computed without calculator. In computers the powers with basis of 2 are found first of all. Such powers must be lightly recognized.

Exercise 11 *Write the following numbers in form of decimal powers. A one-digit numerical value must result.*

$1000 = 10^3$

$1000000 = 10^6$

$0{,}001 = 10^{-3}$

$500 = 5 \cdot 10^2$

$128000 = 1{,}28 \cdot 10^5$

$0{,}18 = 1{,}8 \cdot 10^{-1}$

$0{,}000298 = 2{,}98 \cdot 10^{-4}$

The results are one-digit numerical values. Notice that often by three divisible exponents are used.

Exercise 12 *Write the following numbers in full form.*

$3 \cdot 10^2 = 300$

$64 \cdot 10^5 = 6400000$

$1 \cdot 10^{-3} = 0{,}001$

$58 \cdot 10^{-5} = 0{,}00058$

$1{,}2 \cdot 10^{-6} = 0{,}0000012$

It is also possible to convert the numbers in such a way that by three divisible exponents occur.

Exercise 13 *Calculate the following powers. The result should be written in power form too.*

$10^4 \cdot 10^2 = 10^6$

$5^2 \cdot 5^6 \cdot 3^5 \cdot 3^3 = 5^8 \cdot 3^8$

$5 \cdot 10^2 \cdot 2000 = 10^6$

$320 \cdot 10^{-3} \cdot 0{,}001 = 3{,}2 \cdot 10^{-4}$

$$\frac{7^{24}}{7^{23}} = 7^{(24-23)} = 7^1 = 7$$

$$\frac{5^4}{5^5} = 5^{(4-5)} = 5^{-1} = 1/5 = 0{,}2$$

$$\frac{8^5 \cdot 8^4}{8^2 \cdot 8^6} = \frac{8^9}{8^8} = 8^1 = 8$$

$$\frac{6^8 \cdot 6^3}{2^4 \cdot 3^4} = \frac{6^{(8+3)}}{(2 \cdot 3)^4} = \frac{6^{11}}{6^4} = 6^{(11-4)} = 6^7$$

The powers can be also additionally calculated.

Exercise 14 *Calculate the following roots using the calculator.*

$\sqrt{16} = 4$

$\sqrt{64} = 8$

$\sqrt{256} = 16$

$\sqrt{1849} = 43$

$\sqrt{32,785} \approx 5,726$

$\sqrt{0,057} \approx 0,239$

Simple roots may be calculated by hand. It is also possible to estimate an approximate answer by means of calculator before the exact calculation.

When calculating of roots with a calculator the answers must be appropriately rounded. Rounding to three digits after the decimal point is enough here.

1.4 Binary numbers

Exercise 15 *Convert the following decimal numbers into binary numbers.*

21 = 16 + 4 + 1 = 10101

45 = 32 + 8 + 4 + 1 = 101101

63 = 32 + 16 + 8 + 4 + 2 + 1 = 111111

128 = 10000000

213 = 128 + 64 + 16 + 4 + 1 = 11010101

For this calculation the powers of two from 2^0 to 2^7 must be known. These powers represent the numbers 1, 2, 4, 8, 16, 32, 64 and 128.

Exercise 16 *Convert the following binary numbers into decimal numbers.*

1000 = 8 +0 + 0 + 0 = 8

1010 = 8 + 0 + 2 + 0 = 10

1111 = 8 + 4 + 2 + 1 = 15

11111111 = 128 + 64 + 32 + 16 + 8 + 4 + 2 + 1 = 255

10101010 = 128 + 0 + 32 + 0 + 8 + 0 + 2 + 0 = 170

In these exercises the knowledge of powers of two is also important.

1.5 Calculation with variables

Exercise 17 *Solve the following equations for x.*

$9 + x = b \quad | - 9$
$x = b - 9$

$3x = 3a + 3b \quad | : 3$
$x = 3 (a + b) : 3$
$x = a + b$

$4x + 3a - 2x + 5a = 8x - 7a + 5x + 8b$
$2x + 8a = 13x - 7a + 8b \quad | - 13x - 8a$
$- 11x = - 15a + 8b \quad | : (- 11)$
$x = (- 15a + 8b) : (- 11)$

$5ax + 8bx = 10a + 16b$
$(5a + 8b) x = 10a + 16b \quad | : (5a + 8b)$
$x = (10a + 16b): (5a + 8b)$

$\frac{1}{x} = 5 \quad | \cdot x$

$1 = 5 \cdot x \quad | : 5$

$x = \frac{1}{5}$

$$\frac{1}{x-8} = 16 \qquad | \cdot (x - 8)$$

$$1 = 16\,(x-8)$$

$$1 = 16x - 128 \qquad | + 128$$

$$129 = 16x \qquad | :16$$

$$x = \frac{129}{16}$$

When performing of transformations the basic arithmetic calculation rules must be taken into consideration.

1.6 Calculation of percentage

Exercise 18 *Solve the following exercises.*

How much are 3 % from 400 Euro?

$$\frac{x}{3\,\%} = \frac{400\,\text{Euro}}{100\,\%}$$

$$x = \frac{400\,\text{Euro} \cdot 3\,\%}{100\,\%}$$

$$x = 12\,\text{Euro}$$

3 % from 400 Euro are 12 Euro.

How much are 75 % from 230 kg?

$$\frac{x}{75\,\%} = \frac{230\,\text{kg}}{100\,\%}$$

$$x = \frac{230\,\text{kg} \cdot 75\,\%}{100\,\%}$$

$$x = 172{,}5\,\text{kg}$$

75 % from 230 kg are 172,5 kg.

The value-added tax equals to 16 %. How much does a ware cost without the value-added tax, if it's price amounts 100 Euro tax inclusive?

Pay attention that the value-added tax is added on the ware price. The final price consists of 100 % ware price and 16 % value-added tax, therefore 116 %.

$$\frac{x}{100\,\%} = \frac{100\,\text{Euro}}{116\,\%}$$

$$x = \frac{100\,\text{Euro} \cdot 100\,\%}{116\,\%}$$

$$x = 86{,}21\,\text{Euro}$$

The total price of 100 Euro is the sum of the ware price that equals to 86,21 Euro and the value-added tax on this price which amounts 16 %.

A shop announces remission of the value-added tax on a certain ware within advertising activity. What are the savings for a ware of total price of 150 Euro calculated as an absolute value and as percentage?

Like in previous exercise we calculate the ware price without the value-added tax first.

$$\frac{x}{100\,\%} = \frac{150\,\text{Euro}}{116\,\%}$$

$$x = \frac{150\,\text{Euro} \cdot 100\,\%}{116\,\%}$$

$$x = 129{,}31\,\text{Euro}$$

Consequently, the absolute value of savings amount

150,00 Euro – 129,31 Euro = 20,69 Euro

These savings can be represented as a percentage part of the above mentioned total price as follows

$$\frac{x\,\%}{20{,}69\,\text{Euro}} = \frac{100\,\%}{150\,\text{Euro}}$$

$$x\,\% = \frac{100\,\% \cdot 20{,}69\,\text{Euro}}{150\,\text{Euro}}$$

$$x \approx 13{,}8\,\%$$

1.6.1 Calculation of interests

Exercise 19 *Solve the following exercises.*

A sum of 5000 Euro is funded for 15 years with an interest rate of 5 %. What is the resulting sum at the end of this period with the compound interests included?

$G_n = G_0 (1 + z/100)^n$
$G_{15} = 5000 \text{ Euro} \cdot (1 + 5/100)^{15}$
$G_{15} = 5000 \text{ Euro} \cdot (1{,}05)^{15}$
$G_{15} = 5000 \text{ Euro} \cdot 2{,}079$
$G_{15} = 10395 \text{ Euro}$

The result of power calculation is rounded to three digits after the decimal point. In order to monitor the influence of rounding on the final result more digits after the decimal point can be left.

What would the resulting amount be if interests on interests were not calculated?

5 % of the sum of 5000 Euro amount

5000 Euro · 0,05 = 250 Euro

Within 15 years 250 Euro interests per year will be added to the beginning sum of 5000 Euro. The resulting sum at the end of the period amounts

5000 Euro + (15 · 250 Euro) = 5000 Euro + 3750 Euro = 8750 Euro

The difference to the final sum calculated with compaund interests amount

10395 Euro – 8750 Euro = 1645 Euro

1.7.2 Quadrangle

Exercise 20 *Solve the following exercises.*

A 2-room apartment is proposed for rent. The first room has a length of 4 m and a width of 3 m. The second room has a length of 5 m and a width of 4 m. What is the area of both rooms and the whole apartment?

$A = a \cdot b + c \cdot d$
$A = 4\ m \cdot 3\ m + 5\ m \cdot 4\ m$
$A = 12\ m^2 + 20\ m^2$
$A = 32\ m^2$

The total area of both rooms amounts 32 m^2.

What is the rental fee at a price of 8 Euro/m^2?

rental fee = A · price
rental fee = 32 m^2 · 8 Euro/m^2
rental fee = 256 Euro

The rental fee for both rooms amounts 256 Euro.

Another 2-room apartment has a 5 m-long and 3 m-wide room and a 6 m-long and 4 m-wide room. What is the foundation's area of this apartment?

$A = a \cdot b + c \cdot d$
$A = 5\ m \cdot 3\ m + 6\ m \cdot 4\ m$
$A = 15\ m^2 + 24\ m^2$
$A = 39\ m^2$

The total area of this apartment amounts 39 m^2.

The price of a square meter for this apartment amounts 6 Euro/m^2 only. Is this apartment cheaper or more expensive than the first one?

rental fee = A · price
rental fee = 39 m^2 · 6 Euro/m^2
rental fee = 234 Euro

The rental fee for this apartment amounts 234 Euro. This value is smaller than the first apartment's rental fee, in spite of the fact that the second apartment has a larger area than the first one. Before performing of this calculation an estimation can be made in order to determine which apartment is cheaper.

A room has a length of 5 m, a width of 4 m and a height of 3 m. All walls should be coated with wallpaper. How many square meters of wallpaper are needed ignoring doors and windows?

$U = 2a + 2b$
$U = 2 \cdot 5\ m + 2 \cdot 4\ m$
$U = 10\ m + 8\ m$
$U = 18\ m$

$A = U \cdot h$
$A = 18\ m \cdot 3\ m$
$A = 54\ m^2$

54 m^2 wall paper are needed. The number of needed rolls can be also calculated if length and width of the roles were given.

1.7.3 Triangle

Exercise 21 *Solve the following exercises.*

Two sides of a right triangle, which are shorter than the third side, are 15 m-long and 20 m-long. How long is the third side?

$c^2 = a^2 + b^2$
$c^2 = 15^2 + 20^2$
$c^2 = 225 + 400$
$c^2 = 625$
$c = 25$

The length of the third side is 25 m. Groups of three natural numbers in such calculations are called Pythagorean triplets.

A 9 m-wire should be placed on a wall with a height of 8 m. There is a distance of 3 m between the lower end of the wire and the wall. Does the wire reach the upper end of the wall?

Here, the wire represents the hypotenuse and the distance from the wall represents the length of one of the legs of a right triangle. Therefore, the other leg has the following length

$b^2 = c^2 – a^2$
$b^2 = 9^2 – 3^2$
$b^2 = 81 – 9$
$b^2 = 72$
$b \approx 8{,}48$

The wire can reach a height of 8,48 m which is higher than the wall. It is also possible to calculate how long should be the distance between the wire and the wall, so that their upper ends meet together.

A 20 m aerial mast is fixed with three ropes. The ropes are mounted to the ground at a distance of 13 m from the mast and reach its top. How many meters rope are needed taking into consideration that extra 3 % are needed for the mounting?

The height of the aerial mast and the distance to the fixing point are the legs of a right triangle. The hypotenuse must be calculated.

$c^2 = a^2 + b^2$
$c^2 = 20^2 + 13^2$
$c^2 = 400 + 169$
$c^2 = 569$
$c = 23{,}85$

A rope has a length of 23,85 m after rounding. The length of three ropes amounts

$L = 3 \cdot 23{,}85\ m$
$L = 71{,}55\ m$

A reserve of 3 % must be added to this length.

$L_{total} = L \cdot 1{,}03$
$L_{total} = 71{,}55\ m \cdot 1{,}03$
$L_{total} = 73{,}70\ m$

The total length of needed rope amounts 73,70 m.

Exercise 22 *Solve the following exercises.*

In a right triangle the side c=12 cm and the side b=4 cm. Calculate the angles and the third side length.

The third side in a right triangle is calculated using the Theorem of Pythagoras.

$a^2 = c^2 - b^2$
$a^2 = 12^2 - 4^2$
$a^2 = 144 - 16$
$a^2 = 128$
$a \approx 11{,}31$

The third side has a length of 11,31 cm after rounding.

The angles can be calculated using the trigonometric functions. The size of a right angle is 90° by definition.

The angle β can be calculated from its sine, which equals to the length of the opposite side b divided by the hypotenuse c.

$$\sin\beta = \frac{\text{opposite side}}{\text{hypotenuse}}$$

$$\sin\beta = \frac{b}{c}$$

$$\sin\beta = \frac{4\ \text{cm}}{12\ \text{cm}}$$

$$\sin\beta \approx 0{,}333$$

$$\beta \approx 19{,}5$$

The angle α can be calculated from its cosine, which equals to the length of the adjacent b divided by the hypotenuse c. It is also possible to calculate this angle using its sine. For this the just calculated side lengths are also needed. But it is always preferred to use the given data. So that an error or an inaccuracy in the calculation of the side length will not affect further calculations.

$$\cos\alpha = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\cos\alpha = \frac{b}{c}$$

$$\cos\alpha = \frac{4\ \text{cm}}{12\ \text{cm}}$$

$$\cos\alpha \approx 0{,}333$$

$$\alpha \approx 70{,}5$$

The sizes of the other two angles are 19,5° and 70,5°. The third angle can be also calculated considering the sum value of angles of a triangle. This can be tested by adding of all angles together which results 180°.

A street has a slope of 8 %, so that at a distance of 100 m it rises up to 8 m. What is the angle of the slope?

In this exercise the adjacent of the unknown angle is the length of 100 m and the opposite side is the height of 8 m. To calculate this angle the tangent is needed.

$$\tan\alpha = \frac{\text{opposite side}}{\text{adjacent}}$$

$$\tan\alpha = \frac{8\text{m}}{100\text{m}}$$

$$\tan\alpha = 0{,}08$$

$$\alpha \approx 4{,}57°$$

The angle of the slope amounts 4,57°.

Exercise 23 *Solve the following exercises.*

A barrel has a diameter of 60 cm. An external reinforcement steel band should be mounted on the barrel. How long is the steel band?

$$U = \pi \cdot d$$

$$U = \pi \cdot 60\,\text{cm}$$

$$U \approx 188{,}5\,\text{cm}$$

The band must have a length of 188,5 cm. The value Pi in this exercise can be used with different number of left digits after the decimal point. This will obviously affect the accuracy of the result.

The earth should be surrounded with a band. The earth's radius equals to 6370 km. How long should this band be? What will be the length of the band if there must be a distance of one meter between the band and the ground?

$$U = 2 \cdot \pi \cdot r$$

$$U = 2 \cdot \pi \cdot 6370\,\text{km}$$

$$U \approx 40023{,}8904\,\text{km}$$

$$U = 2 \cdot \pi \cdot r$$

$$U = 2 \cdot \pi \cdot 6370{,}001\text{km}$$

$$U \approx 40023{,}8967\,\text{km}$$

In this exercise the perimeter must be calculated with 4 digits after the decimal point. It is clear that a one-meter increase in the radius increases the perimeter by 6,3 m, which equals to the perimeter of a circle with a radius of 1m.

A wheel has a diameter of 70 cm. How many turns of the wheel are needed to cover a distance of 500 m?

$$U = \pi \cdot d$$
$$U = \pi \cdot 0{,}7\,m$$
$$U \approx 2{,}12\,m$$

$$\text{number of turns} = \frac{\text{distance}}{\text{perimeter}}$$
$$\text{number of turns} = \frac{500\,m}{2{,}12\,m}$$
$$\text{number of turns} = 235{,}8$$

The wheel turns 235,8 times to cover this distance.

A circle with a diameter of 90 cm should be cut out of a square sheet with an area of 1 m². What is the area of the circle? What is the area of the rest of the sheet? How much percent of the sheet are used for the circle?

The area of the circle amounts

$$A = \frac{1}{4} \cdot \pi \cdot d^2$$
$$A = \frac{1}{4} \cdot \pi \cdot 0{,}9^2\,m^2$$
$$A = \frac{1}{4} \cdot \pi \cdot 0{,}81 m^2$$
$$A = 0{,}636\,m^2$$

The area of the rest of the sheet amounts

remaining area =1 m² - 0,636 m²
remaining area = 0,363 m²

The area of the circle represented in form of percentage as a part of the total sheet area

$$\frac{x\,\%}{0{,}636\,m^2} = \frac{100\,\%}{1 m^2}$$

$$x\,\% = \frac{100\,\% \cdot 0{,}636\,m^2}{1 m^2}$$

$$x = 63{,}6\,\%$$

Exercise 24 *Solve the following exercises.*

A can has a diameter of 9 cm and a height of 11 cm. How much sheet metal is needed for the can? What is the content of the can?

The sheet metal is needed for the whole surface area of the can. The basis area and the perimeter should be calculated first

$$A = \frac{1}{4} \cdot \pi \cdot d^2$$
$$A = \frac{1}{4} \cdot \pi \cdot 9^2 \text{ cm}^2$$
$$A \approx 63{,}62 \text{ cm}^2$$

$$U = \pi \cdot d$$
$$U = \pi \cdot 9 \text{ cm}$$
$$U \approx 28{,}27 \text{ cm}$$

The lateral surface area amounts

$A_L = U \cdot h$
$A_L = 28{,}27 \text{ cm} \cdot 11 \text{ cm}$
$A_L = 310{,}97 \text{ cm}^2$

The total area equals to the sum of both circle areas and the lateral surface area.

$A_{Cyl} = 2 \cdot A_{Cr} + A_L$
$A_{Cyl} = 2 \cdot 63{,}62 \text{ cm}^2 + 310{,}97 \text{ cm}^2$
$A_{Cyl} = 438{,}21 \text{ cm}^2$

The content of the can refers to its volume which is calculated as follows.

$V_{Cyl} = A \cdot h$
$V_{Cyl} = 63{,}62 \text{ cm}^2 \cdot 11 \text{ cm}$
$V_{Cyl} = 699{,}82 \text{ cm}^3$

The can contains almost 700 cm^3, or about 0,7 litre.

A sphere is made of stone and has a diameter of 80 cm. What is the volume of the sphere? The density of the sphere amounts 2800 kg/m³. What is its mass?

A diameter of 80 cm corresponds with a radius of 0,4 m.

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$
$$V = \frac{4}{3} \cdot \pi \cdot 0{,}4^3\ m^3$$
$$V = \frac{4}{3} \cdot \pi \cdot 0{,}064\ m^3$$
$$V \approx 0{,}268\ m^3$$

To calculate the mass the density must be multiplied by the volume.

$M = r \cdot V$
$M = 2800\ kg/m^3 \cdot 0{,}268\ m^3$
$M \approx 750\ kg$

The mass of the sphere is about 750 kg.

A container consists of a cylinder with a diameter of 2 m and a height of 4 m. Both cylinder sides are finalized with a half-spherical ends. What is the total volume of the container? Is it possible to fill this container with 12 t of gasoline, when the density of gasoline amounts 750 kg/m³?

We calculate the cylinder's volume and the volume of both half-spherical ends first. Since two equal half-spherical ends form a complete sphere it is possible to calculate the volume of a complete sphere.

$$V_{Zyl} = A \cdot h$$
$$V_{Zyl} = \frac{1}{4} \cdot \pi \cdot d^2 \cdot h$$
$$V_{Zyl} = \frac{1}{4} \cdot \pi \cdot 2^2\ m^2 \cdot 4\ m$$
$$V_{Zyl} \approx 12{,}57\ m^3$$

$$V_K = \frac{4}{3} \cdot \pi \cdot r^3$$
$$V_K = \frac{4}{3} \cdot \pi \cdot 1^3\ m^3$$
$$V_K \approx 4{,}19\ m^3$$

The container's volume equals to the sum of the cylinder's volume and the volume of the sphere.

$V_{tot} = V_{Cyl} + V_S$
$V_{tot} = 12{,}57\ m^3 + 4.19\ m^3$
$V_{tot} = 16{,}76\ m^3$

The total volume of the container amounts 16,76 m^3.

With a known density it is possible to calculate the volume of 12 t of gasoline.

$M = r \cdot V$
$V = M : r$
$V = 12000\ kg : 750\ kg/m^3$
$V = 16\ m^3$

The gasoline has a volume of 16 m^3 and can be filled in the container which has a volume of 16,76 m^3.

In such calculations the units must be always written during different calculation steps. This assures the using of correct dimensions in calculations.

2 Technical physics

2.1 Physical fundamentals

Exercise 25 Convert the following values.

15 km = 15000 m

75 mm = 0,075 m

2150 mm = 0,00215 km

125 kW = 125000 W

3,7 MW = 3700 kW

675 mA = 0,675 A

12,25 A = 12250 mA

7500000 g = 7,5 t

0,137 g = 137 mg

The decimal point should be shifted correctly!

Introduce the following values with suitable measuring units!

27 800 g = 27,8 kg

0,00012 MW = 120 W

0,002 A = 2 mA

47 000 mm = 47 m

0,125 kg = 125 g

Prefixes introducing multipliers of thousands are always preferred. They can be also represented in form of decimal powers.

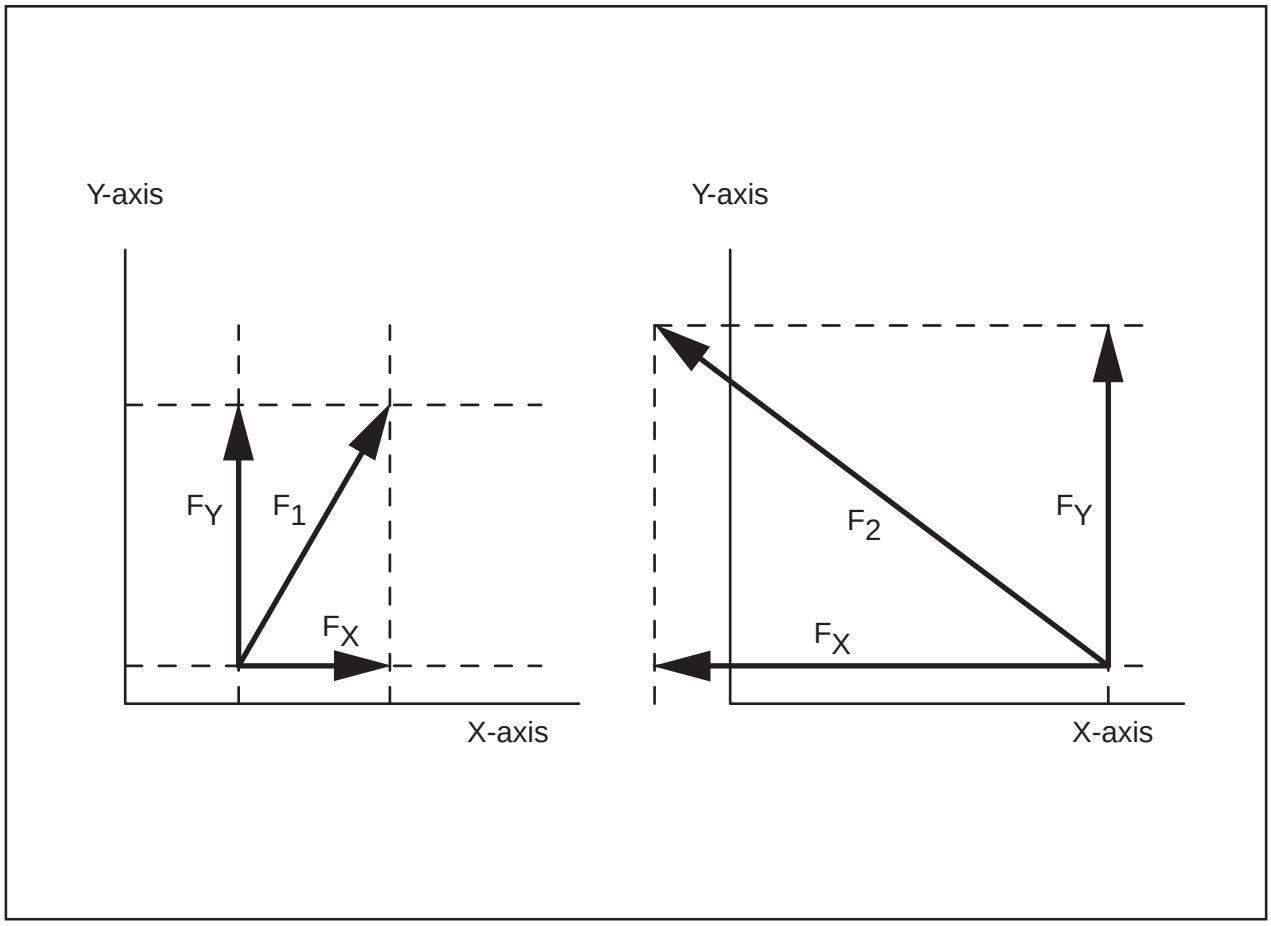
2.2.2 Decomposition of forces

Exercise 26 Determine the partial forces in the X-direction and Y-direction graphically.

Measure the length of force vectors using a ruler. Assume that a length of one millimeter corresponds to a force of 10 newton. What are the values of the forces? The values should be rounded.

F_{1X} = 200N
F_{1Y} = 350N
F_1 = 400N

F_{2X} = 600N
F_{2Y} = 450N
F_2 = 750N

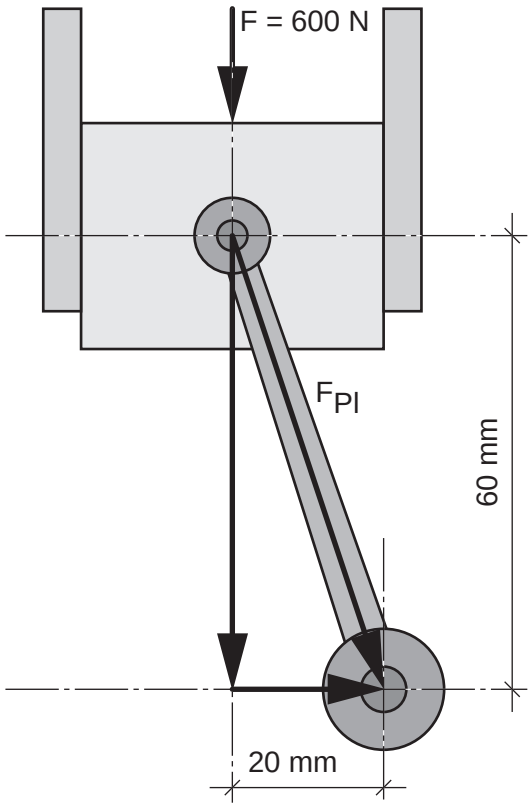


Exercise 27 A force of 600 N acts on a cylinder inside a motor. The force that acts on the drive rod should be graphically plotted. Estimate the value of the force.

The force acts on the cylinder vertically downwards. Because of the sloped position of the drive rod there is an additional sidewards acting force. Both forces act on the drive rod.

Calculate the value of the force that acts at the drive rod.

The value of the force can be calculated by means of theorem of Pythagoras. The resulting force amounts 63,2 N.



2.3 Torque

Exercise 28 The wheels of a motorcycle have a diameter of 50 cm. The tires act on the street with a force of 200 N when speeding up. What is the torque at the wheel's axis required to generate the accelerating force?

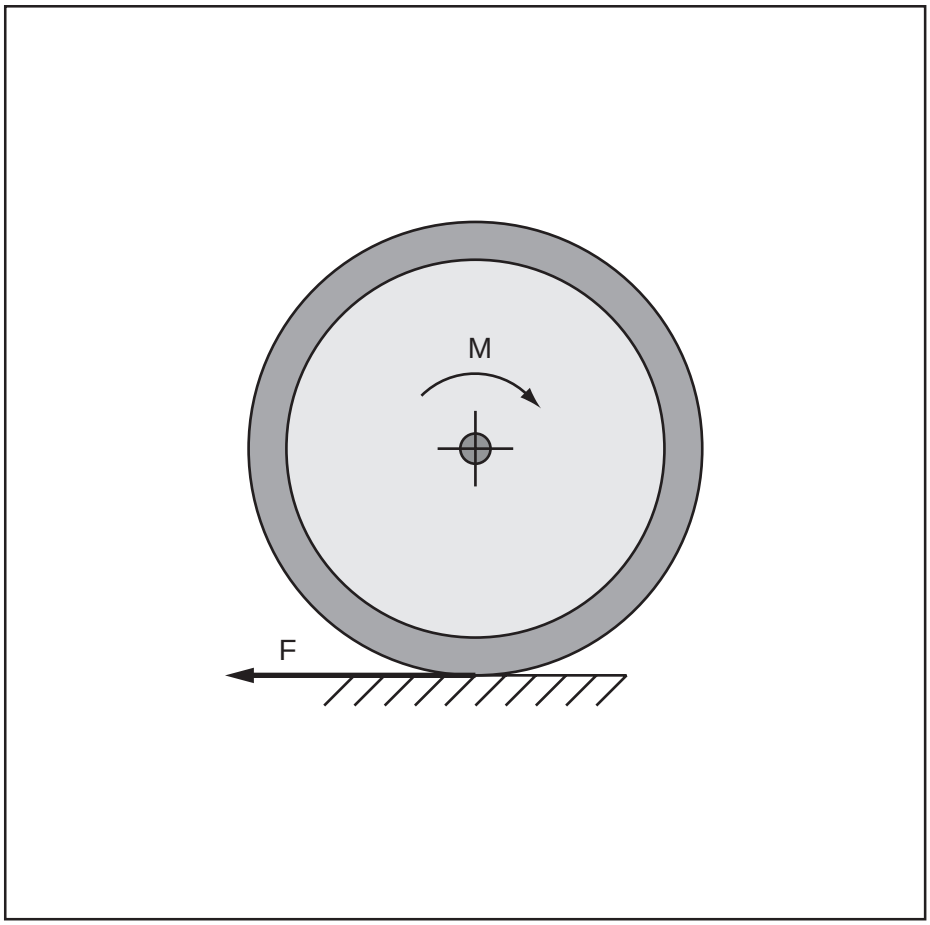
The radius of the wheel amounts 25 cm.

$M = F \cdot l$

$M = 200\ N \cdot 0{,}25\ m$

$M = 50\ Nm$

The wheel should be driven with a torque of 50 Nm.



Exercise 29 A rope drum has a diameter of 20 cm. The driving motor generates a torque of 12 Nm. What is the maximal weight, that can be lifted?

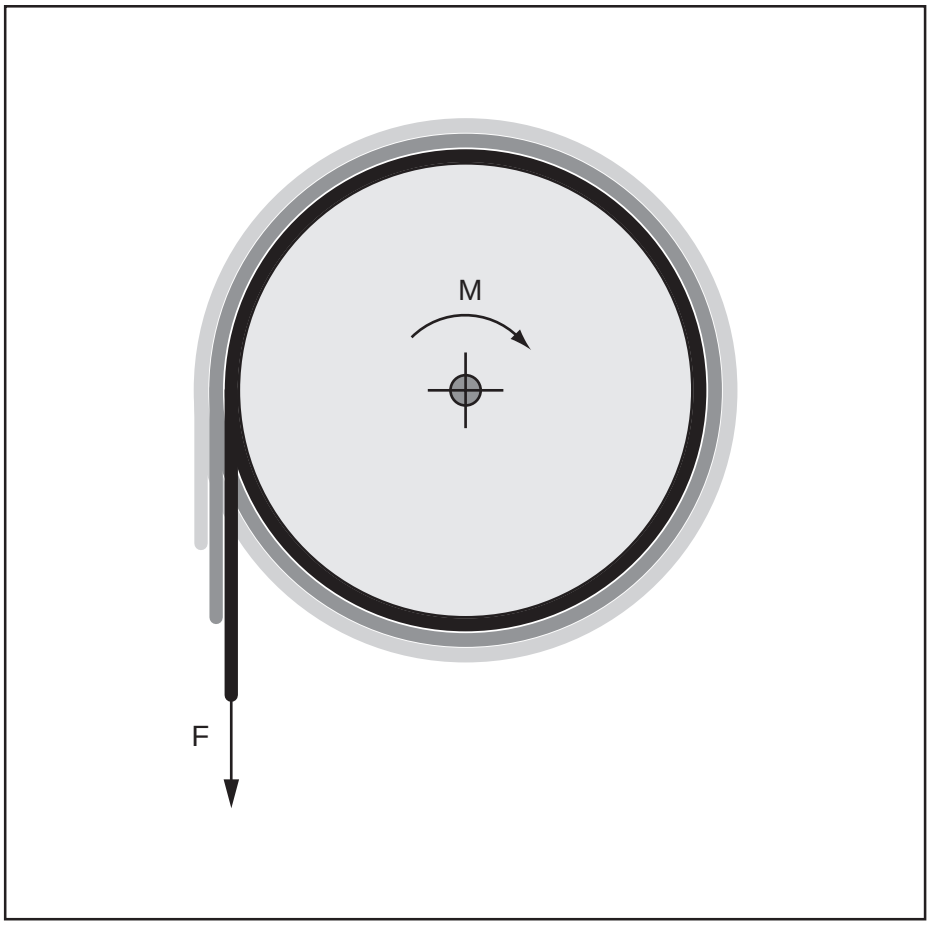
The rope windings are superimposed in several layers on the drum. Each layer increases the drum's radius by one centimeter. With how many layers is the drum still able to carry out a force sufficient to lift a load with a weight of 95 N?

F = M / l
F = 12 Nm / 0,1 m
F = 120 N

The maximal force, that can be carried out amounts 120 N.

F = M / l
l = M / F
l = 12 Nm / 95 N
l = 0,126 m

With one layer the radius amounts 10 cm. With two layers the radius increases by one centimeter to 11 cm, with three layers the radius amounts 12 cm. Hereby, the force is still sufficient to lift the load. With four layers the force will not be sufficient any more.



Exercise 30 Several persons are sitting in different gondolas of a Ferris wheel. At one side of the wheel there are two persons sitting in a gondola at a distance of 5 m from the wheel's central point. In another gondola there are 3 persons. This gondola is located at a distance of 3 m only from the central point.

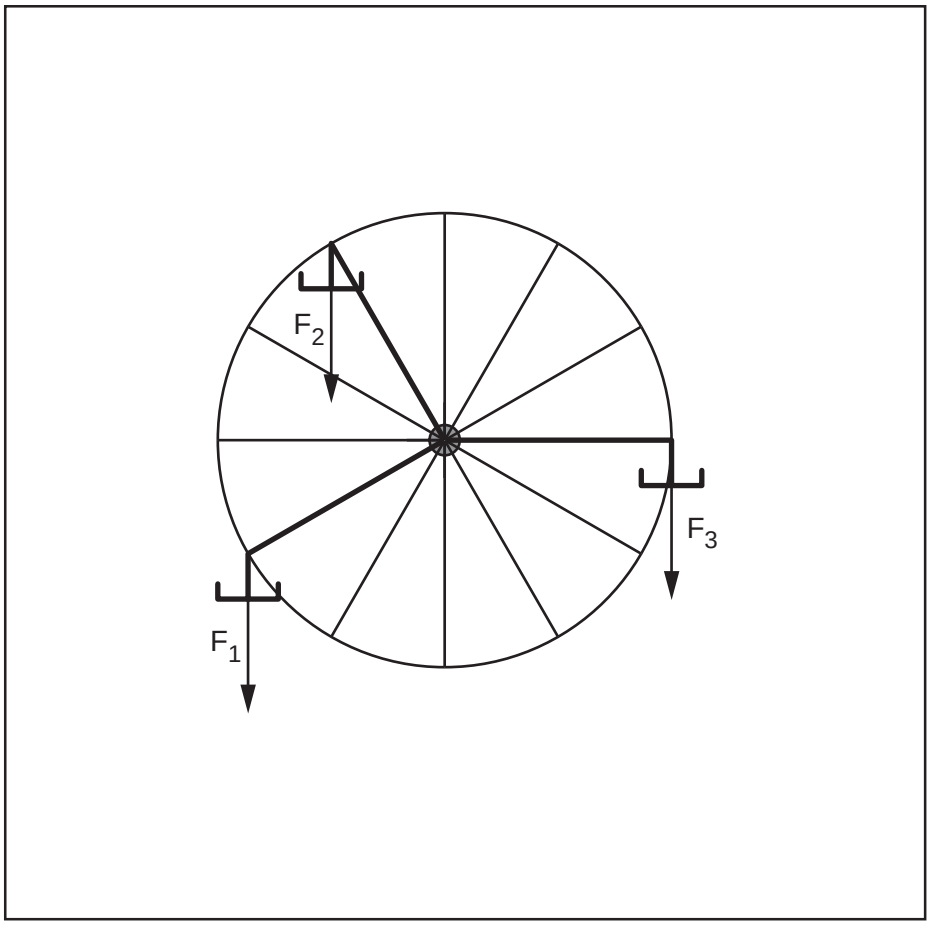
At the opposite side of the wheel there are four persons in a gondola at a distance of 6 m from the central point. Each person acts with a weight equal to 750 N. What is the total torque?

$M_1 = 2 \cdot 750\ N \cdot 5\ m = 7500\ Nm$
$M_2 = 3 \cdot 750\ N \cdot 3\ m = 2250\ Nm$
$M_3 = 4 \cdot 750\ N \cdot 6\ m = 18000\ Nm$

$M_{tot} = M_1 + M_2 - M_3$
$M_{tot} = 7500\ Nm + 2250\ Nm - 18000\ Nm$
$M_{tot} = -3750\ Nm$

The torque generated by the four persons acts in the opposite direction of the other two torques. Therefore, the other two torques must be subtracted from the torque of the four persons.

The total torque of 3750 Nm acts in a direction, that conforms with the downwards moving direction of the four persons.



2.5 Law of the lever

Exercise 31 Three children are sitting on a seesaw. The first child is sitting at a distance of 2,5 m from the rotation point and acts with a weight of 400 N. The second child is sitting at the same side at a distance of 2 m from the rotation point and has a weight of 250 N.

The third child should sit at the other side of the seesaw. His weight amounts 500 N. At which distance should the third child sit in order to make the seesaw balance horizontally?

The first child produces the following torque

$M_1 = F \cdot l$
$M_1 = 400\ N \cdot 2{,}5\ m$
$M_1 = 1000\ Nm$

The torque generated by the second child amounts

$M_2 = F \cdot l$
$M_2 = 250\ N \cdot 2{,}0\ m$
$M_2 = 500\ Nm$

The sum of both torques equals to

$M = M_1 + M_2$
$M = 1000\ Nm + 500\ Nm$
$M = 1500\ Nm$

Both children generate a torque of 1500 Nm. In order to make the seesaw balance horizontally, the third child should generate an equal torque at the opposite side.

$M_3 = F \cdot l$
$l = M_3 / F$
$l = 1500\ Nm / 500\ N$
$l = 3\ m$

The third child should sit at the opposite side at a distance of 3 m from the rotation point in order to make the seesaw balance horizontally.

2.6 Pressure

Exercise 32 A bicycle tire should be pumped up by means of an air pump. The required pressure amounts 0,5 MPa. The air pump has a piston with a diameter of 20 mm. Calculate the force, that should be applied to the piston, in order to pump up the tire.

$A = \pi / 4 \cdot d^2$
$A = 0{,}785 \cdot 20^2\ mm^2$
$A = 314\ mm^2$

The surface area of the piston equals to 314 mm^2.

$p = F / A$
$F = p \cdot A$
$F = 0{,}5\ MPa \cdot 314\ mm^2$
$F = 0{,}5\ N/mm^2 \cdot 314\ mm^2$
$F = 157\ N$

In order to generate a pressure of 0,5 bar, the piston should be pressed with a force of 157 N.

Exercise 33 Pressures of 12 MPa occur for a short time in a combustion motor. The piston has a diameter of 85 mm. What is the force that acts on the piston at the moment of pressure peak?

$A = \pi / 4 \cdot d^2$
$A = 0{,}785 \cdot 85^2\ mm^2$
$A = 5672\ mm^2$

The surface area of the piston amounts 5672 mm^2.

$F = p \cdot A$
$F = 12\ MPa \cdot 5672\ mm^2$
$F = 12\ N/mm^2 \cdot 5672\ mm^2$
$F = 68064\ N \approx 68\ kN$

The force that acts on the piston is about 68 kN.

2.6.2 The transmission of pressure

Exercise 34 A pressure of 60 bar is applied to the piston head side of a hydraulic cylinder with piston rod. In order to make the cylinder run out the hydraulic oil at the piston rod side must leak out of the cylinder. A closed valve prevents the oil from leaking out. The surface area of the piston amounts 19,6 cm^2. At the piston rod side the ring shaped surface area is two times smaller. What is the pressure inside the piston rod chamber? What should be taken into consideration concerning the connecting pipes, which are designed for a maximal pressure of 100 bar?

The force acting on the piston amounts

$F = p \cdot A$
$F = 60\ bar \cdot 19{,}6\ cm^2$
$F = 600\ N/cm^2 \cdot 19{,}6\ cm^2$
$F = 11760\ N$

A force of 11760 N presses the piston. This force generates pressure in the piston rod chamber. The ring shaped surface area is two times smaller than the piston's surface area, and consequently amounts 9,8 cm^2.

$p = F / A$
$p = 11760\ N / 9{,}8\ cm^2$
$p = 1200\ N/cm^2$
$p = 120\ bar$

The pressure generated in the piston rod chamber amounts 120 bar. The blocking valve is connected to the cylinder with pipes designed for maximal pressure of 100 bar. The pipes may break at a higher pressure.

2.8 Friction

Exercise 35 A gripper should catch and lift a cube-shaped workpiece of iron with a mass of 1 kg. The clutches are also made of iron, therefore the friction factor of 0,15 can be used in the calculations.

Besides the force of gravitation an additional acceleration occurs while lifting, which is five times larger than the acceleration of gravity. The acceleration of gravity can be rounded to 10 m/s^2.

What is the force of the clutches required to catch and lift the workpiece?

$F = m \cdot a$

$F = m \cdot 6 \cdot g$

$F = 1\ kg \cdot 60\ m/s^2$

$F = 60\ N$

A force of 60 N acts on the workpiece during the acceleration. This force is distributed equally among the both clutches.

$F_R = \mu_0 \cdot F_N$

$F_N = F_R / \mu_0$

$F_N = 30\ N / 0{,}15$

$F_N = 200\ N$

Each clutch must press the workpiece with a force of 200 N to prevent it from sliding down.

2.9.1 Uniform motion

Exercise 36 The feed motion of a lathe in rapid traverse has a speed of 30 m/min.

What is the speed converted into m/s and in km/h?

What is the time required to cover a length of 250 mm?

v = s / t

v = 30 m / 1 min

v = 30 m / 60 s

v = 0,5 m/s

The feed motion has a speed of 0,5 m/s.

v = 30 m/min

v = 0,03 km / (1 / 60) h

v = 1,8 km/h

Converted to km/h the speed equals to 1,8 km/h.

v = s / t

t = s / v

t = 0,25 m / 0,5 m/s

t = 0,5 s

The length of 250 mm can be covered in 0,5 seconds.

2.9.2 Accelerated motion

Exercise 37 A car runs with a speed of 108 km/h. The driver operates the brakes and the car reaches standstill in 5 seconds. Calculate the deceleration (the negative acceleration) assuming that it is uniform.

What is the time needed to accelerate the car from a speed of 80 km/h to 120 km/h if the acceleration value was equal to the above calculated value, but with a positive sign?

$v = 108 \text{ km/h} = 30 \text{ m/s}$

The speed of 108 km/h conforms to 30 m/s.

$a = \Delta v / \Delta t$

$a = -30 \text{ m/s} / 5 \text{ s}$

$a = -6 \text{ m/s}^2$

The value of the deceleration is 6 m/s^2.

$\Delta v = 120 \text{ km/h} - 80 \text{ km/h}$

$\Delta v = 40 \text{ km/h} = 11{,}11 \text{ m/s}$

The increase of the speed amounts 11,11 m/s.

$a = \Delta v / \Delta t$

$\Delta t = \Delta v / a$

$\Delta t = 11{,}11 \text{ m/s} / 6 \text{ m/s}^2$

$\Delta t = 1{,}85 \text{ s}$

The speed can be increased in 1,85 seconds.

Exercise 38 A parachutist jumps from a plane. Which distance does he cover in 10 seconds, if the air resistance was ignored? What does the minimal jumping altitude amount, taking into consideration that 200 m are needed to open the parachute and to land safely, and that the free fall should last 5 seconds?

The acceleration of gravity in this calculation should be rounded to 10 m/s^2.

$s = 1/2 \cdot a \cdot t^2$

$s = 1/2 \cdot 10\ m/s^2 \cdot 10^2\ s^2$

$s = 1/2 \cdot 10\ m/s^2 \cdot 100\ s^2$

$s = 500\ m$

The parachutist covers a distance of 500 m in 10 seconds.

$s = 1/2 \cdot a \cdot t^2$

$s = 1/2 \cdot 10\ m/s^2 \cdot 5^2\ s^2$

$s = 1/2 \cdot 10\ m/s^2 \cdot 25\ s^2$

$s = 125\ m$

$s_{tot} = 125\ m + 200\ m = 325\ m$

The parachutist covers a distance of 125 m during the free fall, which lasts 5 seconds. This value added to the distance required for safe landing results the minimal jumping altitude of 325 m.

2.9.3 Forces at moving bodies

Exercise 39 The mass of a spaceman with his equipment amounts 120 kg. He is influenced by a fourfold acceleration of gravity at the starting. What is the force, that presses the spaceman to his seat? What is the weight of the spaceman at the moon's surface? The acceleration of gravity of the earth can be rounded to 10 m/s^2. The acceleration of gravity of the moon equals to 1,6 m/s^2.

$a = 4 \cdot g$

$a = 4 \cdot 10\ m/s^2$

$a = 40\ m/s^2$

The fourfold acceleration of gravity at the starting amounts 40 m/s^2.

$F_G = m \cdot a$

$F_G = 120\ kg \cdot 40\ m/s^2$

$F_G = 4800\ N$

A force of 4800 N acts on the spaceman at start.

$F_G = m \cdot a$

$F_G = 120\ kg \cdot 1{,}6\ m/s^2$

$F_G = 192\ N$

At the moon's surface the spaceman is influenced by a force of 192 N only.

2.10 Rotation

Exercise 40 Convert the following values from degree into rad!

10 Grad = 0,175 rad

36 Grad = 0,628 rad

45 Grad = 0,785 rad = $1/4\ \pi$ rad

180 Grad = 3,141 rad = π rad

720 Grad = 12,566 rad = $4\ \pi$ rad

1000 Grad = 17,453 rad

Convert the following values from rad into degree!

π rad = 180 Grad

5 π rad = 900 Grad

7,5 rad = 429,7 Grad

0,25 rad = 14,32 Grad

0,1 rad = 5,73 Grad

2.10.2 Angular acceleration

Exercise 41 A lathe has a spindle with a workpiece, that should be accelerated to a rotational speed of 1200 rpm within 10 seconds. What is the required angular acceleration? Calculate the result in $1/s^2$ and rad/s^2.

$\Delta\omega$ = 1200 1/min = 20 1/s = 125,7 rad/s

The rotational speed after conversion amounts 20 1/s or 125,7 rad/s.

$\alpha = \Delta\omega / \Delta t$

α = 20 1/s / 10 s

$\alpha = 2\ 1/s^2$

The required acceleration amounts 2 $1/s^2$.

$\alpha = \Delta\omega / \Delta t$

α = 125,7 rad/s / 10 s

$\alpha = 12{,}57\ rad/s^2$

The required acceleration amounts 12,57 rad/s^2.

2.11.1 Work

Exercise 42 A cannon bullet has a mass of 5 kg. When fired off, the bullet is accelerated to a speed of 900 km/h.

What is the carried out work? Calculate the value in joule and watt hour.

Which speed does a car with a mass of 1000 kg reach, if an equal work was carried out for the acceleration?

$W = 1/2 \cdot m \cdot v^2$

$W = 1/2 \cdot 5\ kg \cdot 900^2\ km^2/h^2$

$W = 1/2 \cdot 5\ kg \cdot 250^2\ m^2/s^2$

$W = 1/2 \cdot 5\ kg \cdot 62500\ m^2/s^2$

$W = 156{,}25\ kJ = 43{,}4\ Wh$

A work of 156,25 kJ or 43,4 Wh is carried out for the acceleration.

$W = 1/2 \cdot m \cdot v^2$

$v^2 = 2 \cdot W / m$

$v^2 = 2 \cdot 156250\ J / 1000\ kg$

$v^2 = 312{,}5\ m^2/s^2$

$v = 17{,}68\ m/s = 63{,}6\ km/h$

This work can accelerate the car to a speed of 63,6 km/h.

2.11.2 Energy

Exercise 43 A concrete block with a mass of 10 kg is lifted up to 5 m. What is its potential energy at this height?

The block falls down from a 5 m - height. What is its speed at the moment of impact? The following formula should be transposed correspondingly

$s = 1/2\ v^2/a$

Calculate the kinetic energy at the moment of impact. Compare the resulting value with the potential energy.

The value of the acceleration of gravity can be rounded to 10 m/s^2.

$E_{pot} = m \cdot g \cdot h$

$E_{pot} = 10\ kg \cdot 10\ m/s^2 \cdot 5\ m$

$E_{pot} = 500\ J$

At a height of 5 m the block has a potential energy of 500 J.

$s = 1/2\ v^2/a$

$v^2 = 2 \cdot s \cdot a$

$v^2 = 2 \cdot 5\ m \cdot 10\ m/s^2$

$v^2 = 100\ m^2/s^2$

$v = 10\ m/s$

At the moment of impact the speed of the block amounts 10 m/s.

$E_{kin} = 1/2 \cdot m \cdot v^2$

$E_{kin} = 1/2 \cdot 10\ kg \cdot 10^2\ m^2/s^2$

$E_{kin} = 500\ J$

The kinetic energy amounts 500 J at the moment of impact.

The kinetic energy equals to the potential energy required to lift the block.

2.11.4 Power

Exercise 44 An elevator has a mass of 500 kg. It should go up to a height of 30 m within 30 seconds. What is the required power, ignoring the acceleration?

The acceleration of gravity can be rounded to 10 m/s^2.

$W = m \cdot g \cdot h$

$W = 500\ kg \cdot 10\ m/s^2 \cdot 30\ m$

$W = 150\ kJ$

A work of 150 kJ should be carried out to lift the elevator to a height of 30 m.

$P = W / \Delta t$

$P = 150\ kJ / 30\ s$

$P = 5\ kW$

The required power amounts 5 kW.

2.12.4 Heat energy and heat capacity

Exercise 45 A car with a mass of 1000 kg is decelerated from a speed of 90 km/h to standstill. The brake disks and the brake pads transform the kinetic energy into heat. They have a total mass of 10 kg. The specific heat capacity for brake disks and pads, which are made of iron, is c = 460 J/kgK.

What is the temperature increase of the disks and pads in degrees? Calculate the kinetic energy first and use the result for the calculation of heat capacity.

What is the amount of the water that can be heated from 20 °C to 95 °C applying the above calculated energy?

$E_{kin} = 1/2 \cdot m \cdot v^2$

$E_{kin} = 1/2 \cdot 1000\ kg \cdot 25^2\ m^2/s^2$

$E_{kin} = 312{,}5\ kJ$

The kinetic energy amounts 312,5 kJ. This energy is completely converted into heat.

$Q = c \cdot m \cdot \Delta T$

$\Delta T = Q / (c \cdot m)$

$\Delta T = 312{,}5\ kJ / (0{,}46\ kJ/kgK \cdot 10\ kg)$

$\Delta T = 312{,}5\ kJ / (4{,}6\ kJ/K)$

$\Delta T = 67{,}9\ K$

The temperature of the brake disks and pads increases by 67,9 K.

$Q = c \cdot m \cdot \Delta T$

$m = Q / (c \cdot \Delta T)$

$m = 312{,}5\ kJ / (4{,}18\ kJ/kgK \cdot 75\ K)$

$m = 0{,}997\ kg$

The generated amount of heat energy can heat about one kilogram of water.

3 Technical drawing

3.1 The fundamentals of technical drawing

Exercise 46 *What is the main purpose of technical drawings?*

A technical drawing is an important means of communication and information interchange. It may include the full information required for manufacturing and production.

Why is the standardization very important in technics?

The standards make the exchange of information and products securer. The standards are important rules in technics.

What do the abbreviations DIN and ISO mean?

The DIN refers to the German Institute for Standardization (registered association). The ISO indicates the International Organization for Standardization.

How many sheets of the format A4 can be made from a sheet of the format A0?

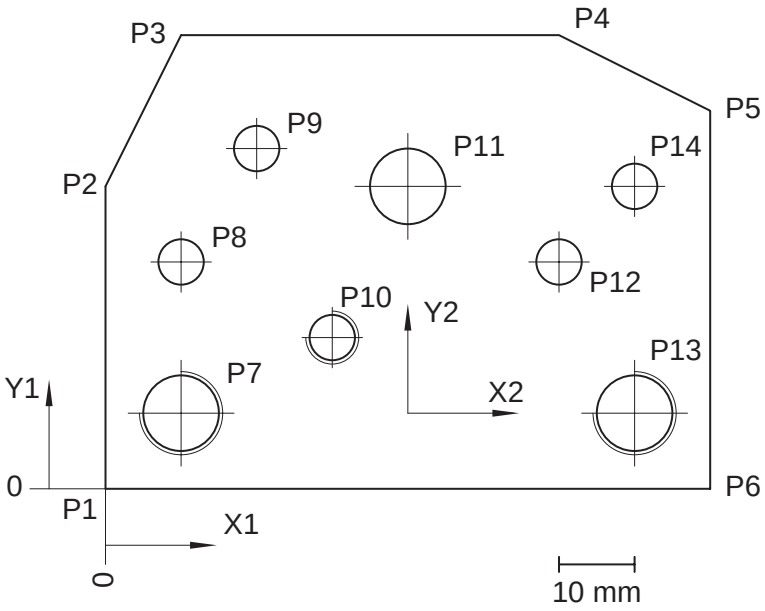
A sheet of the format A0 corresponds to two sheets of the format A1. These can be used to made for sheets of the format A2. Consequently, eight sheets of the format A3 can be made, and then 16 sheets of the format A4.

The mass of the standard commercial reprographic paper amounts 80 g/m^2. What is the mass of a single sheet?

A sheet of the format A0 has an area of one square meter. Consequently, this sheet has a mass of 80 g. Since a sheet of the format A4 corresponds to a sixteenth part of the format A0 its mass equals to 80 g : 16 = 5 g. Therefore, a sheet of the format A4 has a mass of five grams.

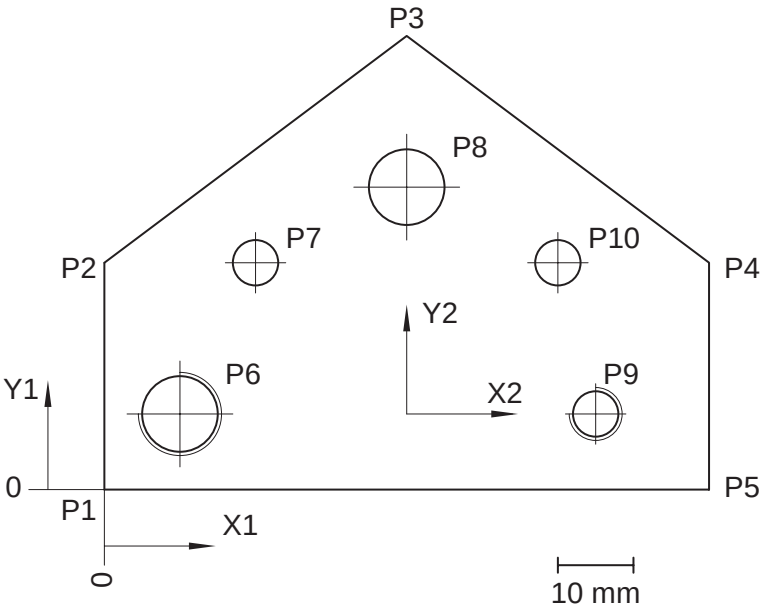
3.6.2 Numerically controlled machines

Exercise 47 Create a coordinate table according to the following drawing. All vertex points should be indicated with the coordinate system 1. The drill holes and screw threads should be determined with the coordinate system 2.



	Coordinate table (dimensions in mm)			
Zero point of coordinates	Pos. Nr.	X	Y	Drill hole Screw thread
1	P1	0	0	
1	P2	0	40	
1	P3	10	60	
1	P4	60	60	
1	P5	80	50	
1	P6	80	0	
2	P7	-30	0	M12
2	P8	-30	20	6
2	P9	-20	35	6
2	P10	-10	10	M8
2	P11	0	30	10
2	P12	20	20	6
2	P13	30	30	M12
2	P14	30	0	6

Exercise 48 Create a drawing according to the following coordinate table. All vertex points are indicated with the coordinate system 1. The drill holes and screw threads are determined with the coordinate system 2.



	Coordinate table (dimensions in mm)			
Zero point of coordinates	Pos. Nr.	X	Y	Drill hole Screw thread
1	P1	0	0	
1	P2	0	30	
1	P3	40	60	
1	P4	80	30	
1	P5	80	0	
2	P6	-30	0	M12
2	P7	-20	20	6
2	P8	0	30	10
2	P9	20	20	M8
2	P10	25	0	6

Mechatronics

Module 2: Social behaviour,
(Part 1) Cross Cultural Training

Trainerguideline
(concept)

Christian Stöhr

Christian Stöhr Consulting,
Germany

EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

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Bildung und Kultur

Leonardo da Vinci

Teach ware concept working out and proving project partners

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- Corvinus University Budapest, Institute for Information Technologies, Hungary
- Stockholm University , Institute for Sociology, Sweden
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- Christian Stöhr Unternehmensberatung, Germany
- Neugebauer and Partner OHG Dresden, Germany
- Korff Isomatic sp.z.o.o. Wroclaw, Poland
- Euroregional Chamber of Industry and Commerce Jelenia Gora, Poland
- Dunaferr Metallwerke Dunajvaros, Hungary
- Knorr-Bremse Kft. Kecskemet, Hungary
- National Institute for Vocational Training Budapest, Hungary

Teach ware concept:

Manual, exercises and solutions books for

- Module 1: Fundamentals
- Module 2: Cross-cultural Competencies, Projectmanagement
- Module 3: Fluidics
- Module 4: Electrical Drives and Controls
- Module 5: Mechatronic Components
- Module 6: Mechatronic Systems and Functions
- Module 7: Commissioning, Safety, Teleservice
- Module 8: Remote Maintenance, Diagnosis

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Trainerguidline module Social Behaviour and Intercultural Competence

Seminar overview

Seminar description / classification of industrial sector:

- Mechatronics

Learning targets:

Participants study fundamental aspects to the following themes:

- Cultural awareness
- Iceberg Model of culture
- Stereotypes and cultural generalizations
- Hofstede´s cultural dimensions
- Perception of time and priorities
- Source of status
- Communication styles
- Strategies for working abroad

Requirements:

- none

Group of participants:

- Skilled personnel from the fields of designing, assembling, service, maintenance.

Duration of the seminar in minutes:

- 1260 minutes

Trainer equipment

- Trainer book M2 SI
- Additional materials as outlined in the exercises

Miscellaneous material for trainer:

- Video projector / overhead projector
- Whitebord / Blackboard

Seminar equipment for participants per 1 person:

- Text book M2 SI
- Exercise book M2 SI

Miscellaneous material for participants per 1 person:

- Pad, pen

General notes to the module Social Behaviour and Intercultural Competence

Aims of the module Social Behaviour and Intercultural Competence

This seminar will introduce key features and dimensions of culture for Mechatronicans.

The aim of the Cross Cultural Training is to increase the intercultural and social competence of the participants. Therefore the seminar is entitled “Social Behaviour and Intercultural Competence“. This aim is combined with a number of essential and realistic training aims, including:

- to introduce and boost interest in the topic
- Understanding that it is necassary and useful to increase one´s own competence and communication skills to facilitate professional contact with people from other cultures
- To increase awareness of possible culturally-based differences and the impact of these differences in work related interaction situations
- To provide both overall strategies and specific tools and for adjusting to a new culture

The approach of the seminar is to bypass superficial cultural differences and provide a framework through which a wide range of culturally-based understandings can be identified and put in perspective. Our purpose is not, therefore, to present all views of all cultures about all the different aspects of culture. Nor is it to fundamentally change the participants´ ways, or to remove all their prejudices and their cultural peculiarities. Such an approach would not be especially effective and might also lead to a disorientation of the participants.

The aim should also not be seen as the teaching of right and wrong behaviour, as this does not help to reduce misinterpretations and misunderstandings as long the patterns of thinking behind the acts of behaviour are unknown.

About this book and the seminar

The trainer book is intended to support the trainer in the conduct of the seminar with the help of suggested lessons and exercises. It contains a suggested seminar structure, with exercises and solutions, didactic notes as well as additional information beyond the content of the text book.

The book is connected to the text and exercise book and refers to certain contents from these materials. In order to maintain the quality of the seminar, all three books are needed.

Trainers should nevertheless already have intercultural knowledge as well as pedagogical experience.

The exercises are adapted to the needs and educational standards of technicans. The seminar contains a variety of exercises, including simulations and role-playing games. These pedagogic instruments can be quite demanding so it is advisable that the trainer should have some experience with such exercises.

The basic format for the trainer notes is consistent for all of the chapters, with a few items - session objectives, time needed and delivery – specific to each session. In addition, some sessions contain pedagogical notes and materials needed. A guide to the different formats that explains what the trainer has to expect under the certain points is presented below:

Session Objectives

This section briefly outlines what the trainer should seek to accomplish in this session.

Estimated time

This section indicates approximately how long this session can be expected to take.

Materials Needed

Performance of some exercises may require materials in addition to the exercise books or copies of handouts from this book. Those materials are listed under this point.

Delivery

This describes the intended structure of the session. It inlcudes exercises, solutions and suggestions what the trainer should say or which questions should be discussed.

Exercise

Exercises within the point of delivery are marked separately in order to improve the orientation for the trainer. Exercises that refer to the exercise book have a number that corresponds to those found in the exercise book. There are also additional possible exercises that are not included in the exercise book.

The suggested structure for the seminars and exercises are intended to be flexible and can be adapted to the special need of a certain seminar. In relation to the theme of a session, a trainer might also add additional supplemental exercises.

1 Introduction Intercultural training

Session objectives

To let the participants introduce themselves.

To introduce the general aim of the seminar and help participants get a feel for what cross cultural training is about, what intercultural competence is and activate already existing knowledge of the participants.

To present an overview of seminar content and take up any necessary organisational matters.

Estimated time

110 min

Delivery

Let the participants briefly introduce themselves. Each should say a few words about his/her background.

Do then the welcome exercise as a warm up action.

Exercise

Welcome exercise:

Didactic note

The aim is to generate a discussion about behaviours in different cultures.

Materials needed

Instruction cards (page 7)

Delivery (welcome exercise)
Make a copy of the instruction cards and cut them out.

Explain the participants the situation that everybody has just arrived at the airport in a foreign country and is asked to find his/her host. As this country is very multicultural, the salutatory rituals vary quite a bit.

Divide the seminar group into guests and hosts depending on the size of the seminar group. A host can also have several guests. Everybody gets a card with instructions and the order to reveal onself without using words.

Pedagogical note

If the members of the group are still very unfamilar with each other you can remove the cards with those salutatory rituals, where the participants have to touch each other.

After the game, discuss with the group how they experienced this exercise, e.g. using the following questions:

- Which salutatory rituals were comfortable, which were not?
- Why were some rituals comfortable and others not?
- What feelings did you have while experiencing the unfamiliar rituals?
- What spontaneaus reaction did it provoke in you?

- Did any of the ceremonies which you did not understand as salutatory seem hostile or overly familiar?

- What strategy did you use to go through the group without taking too much damage?

- What can one do if there are different customs?

- Who has priority? Which rules should apply?

Instruction cards for Welcome exercise

You belong to the Copper-Eskimo **You greet each other through** Gentle push against head and shoulder	**You belong to the** Eipa from New Guinea **You greet each other through** Silence
You belong to the Dani from New Guinea **You greet each other through** Hugging several minutes and tears of emotion	**You belong to the** Loango **You greet each other through** Applause
You belong to the Assyrians **You greet each other through** Give some clothes	**You belong to the** Germans **You greet each other through** Shake hands
You belong to the Indians **You greet each other through** Laying your palms together, hold them in front of the body and bowing slightly	**You belong to the** Latin Americans **You greet each other through** Put the head on the right shoulder of the partner, give 3 firm pats on the back, then do the same with the head on the other shoulder
You belong to the Mongolians **You greet each other through** Sniffing one another at the cheeks and touching and rubbing with the nose	**You belong to the** Turks **You greet each other through** The younger kisses the hand of the older and leads it to his / her own forehead; the older thanks verbally
You belong to the Dutch **You greet each other through** Hugging and kissing the cheek 3 times	**You belong to the** New Zealander **You greet each other through** Take the hand of the other with both hands and shake it vigorously

When the exercise is completed present overview information about the seminar, its organisational and formal aspects, including:

- Presentation of the trainer and his/her experience in intercultural training

- Remarks to the seminar structure, breaks, duration etc.

Pedagogical note In order to strengthen the attention and active engagement of the participants you can also emphasize the importance of personal experience early on, and thus emphasize that it is active participation in the exercises which makes learning effective. You should also stress in this regard that participants should indicate if an exercise feels too demanding or stressful and that he or she can ask to stop at any time.

After the discussion introduce the aims and contents of intercultural training and competence using the definitions in the textbook (page 4). Then start as with the Cultural-Awareness-Test.

Exercise **Exercise 1 Cultural-Awareness-Test Part A:**

Have each open their exercise books on page 1 and answer the questions quickly and as best they can.

Done this show the correct answers.

Answers for exercise 1:

1. false 2. false 3. true 4. C 5. C 6. false 7. true 8. true 9. false 10. true 11. false 12. true 13. true 14.false

After the exercise 1 t start directly with exercise 2:

Exercise **Exercise 2 Cultural-Awareness-Test Part B:**

Build 2-4 groups with 5-8 participants each, depending on the size of the seminar. Let each group develop its own Cultural Awarness Test (exercise book page 2) and exchange it then with another group. Each group should respond to its partner group´s test.

Pedagogical note The second excersise in groups offers an easy way to introduce group-oriented work, which will be important throughout seminar. It also engages the existing knowledge of the participants and helps participants to realize and understand that many of their normal customs and self-evident acts of behaviour as culturally based.

Discuss the results.

Pedagogical note Discussion of the results should show that there are indeed cultural standards. This basic insight is the basis for the further introductory discussion about ”What is culture?“.

The aim of the two cultural awareness exercises is to help engage the participants in thinking about questions of culture and get a basic impression of the theme. Is not to answer as many questions right as possible.

2 What is culture?

Session objectives To help participants to form a definition of culture.

To give the participants an idea of the wide variety of elements included in the concept of culture.

To illustrate that culture has visible and invisible aspects and to show the relationship between them.

To establish the notion that people from different cultures may behave differently from each other, especially where the values and beliefs that guide their behavior are different.

To demonstrate that dealing with these differences can be a demanding task, but is doable.

Estimated time 150 min

Delivery

Ask and discuss the question with the seminar participants:
“What is culture?“

Collect the participant answers on a whiteboard.

Discuss the definitions of culture offered in the textbook on page 5, along with the five elements of culture that are found on the pages immediately following in the textbook. Ask for examples. (One example for every element is given in the text book.)

Pedagogical note The theroretical portions of these discussions (including the subsequent portions covering Hofstede´s Iceberg model) have several functions. In addition to the transfer of knowledge it demonstrates that cross-cultural training is based on well-developed scientific research outcomes anchored in scientific disciplines. Further, it illustrates to the participants that the trainer has a high degree of theoretical knowledge. This is important given that in contrast to other modules, the training consists of several advanced pedagocial methods such as role-playing games and group exercises. This helps avoid a situation in which the participants take it too easy in the seminar do not engage themselves adequately.

Conduct the Iceberg Model exercise.

Exercise

Exercise 3 Iceberg Model:

In the exercise book there is a list of cultural aspects which the participants should order in the iceberg diagram in the appropriate position above or below the waterline. They can do this in their exercise book on page 4. the correct answers can be provided after 15-20 minutes.

Answers for exercise 3:

Cultural Aspects on the Surface:

- Music
- Literature
- Eating habits
- Religious rituals
- Facial expressions
- Styles of dress
- Holiday customs
- Paintings
- Gestures
- Food

Cultural Aspects beneath the Surface:

- Importance of time
- Concept of beauty
- Nature of friendship
- Concept of self
- Understanding of the natural world
- Concept of leadership
- Notions of modesty
- Work ethic
- Child raising beliefs
- General world view
- Values
- Concept of fairness
- Religious beliefs
- Concept of personal space
- Rules of social etiquette
- Negotiation style
- Adaptability to change
- Value of relationships

Pedagogical note

As an alternative delivery this can be done as a group exercise. To do so, prepare an empty model of the iceberg together with paper strips with each of the different aspects. Then you can give each participant one strip which he/she should assign and provide the rationale for the choice.

Explain the Iceberg-Model of Hofstede as outlined in the textbook on page 9.

Play then the Barnga Game.

Exercise **Barnga - A game about inter-cultural awareness:**

Pedagogical note In this section, participants will play the game Barnga, the rules can be found below. This is one of the most important exercises in the entire seminar. It deals with a fundamental concept in intercultural communications and touches on one of the most common issues with which workers struggle. The concept is the relationship between a person´s behavior, the things a person does, and his or her underlying beliefs and assumptions. The exercise demonstrates that people behave the way they do because of the things they believe in. If the participants can understand this essential relationship between ideas and behavior, then they can begin to accept that people who work from a different belief system will, of course, behave very differently. But that person's behavior will make sense to that person, it also carries its own internal logic. It will be as logical to a person with a different culture as the participant´s behavior will be to him or her.

Pedagogical note In Barnga, participants experience the shock of realizing that despite many similarities, people of differing cultures may perceive things differently and may play by different rules. The participants learn that they must understand and reconcile these differences in order to function effectively in a cross-cultural group.

Materials needed One Cardset (A-10, no face cards) for every table
A copy of rules for every table
Popsicle sticks (or similar sticks)

Delivery (Barnga game)

Pedagogical note The participants play a simple card game in small groups, where conflicts begin to occur as participants move from group to group. This simulates real cross-cultural encounters, where people initially believe they share the same understanding of the basic rules. In discovering that the rules are different, players undergo a mini culture shock similar to actual experience when entering a different culture. They then must struggle to understand and reconcile these differences to play the game effectively in their "cross-cultural" groups. Difficulties are magnified by the fact that players may not speak to each other but can communicate only through gestures or pictures. Participants are not forewarned that each is playing by different rules; in struggling to understand why other players don't seem to be playing correctly, they gain insight into the dynamics of cross-cultural encounters

Before starting the game, make sure that you are familar with all rules that apply. Introduce the game emphasing that although it might seem as a simple card game there is a deeper sense within this exercise. If the group is not experienced with game situations in a seminar, the introductory stage is of especially relevant.

General game Set-up:

Set up (approximately) 6 tables (about 4 people per table, depending on the number of people participating).

On each table there should be a copy of the rules for that table – one copy per player plus a deck of cards (use only A-10, no face cards).

To start, let the participants play a few rounds with the rules and with talking allowed. Next, EVERYTHING is removed from the playing tables. Play continues with everyone at his own table. From this point, further talking is prohibited.

Winners will receive one popsicle stick (see below for how to win).

After allowing a few rounds without talking at the home table, participants must switch tables. The person who won the most tricks moves clockwise to the next table, the person who loses the most tricks moves counter-clockwise to the next table.

What the players do not yet know is that each table has learned a different set of rules (see below).

The rules of the card games:

Depending on the number of players, rule sheets can be altered or discarded for the number of tables being used. Some samples of rules are as follows:

Table 1: Ace high, no trump
Table 2: Ace low, diamonds trump
Table 3: Ace low, clubs trump
Table 4: Ace high, hearts trump
Table 5: Ace high, spades trump
Table 6: Ace low, no trump

In all cases, other cards will be worth face value (10 high, 2 low)

The rules shared by each table:

1. Players are dealt 5 cards each.

2. Whoever wins the most tricks will move clockwise to the next table.

3. Whoever loses the most tricks will move counter clockwise to the next table.

4. Everyone else stays at the same table.

5. Ties are resolved by the paper rock scissors game.

6. Each round will be about 5 minutes long and each round consistof any number of games that the time allows.

7. After the initial round, players will not be allowed to see the rules or speak to each other. Gestures and pictures are allowed, but players are not allowed to use words.

8. The game “winner” will be the person who has won the most tricks in total. (Of course, once game play starts, winning will likely take a back seat to trying to figure out what everyone else is doing, as they are playing by different rules.)

9. Players can keep track of scores with popsicle sticks (one stick per trick won).

10. The dealer can be anyone at the table, the person who plays first will be to the right of the dealer.

11. The first player for each trick may play ANY suit. All other players must follow suit (play a card of the same suit). For each round, each player plays one card.

12. If a player does not have that suit, a card of any suit must be played.

13. The hand is won by the person with the highest card of the original suit (players will begin to become confused when some players believe their card is trump, and others disagree or contradict this).

After playing a number of rounds either use a set time limit, or allow the number of rotations according to the number of tables in play (6 rounds for 6 tables). After that, the particpants can return to their original seats or stay at the last position. Participants should be made aware that they were playing by different rules, and the following questions should be discussed:

If you could describe the game in one word, what would it be?
What did you expect at the beginning of the game?
When did you realize that something was wrong?
How did you deal with it?
How did not being able to speak contribute to what you were feeling?

Pedagogical note

After this dicussion, the participants should be aware of that cultural differences can are a problem for effective communication. So you can explain again, that there is a need to consider these differences and that the seminar will help the participants to access these problems.

Then you can start with explaining the fundamentals of culture.

3 Fundamentals of Culture

Session objectives To distuinguish stereoptyping from cultural generalizations.

To introduce the the puprose and limitations of modelling culture.

To introduce the 5 dimensions of Hofstede´s cultural model.

To have Participants consider how people from countries with different scores in each dimension might view each other and which problems in intercultural interaction processes might occur.

Estimated time 475 min

Delivery

3.1 Stereotyping and cultural generalizations

Do the excercise that covers stereotyping.

Exercise **Exercise 4 European stereotypes:**

Let the participants open the exercise book on page 5, where they will find several statements. The task is to complete the sentences with European nationalities, which fits best in this context. Ask the participants to use the same nationalities in both paragraphs.

Suggested answers:

Heaven is where :

The police are British.
The cooks are French.
The mechanics are German.
The lovers are Italien.
And it's all organised by the Swiss.

Hell is where :

The police are German.
The cooks are British.
The mechanics are Frensh.
The lovers are Swiss.
And it's all organised by the Italiens.

Note that there might be other appropriate solutions as well.

Explain then the concepts of stereotyping in contrast to generalizing as outlined in the textbook on page 10.

Emphazise that although this seminar will introduce cultural generalizations in order to access another culture, they must not be misinterpreted and misunderstood as stereotypes.

3.2 Generalizing culture - Geert Hofstede´s cultural dimensions

Explain that culture is a very complex concept and that one needs simpler approaches to address it. Show that there a several of such approaches and that each of them emphasizes certain points while leaving out others.

Do the exercise 5

Exercise

Exercise 5 Hofstede´s cultural dimensions questionnaire:

Have the participants open the exercise book on page 6 and complete the questionnaire. State that the questionnaire will be evaluated at a later time.

Pedagogical note

It is the Values Survey Module 1994, an original 26-item questionnaire developed for comparing culturally determined values of people from two or more countries or regions (the 6 demographic question are not inlcuded in this exercise). The 20 content questions allow index scores to be calculated on five dimensions of national value systems as components of national cultures: Power Distance, Individualism, Masculinity, Uncertainty Avoidance, and Long-term Orientation.

Pedagogical note

The purpose of this exercise is to offer the participants an understanding of how Hofstede´s dimensions, which will be explained in very detail in the following sessions, are developed and what they are based on.

Important

Note, that at this point the participants shall only complete the questionnaire, the calculation of the scores will be performed after all dimensions are introduced. The formulas for the index calculation can therefore be found on page 26 of this book.

Briefly present the five dimensions of cultural differences as developed by Hofstede (textbook on page 11ff.):

- Individualism
- Power-distance
- Uncertainty avoidance
- Masculinity
- Long-term supplying

Explain that the first four dimensions will be examined more deeply subsequent lectures, the fifth will be left out as this dimension was not fully developed and is less relevant in a European context.

The concept goes again back to Hofstede´s famous analysis of 56 countries. Each of this country gets a score in each dimension, meaning the degree of this special dimension.

Pedagogical note As the target group of this seminar is non-academic technicans, this kind of modeeling will help the participants to access the “soft“ theme of culture. After explaining these dimensions with a few examples (as this is just meant as a introduction) you can use the complete scale offered in the textbook on page 20 in order to show and explain differences for a few countries.

Pedagogical note This scale is already a practical tool, which participants can use to get familar with a different culture where they will work. Thus it also shows the practical worth of this seminar and ensures the participant´s attention. In case you would like more information about this approach you can find some additional information here:

Background information for Hostedes cultural dimensions

Geert Hofstede´s idea about culture is based on one of the largest empirical studies ever done on cultural differences. In the 1970s, he was asked by IBM (already then a very international company) to advise them on the fact that in spite of all attempts by IBM to establish worldwide common procedures and standards, there were still vast differences in the way the plants were running, e.g. in Brazil and Japan. Hofstede´s initial research focused the differences in how IBM was running.

In several stages, including in-depth interviews and questionnaires sent out to all employees of IBM worldwide, he tried to put his finger on the differences that existed in the various plants. Geert Hofstede´s Value Survey Module was designed for measuring culture-determined differences in a survey between matched samples of respondents from different countries and regions. It consists of 20 content questions and 6 demographic questions.

Since the educational background of IBM´s employees was roughly the same everywhere and since the structure of the organisation, the rules and the procedures were also the same, he worked from the assumption that systematic differences found between the different locations had to be based on the culture of the employees in a particular plant and by extrapolation, largely on the culture of the host country.

As outlined earlier describes culture as ”the collective programming of the mind which distinguishes the members of the human group from one another“.

After several rounds of research, he reduced the differences in culture to four basic dimensions. All other differences, he argued, could be traced back to one or more of these four basic dimensions of culture.

The first four dimensions Hofstede identified were high/low power distance, individualism/collectivism, masculinity/femininity and high/low uncertainty avoidance. After additional research, he added a dimension dealing with time orientation.

Hofstede´s model has been praised for its empirical basis. Hardly any other study or theory of culture can offer similar quantitative support. On the other hand, the model gives no explanation why there should be only five dimensions - or why only these particular dimensions constitute the basic components of culture. Furthermore, the model implies culture to be static rather than dynamic, why or how cultures develop cannot be explained within the model. In addition, Hofstede has been criticised for focusing only on culture as a trait at the national level, and having no eye for the cultural diversity that prevails within most modern societies, for sub-cultures, mixed cultures, and individual development.

The description of the dimensions, at times carries with it the danger of implicitly valuing some cultures as being ”better“ than others. Still, for many people, the model´s five dimensions seem intuitively very relevant to the make-up of societies and useful as well as a frame of reference when trying to analyse the different contexts people live in (e.g. working “culture“). In addition, the participants are motviated to ask to what extent does the model offer more insights - and to what extent do people just create more stereotypes?

Introduce the first of the five dimensions of cultural differences as developed by Hofstede (textbook on page 11ff.):

3.2.1 Individualism index (IDV)

Conduct the exercise Individualist and collectivist values.

Exercise **Exercise 6 Individualist and collectivist values and behaviours:**

Let the participants open the exercise book on page 8. There they will find statements about different values and behaviours. For each statement, the participants should indicate whether they consider it to be a more individualistic or collectivistic value. In addition, each participant should indicate whether they tend to agree or disagree.

As a group, you should then take up each statement and discuss whether and why it should be considered individualistic or collectivistic.

Discuss the agreements and disagreements either in groups of 3-5 participants or in the seminar. The participants should find out whether they tend to give individualistic or collectivistic answers.

Answers (exercise 6):

The following values tend to be more characteristic of people with a individualist world view:

1, 2, 3, 4, 7, 8, 9, 10, 12, 13, 15, 16, 17, 19, 21, 22, 23, 24, 27, 29, 34, 38, 39

The following values tend to be more characteristic of people with a collectivist world view:

5, 6, 11, 14, 18, 20, 25, 26, 28, 30, 31, 32, 33, 35, 36, 37, 40

After the exercise you can also lead a short discussion of the concepts, using the following questions:

- What might individualists think of collectivists? How would collectivists come across to individualists?
- What would collectivists think of individualists? How would individualists come across to collectivists?
- What examples of individualist or collectivist behaviors have participants observed in their everyday life?
- How might individualist or collectivist differences affect work in an other country?

Play the first role game.

Exercise **Roleplay - Indivdualist and collectivist behaviour:**

Game objectives To experience the feeling of beeing confronted with collectivist and individualist values in an practice oriendted work scenario.

To offer an introduction into playing role games.

Materials needed Copies of the Trainee handouts (page 20 f.)

Delivery

Copy the two handouts and then cut the copies in half for distribution to the two partners in each of the two role plays.

If possible, distribute the roles to the two partners a day or so before the actual session, so they can practice what they are going to say.

Make sure that each partner gets to do one role play as the role 1 and the second role play as role 2. Partners should not be allowed to read each other´s role, only the ones they are given by you.

Tell the participants to read the roles and prepare what they are going to say when the time comes. They should try to represent the individualist or collectivist point of view as much as they can, but they don´t have to feel completely boxed in in that regard.

They also do not necessarily have to come to a resolution of the problem.

In addition, tell them they will be doing the role plays one-on-one, with each other and not in front of the class

When starting the exercise, have each pair do the first role play first. Allow from 5 to 10 minutes and then terminate the playing.

Lead a discussion by asking how things went and have various pairs relate how the play unfolded. You may find the following questions helpful:

- Who got his or her way in the role play?
- Why did that person prevail?
- Was it hard playing the host-country role?
- How did you feel as this was unfolding?
- What useful lessons did you learn from this experience?

Now have the participants do the second role play, changing parts.

Follow this with a second discussion, using the questions as above, with one additional question:

- Now that you have played both roles, which was more difficult and challenging to you? Why?

Pedagogical note Some partipants may initialy feel uncomfortable doing role plays. You should hand out the roles ahead of time to help minimize such discomfort. You can also emphasize that they will not be doing these in public, that is, in front of the whole group, but only with their partner.

Role 1: The Mechatronican from the UK

You are Jon Smith, a British mechatronican who was sent to Brazil to train the workers in an engineering supply company. Today was the day of an important exam which you gave to your trainees.

During the course of the exam, you noticed one participant whispering to another sitting nearby. This happened repeatedly and you were able to establish beyond any doubt that the one participant, Alex, was giving answers to the other.

You had warned your particpants about this before and now you have taken the action you said you would: you confiscated the papers of both participants, sent them out of the seminar room, and will not let them pass. It is now the end of the seminar and Carlos Fernandes has come to see you.

Role 2: The worker Carlos Fernandes

You are Carlos Fernandes, a Brazilian worker in an engineering company who takes part in a seminar given by a Britsh mechatronican, Jon Smith. During an important exam today, you were helping your friend, when the British suddenly took your exams away from both of you and sent you out of the seminar room, explaining that you would both fail this exam. This means you will probably get in trouble with your department head since the qualification is needed to remain a supplier for the big British company.

You were helping your friend because he is weak in this field and would probably not have passed this exam without your help. If he didn´t pass he would be very embarrassed to tell his collegues. The two of you, who are best friends, have always helped each other like this and in your culture you consider it selfish and shameful to withhold information or any kind of help from a friend if you are able to offer that help.

You think Jon Smith has been very unfair to treat this situation in such a severe manner and you have come back after the semiar to discuss the matter and ask for a more favorable resolution. Your future livelihood may be at stake here and even if it isn´t, you believe you have been penalized for what is only proper behavior in your culture. If the the British had wanted to guard against cheating, then he should have done what all teachers do: put questions on the test that no one has studied or can answer.

Role 1: The German Mechatronican

You are Thomas Richter and assigned to a Bulgarian engineering company where you work as an assistant to the department manager. The comany is run by a board of overseers who meet once a month to discuss policies and approve major expenses. You have thought ever since you arrived that the company needed a second press to handle the increasingly number of forming tasks. You have contacted a funding organization in the capital that is willing to donate half the cost of a press to the copmany - provided the board agrees to pay the other half.

You know that two of the senior, longest-serving board members are against spending money on a press. “We´ve gotten by very well with one press.“ they say, and they feel that the workers can do the rest of the work manually. You also know that the rest of the board - the six other overseers - supports buying the new press. You have therefore just asked the department manager, Andre Ivanov, to bring the matter up at the next monthly meeting, which is this Friday. You know if there is a vote, you will win. Adding pressure to act on the matter, if you don´t buy the press within the next three weeks, the donating organization will withdraw its offer. A final motivating factor is an attachment you have to being able to say that you were responsible for getting the company a second press.

Role 2: The Bulgarian department manager

You are Andre Ivanov, the department manager of a Bulgarian engineering company where a German mechatronican, Thomas Richter, works as your assistant. He has been saying for some time that the company needs a second press to handle its increasingly large volume of forming tasks and you agree. Now the German has found a funding organization in the capital that is willing to donate half the cost of the press if the board of overseers which runs the company will agree to pay the other half. This offer is only good for the next three weeks, after which it will be withdrawn.

The German mechatronican has just asked you to bring the matter up for a vote at the next monthly meeting, this Friday. You know that while a majority of the overseers on the board is in favor of the purchase, the two most senior and longest-serving members are against it. They believe that the company has managed very well with one press and can continue to do so. You respect these two figures immensely; they have made the clinic into the success it is today. One of them even helped you get your present position. You do not want to risk offending them and therefore do not want to bring this matter to a vote until you can bring them around to the majority view. You know, however, that that will take longer than the three-week window of opportunity that has been made available to you. Even so, you feel strongly that in the end harmony on the board is of much greater value to the company than a second press.

3.2.2 Power distance index (PDI)

Introduce then the second of the five dimensions of cultural differences as developed by Hofstede (textbook on page 16ff.):

Do the exercise Power distance behaviour.

Exercise **Exercise 7 Power distance behaviour Part A:**

Have the participants open the exercise book on page 10. There they will find statements about different values and behaviours. For each statement, the participants should indicate whether they consider it as representing a higher or lower power distance.

In addition, each should indicate whether they tend to agree or disagree with the statement. Then go through every statement and discuss whether and why it should be considered to be high or low power distance.

Discuss the agreements and disagreements either in groups of 3-5 participants or in the seminar. Each participant should determine whether he/she tends to give ansers with low or with high power distance.

Answers (exercise 7):

The following values tend to be more characteristic of people with a low power distance:

3, 4, 6, 9, 10, 13, 18

The following values tend to be more characteristic of people with a hihg power distance:

1, 2, 5, 7, 8, 11, 12, 14, 15, 16, 17, 19

Exercise **Exercise 8 Power distance behaviour Part B:**

Divide the participants into groups and have each group open the exercise book on page 11. Ask the participants to read the four incidents and write down the detected differences in the interpetations of the situation.

Reconvene the groups and lead a discussion of each incident. Below you will find some questions you could use:

Dialogue 1:

What will the Polish director think when the mechatronican goes and questions him?

Suggested answer:
He may think he is rude to be questioning his decision like this.

Why does the mechatronican seem to think it is OK to question the director´s decision?

Suggested answer:
He comes from Great Britain, a low power distance culture, where it is more acceptable for subordinates to question their supervisors if they think a decision is wrong.

What should you do in high power distance cultures if you think the boss has made a mistake?

Suggested answer:
Don´t confront the boss directly - at least not in public. Send a message through a third party or go directly to the boss but phrase your criticism diplomatically. In many cases, subordinates do nothing, letting a supervisor deal with the consequences.

Dialogue 2:

What is the chief going to think of this surprise?

Suggested answer:
He may not be pleased that the mechatronican has taken action without first getting permission or approval.

Why will the chief be upset by what has happened?

Suggested answer:
He may interpret what the mechatronican has done as a challenge to his authority; if people go and do things on their own, without getting permission, they undermine the decision-making prerogatives of the boss.

Dialogue 3:

Why does the Mechatronican think the provincial representative might want to eat with the workers?

Suggested answer:
In Great Britain, differences in rank and status are not so strictly observed; relations between authority figures and those they oversee are sometimes more casual and informal.

How might it look to other people in Poland if Mr. Sadlowski ate with the ”commoners”?

Suggested answer:
For one thing, the other people of Mr. Sadlowski´s rank might be quite offended or take his action as an insult. For another, Mr. Sadlowski might undermine his authority with subordinates by suggesting he was one of them. Finally, the subordinates - except for the Mechatronican - might feel uncomfortable having lunch with such a dignitary.

Dialogue 4:

What is the mistake the Mechatronican makes here?

Suggested answer:
Going around the chain of command.

What is the manager likely to say if the Mechatronican goes directly to him?

Suggested answer:
He will probably ask if the Mechatronican has spoken to Mr. Pacholewski.

How is Mr. Pacholewski likely to feel when he hears what has happened?

Suggested answer:
He may feel humiliated or angry that he was bypassed.

What should the Mechatronican do in this situation?

Suggested answer:
Begin by trying to work through Mr. Pacholewski, however hopeless he may consider it to be. If nothing happens, then go to the next level; it is acceptable to go above Mr. Pacholewski but not good to go around him.

3.2.3 Uncertainty avoidance index (UAI)

Introduce the third of the five dimensions of cultural differences as developed by Hofstede (textbook on page 18ff.):

Do the uncertainty avoidance exercise:

Exercise **Exercise 9 Uncertainty avoidence:**

Have the participants open the exercise book to page 13. There they will find statements about different values and behaviours. Have the participants indicate for each statement whether they consider it as representing a higher or lower uncertainty avoidance. Have each participant indicate for each statement whether they tend to agree or disagree with it. Then go through every statement and discuss whether and why it it is considered to be high or low uncertainty avoidance.

Discuss the agreements and disagreements either in groups of 3-5 participants or in the seminar. The participants should find out whether the answers they give tend to indicate high or low uncertainty avoidance.

Answers (exercise 9):

The following values tend to be more characteristic of people with a low uncertainty avoidance:

4, 6, 7, 8, 10, 13, 16, 18, 20, 22

The following values tend to be more characteristic of people with a high uncertainty avoidance:

1, 2, 3, 5, 9, 11, 12, 14, 15, 17, 19, 21

3.2.4 Masculinity index (MAS)

Introduce then the fourth of the five dimensions of cultural differences as developed by Hofstede (textbook on page 20ff.):

Do the masculinity versus feminity exercise:

Exercise **Exercise 10 Masculinity versus Feminity:**

Have the participants open the exercise book on page 14. There they will find statements about different values and behaviours. Participants should indicate for each statement whether they consider it to represent a masculine or femine value or behaviour. Have each participant indicate for each statement whether they tend to agree or disagree with it. Then go through every statement and discuss whether and why it would be considered feminine or masculine.

Then discuss either in groups of 3-5 participants or in the seminar the agreements and disagreements. The participants shall find out whether they tend to give maculine or feminine answers.

Answers (exercise 10):

The following values tend to be more characteristic for masculine people:

3, 4, 6, 7, 10, 11, 12, 14, 17, 18, 19, 22

The following values tend to be more characteristic for feminine people:

1, 2, 5, 8, 9, 13, 15, 16, 20, 21

As mentioned before, the last dimension of Hofstede shall not be discussed deeper in this context. The final part of this section is a summarizing exercise which inlcudes all of Hofstede´s dimensions:

Exercise **Exercise 11 Cultural Dimensions:**

Have the participants open the exercise book to page 15. Ask each to place him / herself and the other persons mentioned on the worksheet within the five cultural dimenensions from Hofstede, which can be seen as a continuum. For each of the dimensions, participants should think about where they would place themselves in this continuum and mark it with X. Then they should do the same for the other persons or institutions listed on the worksheet.

Give 10 minutes time to finished this exercise.

Before discussing the results, calculate the scores of the questionnaire (exercise 5) togehter with the participans.

Exercise **Calculating the own score of Hostede´s cultural dimensions:**

Have the participants calculate their own scores on Hofstede´s cultural dimensions, using the their own answers in exercise 5 and the formulas given below.

Pedagogical note By analysing the answers of the questionnaire, the participants find out how they score on the different dimensions. Besides the verification of Hofstede´s dimensions on average (if the results of the participants and the actual scores of the particular country are compared), the deviations from the country score show that the answers to all of the questions can vary not only from culture to culture but also from subgroup to subgroup and from one individual to another and will also be influenced by other characteristics of the respondents, such as gender, age, level of education, occupation, kind of work, etc. This is a very important aspect and you should explain it very clearly at this point.

All content questions are scored on five-point scales (1-2-3-4-5). The calculation goes as follows:

Power Distance Index (PDI):

PDI = - 35 * (03) + 35 * (06) + 25 * (14) - 20 * (17) - 20

in which (03) is the participant´s score for question 03, etc.

Example If a participant marked question 3 with 2, 6 with 4, 14 with 4, and 17 with 3, his score would be: - 35 * 2 + 35 * 4 + 25 * 3 - 20 * 2 - 20 = 85, indicating a comparativley high score on the power distance scale. The other dimensions are calculated in the same way.

Individualism Index (IDV):

IDV = - 50 * (01) + 30 * (02) + 20 * (04) - 25 * (08) + 130

Masculinity Index (MAS):

MAS = + 60 * (05) - 20 * (07) + 20 * (15) - 70 * (20) + 100

Uncertainty Avoidance Index (UAI):

UAI = + 25 * (13) + 20 * (16) - 50m(18) - 15 * (19) + 120

Long-term Orientation Index (LTO):

LTO = - 20 * (10) + 20 * (12) + 40

The index normally has a value between 0 and 100, but values below 0 and above 100 are technically possible, and if the calculation is just done for one person as in this exercise even probably.

If you would like to calculate the score of the whole seminar group just replace the participant´s score on a particular question by the average of the answers of the whole group, calculated to two decimals.

Let the participants then compare their personal scores with the results of exercise 11 and the country scores (textbook page 20 f.) Discuss the results using the follwing questions:

- Was it easy or difficult to fill in the worksheets?
- Did your own score on Hofstede´s cultural dimensions match the own placement in exercise 11 and the country scores? If not why?
- Do you think it makes sense to categorise yourself, your organisation your country and others in this way?
- How did it feel to be categorised by others in this way?
- What can be the possible problems of categorising people like this?

Pedagogical note

Participants often start comparing different national ”cultures“ on Hofstede’s dimensions, with questions such as: ”Am I really more hierarchical? Do I really need more security than others? So while on the one hand, Hofstede´s dimensions provide a framework through which one can interpret cultural misunderstandings and start addressing these differences with participants (e.g.: what is your idea about power and leadership?), on the other hand, they quickly lead people to think about themselves and question whether the generalizations apply to everybody in a given country.

As another advantage, the process of introducing the five dimensions and identifying one´s preferences along these dimensions, raises the question of cultural relativity: is there really no ”better“ or ”worse“? Are hierarchical structures just as good as egalitarian ones? Are strict and closed gender roles just as good as those that are open and flexible? How far does it go? And if one wants to mediate in a cultural conflict along those dimensions, should one take a neutral position (and is this possible to do)?

If you would like to include additional discussion of the five cultural dimensions, you can also present an example for how a country would be analysed with the use of Hofstede´s dimensions. As an example, we present the USA below:

Example

USA score:

Country	**PDI**	**IDV**	**MAS**	**UAI**	**LTO**
United States	40	91	62	46	29

The high Individualism (IDV) ranking for the United States indicates a society with a more individualistic attitude and relatively loose bonds with others. The populace perceives itself as more self-reliant and looks out primarily for themselves and their close family members.

The next highest Hofstede Dimension is Masculinity (MAS) with a ranking of 62, compared with a world average of 50. This indicates the country experiences a higher degree of gender differentiation of roles. The male dominates a significant portion of the society and power structure. This situation generates a reaction in the female population in which some woman become more assertive and competitive, shifting toward the male role model and away from the female role.

The United States was also included in the group of countries that had the Long Term Orientation (LTO) Dimension added. The LTO is the lowest Dimension for the US at 29, compared to the world average of 45. This low LTO ranking is indicative of the societies' belief in meeting its obligations and tends to reflect an appreciation for cultural traditions.

The next lowest ranking Dimension for the United States is Power Distance (PDI) at 40, compared to the world Average of 55. This is indicative of a belief in greater equality between societal levels, including government, organizations, and even within families. This orientation reinforces a cooperative interaction across power levels and creates a more stable cultural environment.

The last Geert Hofstede Dimension for the US is Uncertainty Avoidance (UAI), with a ranking of 46, compared to the world average of 64. A low ranking in the Uncertainty Avoidance Dimension is indicative of a society that has fewer rules and does not attempt to control all outcomes and results. It also has a greater level of tolerance for a variety of ideas, thoughts, and beliefs.

Other examples and information can be found under:

http://www.geert-hofstede.com

4 Features of Culture

Session objectives To introduce different world views with respect to time and status.

To learn the different culturally-based types of communication.

To present examples of characteristic behaviours typical of people from countries with differing word views and different types of communication.

To enable participants to practice how they would handle situations in which differences in these two world views can generate problems or lead to frustrations.

Estimated time 225 min

Delivery

Pedagogical note After the discussion of Hofstede´s general approach, the fourth part of the seminar takes up detailed features of culture that influence working behaviour and therefore should be considered when approaching work in a new country.

You may start with the presentation of the concepts of time.

4.1 The perception of time and priorities

Pedagogical note The concept of time is among the easiest for the participants to understand. It should therefore be chosen as the first concrete cultural phenomenon to examine. However, there may be good rationale for starting with others.

As an easy energiser, start with the following short exercise, which opens up the whole concept of time and each individual´s relationship to it.

Exercise **Exercise Time:**

Materials needed A watch (for the trainer)

Delivery

In this exercise the participants live through their own minute of time and compare the results. Introduce the session with something like: ”We all know time is relative - but what does this really mean?“

Ask the participants to put away any watches they might have. If there is a clock in the room, cover it; if the clock ticks then remove it. Then everybody has to practice sitting down on their chairs silently and with eyes closed. After that ask ask everyone to stand up and close their eyes. On the command „GO!“, each person is to count out 60 seconds and sit down when they have finished. Stress, that this exercise can only work if everyone is quiet during the entire exercise. Once each person sits down he/she can open their eyes, but not before.

Pedagogical note

Even within culturally homogeneous groups, this exercise can produce fairly spectacular results. Be careful not to laugh at the people who are last. They might just be having a very “slow” day.

Go on to discuss whether there are culturally different perceptions of time. Emphasize that although time is a concept that at first seems quite straightforward, there is much more to it.

Explain to participants that time is often a cultural phenomenon. How time is treated varies from one culture to another. However, views of time may also vary within cultures, based on the personal preferences of individuals or the kind of environment in which the live and work, etc. We know that time is cultural, whether a particular approach applies to large groups of people or the majority of people in a particular culture.

Explain to the participants that people in different places have very different concepts of time. Some cultures are more “clock-driven“ than others. In some cultures, it is normal for people to arrive “late” for an appointment, and therefore, this is anticipated in advance. In other cultures, it is expected that people will arrive “on time”. Neither behavior is right or wrong, better or worse - they are simply different. It is differences in understandings and expectations that is most likely to generate tension.

You can use one or more of the following questions with the participants:

- Am I a punctual person?
- What is the meaning of the word “punctual“ in my opinion?
- How is punctuality defined in this country?
- What significance does time have in this country?
- In how far does the understanding of time influence our interactions?
- What are the points around which conflicts between myself and others regarding “time“ may arise?
- How could those problems be solved?

Introduce the monochronic and polychronic concepts of time with examples and conclusions. Do then the time exercise:

Exercise

Exercise 12 Monochronic and polychronic time concepts:

Have the participants open the exercise book to page 16. After reading the paired statements, the participants should decide whether a statement reflects a more monochronic or more polychronic time concept. Each should then circle the one that best describes the action he/she would take or the way he/she feels about the particular topic.

Answers (exercise 12):

The following behaviors tend to be more characteristic of people with a monochronic world view:

1a, 2b, 3a, 4b, 5a, 6a, 7b, 8a, 9b, 10b.

The following behaviors tend to be more characteristic of people with a polychronic world view:

1b, 2a, 3b, 4a, 5b, 6b, 7a, 8b, 9a, 10a.

Pedagogical note

The exercise will help the participants to discover whether their own concepts of time tend toward more monochronic or polychronic ends of the continuum. Explain to the participants that there is nothing scientific about this exercise. Most of the paired statements are taken out of context, so they might select one alternative in one situation and the opposite alternative in another set of circumstances.

After the exercise, explain the conclusions of different time conceps - that if there are different understandings of time between members of different cultures, this activates different evaluations and feelings which can lead to misunderstandings. The most relevant points are meetings and deadlines. Then do exercise 7.

Exercise

Exercise 13 Dealing with different time concepts:

Have the participants open the exercise book on page 17 and explain that you are going to look at specific examples of possible problems that are listed in the exercise book.

Divide the participants into several groups of 3-6 persons (depending on the number of participants in the seminar) and ask each group to read and to respond to the six situations (alternatively, you can assign three situations to each group).

After they have done the exercise, bring the groups back together and have participants list the suggestions or tactics they came up with for each situation. Ask the participants if any of them have already been in such situations and have them explain how they thought about it and what they did.

Pedagogical note

The participants may not have had any experiences with cultural difference and may wonder if it really poses problems. They may also believe that such problems are minor and very easy to deal with. Here it is helpful if you can draw from your own experience with observations that can lend additional credibility to the exercise, pointing out that these differences are real and can be very frustrating.

4.2 The source of status

Introduce the concept of Status.

Do the excercise Status.

Exercise **Exercise 14 Status:**

Divide the participants into groups and have each group open the exercise book on page 19. Ask the participants to read the four incidents and discuss what they would do in each situation.

Reconvene the groups and lead a discussion of each incident. You will find below a sampling of some of the questions you could use:

Text 1:
Why are the other teachers upset?

Suggested answer:
Because deference is expected of higher ranking people in their culture.

Why does the Swede not want his and her trainees to stand?

Suggested answer:
Swedish culture is highly oriented toward status equality (which does not mean however, that there are no status differences). Swedish people are therefore uncomfortable with such overt expressions of rank – especially any that contain assumptions that higher ranking people should get special treatment as if they were somehow superior to lower ranking people.

Why are Swedish people uncomfortable with deference to authority or rank?

Suggested answer:
Because of our strong belief in egalitarianism, that everyone is inherently equal.

Text 2:
What would happen if you spoke up and objected to this treatment by your boss?

How does a foreign expert decide what to do in situations like these, where what is apparently ”correct“ in the local culture may be personally offensive to this person?

Text 3:

Do you think the CEO made the right decision? Why?

Do you see why it was a problematic decision for this culture?

What do you do when ”the right thing“ in the culture in which you work is not right in your culture?

Text 4:

Why are the professionals upset with the Mechatronican´s behavior?

Suggested answer:
Because they have had to work hard to achieve their status and feel they have earned the right to be distinguished from those who have not achieved such a status.

Why does the mechatronican see nothing wrong with sitting with the laborers?

Suggested answer:
Because in U. S. culture it is okay for people of different ranks and status to intermingle.

Pedagogical note Participants may react quite strongly to some of these exercises and become emotional. Some of these situations strike at the heart of a very important value in some countries - egalitarianism - about which people in some cultures feel very strongly. Some participants may say they can´t or won´t do the culturally expected thing in these situations, which, of course, may upset them when they realize it is not as easy as they thought to be culturally sensitive. Try to reassure them that this happens to all many people and that the decision to stand on personal principle is not wrong or bad - as long as it is made very carefully and in a way that minimizes the unpleasant consequences.

4.3 Direct versus indirect communication

Start the lecture by making a chart with direct communication / low context on one side and indirect communication / high context on the other. Take the qualities as outlined in the in the definitions in the textbook on page 31 and list it under each category.

Sample qualities e.g.:

Direct communication / Low context:

- more homogeneous cultures
- collectivist
- more shared experience and understanding
- tendency to infer, suggest and imply
- need to read between the lines
- words should not be interpreted literally

- what is not said and done may be the message
- nonverbal cues important
- maintaining and strengthening relationship with other person is a key goal, regardless of task content

Indirect communication / high context:

- heterogeneous cultures
- more individualist
- less innate or shared understanding
- less can be assumed
- rely on verbal communication
- words interpreted literally
- little reading between the lines
- no meaning in what is not said and not done
- must be explicit
- goal is to give and get information.

Present the definitions of the two styles, using the chart.

Ask the participants to complete the exercise

Exercise **Exercise 15 Communication styles:**

Have participants open the exercise book to page 21. The exercise consists of 20 statements, where the participants are asked to decide whether a statement applies to a culture where communication is indirect / high context or direct / low context.

Suggested answers (exercise 15):

Behaviors commonly associated with low context cultures:

6, 7 ,10, 11, 13, 15, 16

Behaviors commonly associated with high context cultures:

1, 2, 3, 4, 5, 9, 12, 14, 17, 18, 20

Pedagogical note Be aware that the statements provided in the exercise are all presented out of context. The participants might complain that whether a person behaves in a certain way (e.g., 2. “People are reluctant to say ‘No‘.“) depends more on the details of the situation, not whether he or she comes from a direct or indirect culture. This is true and and there is no need to argue with this point. Instead, point out that in this exercise you are only trying to define the two extremes of the communication continuum and trying not to think of specific situations. In other words, there is no reason not to agree with the participant that context or the specific situation make all the difference – but this fact does not reduce the value of the exercise.

Conduct the two exercieses indirect communication and encoding indirect communication:

Exercise **Exercise 16 Indirect communication Part A:**

Have the participants open the exercise book to page 22. In this exercise participants are given a chance to practice indirectness with a series of eight direct statements. While these statements could be appropriate in several situations, the setting here is a meeting. Ask them to rephrase them to make them more indirect.

You might use the first statement as an example.

Suggested answers (exercise 16):

1. Do you think that's a good idea?
   Are there any other ideas?
   I like most parts of that idea.

2. That´s an interesting point.
   That´s another good point.

3. I have one possible suggestion.
   What do you think of this idea?

4. Does anyone else have any suggestions?
   Have we heard all the opinions?

5. I have some other figures here.
   Those figures may be slightly old.

6. I would do that like this.
   Have you tried doing that this way?

7. I have another idea.
   What do you think of this idea?
   May I make a suggestion?

Exercise

Exercise 17 Indirect communication Part B:

Have the participants open the exercise book to page 23. In this Exercise, participants are presented with a series of indirect statements and asked to decode them - to explain in direct language what the speaker probably means. You can use the first statement as an example.

Suggested answers (exercise 17):

1. That´s a very interesting viewpoint.
   I don´t agree.
   We need to talk more about this.
   You´re wrong.

2. This proposal deserves further consideration.
   We don´t like it.
   It needs work.
   Propose something else.

3. I know very little about this, but...
   I´m something of an expert on this but am too polite to say so.
   What I think we should do is...

4. We understand your proposal very well.
   Do you have another one?
   We don´t like it.

5. We will try our best.
   Don´t expect much to happen.

6. I heard another story about that project.
   I don´t agree with what you said about that project.

7. Can we move onto the next topic?
   We don´t want to talk about this now.
   We need to consult with people not in the room before we can decide.

5. Working abroad

Session objectives

To illustrate the motivational and practical problems of working abroad.

To provide guidelines and strategies to deal with possible motivatoinal and practical problems when entering a new country.

To help participants gain a feel for the complexities of carrying out a project in cooperation with people from another culture.

Estimated time

300 min

Delivery

Pedagogical note

Following the lectures about how culture can differ and how to analyse a certain country, this section refers mainly to the practical problems that can occur when people encounter in a new culture for the first time. It reduces the fear which might have come up through the illustration of the complexity of culture by demonstrating that the first ”negative“ reactions in a new country are normal and part of the process of adjusting. The guidlines offered in the textbook (page 33ff.) will help the participants and should not be left home when a participant starts working abroad.

Point out that staying abroad can be challenging and that the huge number of new things to pay attention to and keep track of can create a lot of psychological stress.

Explain what culture shock is and present the different methods for dealing with cultural stock as outlined in the textbook on page 30.

Illustrate the different stages a person in a new culture goes through in the adjusting process. Point out that these stages are based on scientific examinations and similar for all people, even if some people go faster through a certain stage than others. Nevertheless the methods presented in the course of this seminar will help when adjustment feels difficult.

For additional practical advice refer back to the Iceberg Model and the Barnga game which were content of this seminar in Chapter 2. It will be helpful to emphasize that it is nearly impossible to avoid interpreting others' behaviour through our own categories, and that there is even a specialized term for this effect - self-reference criterion (SRC) - introduced by J.A. Lee. Discuss the different strategies to avoid this phenomenon on to manage it as effectively as possible (textbook on page 32).

After this discussion, you should emphasize that the most important access to another culture happens through observations. Review the different questions, which can be used as a guide for the search for information in another culture.

For the final exercise - play the roleplay: the Derdians

Exercise **Roleplay - The Derdians:**

Game objectives The Derdians want to build a bridge, but don´t know how. They invite building contractors from abroad to teach them how to build a bridge.

Pedagogical note This game is a simulation of a meeting of two cultures. A team of building contractors goes to another country in order to teach the people there how to build a bridge. The participants will learn how it feels to have to perform a task with people from a differnt culture under time pressure.

Estimated time 120 minutes (inlcuding debriefing)

Materials needed Construction paper (or cardboard), glue, scissors, ruler, pencil, game descriptions for Derdians and bridgebuilders, two rooms if possible.

Delivery

Pedagogical note The culture of the experts and the people from Derdia is different. In order to maximize the experience of the participants, this is a practice scenario, a real task, which has paralles to the future content of the Mechatronicans work field. The bridge builder group has to learn to adapt to different cultural behaviours, which will seem strange to them. Although the game is fun, make sure that the participants take their tasks seriously.

First divide the whole group into two groups. One group should consist of 4-8 persons (the building contractors) and the other group should include the rest of the students (the Derdians). In any case, the group of Derdians should be larger than the bridge buider group. If the seminar is very large, you can also create a third group of observers.

Separate the groups immediately (preferably in two different rooms). If you have a group of observers they join the building contractors, as they shall not see the behavioural rules of the Derdians in advance.

Important As it is possible that your seminar mainly consists of men, but the roles of men and women are partially different, you have to make sure that there are at least 4-5 woman, especially in the group of the Derdians. If necassary, you will have to nominate some women out of the group of men.

The game:

Make copies of the instruction letters for the bridge builders and the Derdians.

Inform each group what to do. If there are two trainers, you can do this simultaneously. Otherwise, go first to the building contractors and then to the people of Derdia. If you are alone, you will have to switch between the groups from time to time. After the instructions are given the participants should have about 20 minutes to get familar with the instructions:

The building contractors:

1. Hand the buiding contractors the letter on what they can and what they do not.

2. Tell them AFTER the building contractors have read their role that the derdians are a bunch of strange people. Tell them some funny stories and let them think of a way to teach the Derdians how to build a bridge.

3. On a specified signal, two of the building contractors will make a short visit to Derdia. Afterwards, they will inform the larger group of building contractors what they experienced.

The Derdians

1. Give the Derdians the letter containing instructions.

2. Observe closely to assure that the Derdians carry out their instructions as detailed in the letter and motivate them to practice their behaviours.

After 20 minutes, two members of the bridge building team will be allowed to go and make contact for 3 minutes with the Derdian village (the other room) where the bridge will be built (e.g. make observations, to check the natural and material conditions, make contact with the Derdians, etc.). Observers are allowed to follow the technican.

Then send them back and give 10 minutes to analyse the report and complete the preparations.

After these preliminary meetings, send the whole team of bridge builders (and obvservers) to Derdia to teach the Derdians how to build the bridge. To do this the groups should have 30 minutes time.

After the bridge is finished, test the stability of the bridge between two tables.

Debriefing:

After the exercise the two groups of participants discuss their experiences and ask for reactions and comments pertaining to the following three categories:
1. Facts

2. Feelings

3. Interpretations

Questions for the discussion are e.g.:

- Was it difficult to find your respective role?
- What feelings were activated by your respective role?
- How did the group of bridge builders dealing with the time pressure?
- How was it possible to for the bridge builders to “decode“ the other culture?
- Is it possible to adapt these experiences for living together with other cultures?

The following points should be discussed in plenary:

- We have a tendency to think that others think the same way we do.
- We often make snap judgements - interpret things right away, without becoming aware of the differences in cultural behavior.
- How were the roles distributed/What role did I take? What does that reveal about my identity? Did I feel comfortable with my role?
- Is that image I have the same that was perceived by the others?
- What influence did my cultural background have on the role I took on?

Instructions for the Derdians

The Situation:

You live in a country called Derdia. The village you live in is separated from the next city where there is a market alongside a deep canyon. To reach the market you have to walk for two days. If you had a bridge across the canyon, you could get there in 5 hours.

The government of Derdia made a deal with a foreign firm to come to your village and teach you how to build a bridge. As a result, tyour people will become Derdia's first engineers. After having built that first bridge with the foreign experts, you will be able to build bridges all over Derdia to simplify other people's lives.

The bridge will be built out of paper, using pencils, rulers, scissors and glue. You are familiar with the materials and tools, but you don't know the construction techniques.

Social behaviour:

The Derdians are accustomed to touching each other. Their communication doesn't work without touching. Not being in contact while talking is considered very rude. You don't have to be in direct contact, however. If you join a group, you just hang on to one member and are instantly included in the conversation.

It is also very important to greet one another when you meet - even when you just pass someone.

Greetings:

The traditional greeting is a kiss on the shoulder. The person who starts the greeting kisses the other on the right shoulder. The other then kisses on the left shoulder. Every other form of kissing is insulting! Shaking hands is one of the biggest insults possible in Derdia. Whenever a Derdian ever is insulted by not being greeted or touched while being talked to, he/she starts shouting loudly about it.

Yes / No:

Derdians don´t use the word no. They always say yes, although if they mean "no", they accompany the verbal "yes" with an emphatic nodding of the head (you should practice this well).

Work behaviour:

While working, the Derdians also touch a lot. The tools are gender-specific: scissors are male, pencil and ruler are female. Glue is neutral. Men never, ever touch a pencil or a ruler. The same goes for women and scissors (it probably has something to do with tradition or religion).

Foreigners:

Derdians like company. Therefore they also like foreigners. But they are also very proud of themselves and their culture. They know that they´ll never be able to build the bridge on their own. On the other hand they don´t consider the foreigner´s culture and education as superior. Building bridges is just a thing they don´t know. They expect the foreigners to adapt to their culture. But because their own behaviour is natural to them, they can´t explain it to the experts (this point is VERY important).

A Derdian man will never make contact with another man unless he is first introduced by a woman. It does not matter whether the women is Derdian or not.

Instructions for the bridge builders

The situation

You are a group of international bridge contractors working for a multinational construction company. Your company has just signed a very important contract with the government of Derdia in which it committed itself to teach Derdians how to build a bridge.

According to the contract signed, it is very important that you respect the deadline agreed, otherwise the contract will be cancelled and you will be unemployed.

The Derdian government has a great interest in this project, which is funded by the European Union.

Derdia is a very mountainous country, with many valleys and deep canyons, but no bridges. It therefore always takes many days for Derdians to go from the villages to the market in the main city. It is estimated that with the bridge the Derdians could make the trip in only 5 hours.

Since there are many canyons and rivers in Derdia, you can´t just build the bridge there and take off again. You´ll have to instruct the Derdians how to build a bridge themselves.

Playing the simulation

First you should take time to carefully read these instructions and decide together about how you are going to build the bridge.

After a specified time, two members of your team will be allowed to go and make contact for 3 minutes with the Derdian village where the bridge will be built (e.g. make observations, to check the natural and material conditions, make contact with the Derdians, etc.).

You will then have 10 minutes to analyse their report and complete the preparations.

After this, the entire eam of engineers goes to Derdia to teach the Derdians how to build the bridge.

The bridge

The bridge will be symbolized by a paper bridge. The bridge will link two chairs or tables over a distance of approximately 80 cm. For the construction of the bridge you can use the material you will get in Derdia. The resulting bridge has to be stable; at the end of the building process it should support the weight of the scissors and glue used in its construction.

The pieces of the bridge cannot simply be cut out and assembled in Derdia because otherwise the Derdians would not learn how to do it themselves. They have to learn all the stages of the construction.

The bridge has to consist of paper stripes only, of variable length and 4 cm wide. Each piece needs to be drawn with pencil and ruler and then cut out with the scissors.

Materials

The bridge will be made with paper / cardboard. You can use for the planning and building: paper, glue, scissors, ruler, pencils.

Time

For studying these instructions: 20 minutes

For doing a short visit in Derdia: 3 minutes

For planning and preparation based on the information you recieved before going to Derdia: 10 minutes

To teach the Derdians to build: 30 minutes

References and suggested further readings

Books and articles

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Internet

http://www.geert-hofstede.com

http://www.kwintessential.co.uk

Acknowledgements

Social Behaviour, Cross cultural training is an ownstanding module of the teachware package Mechatronics, developed in the MINOS project, funded by the Leonardo program of the European Commission.

There were many people who have contributed to this work.

The author acknowledges the following people, which contributed, enhanced and reviewed the material:

Andre Henschke, Geert Hofstede, Marcus Carson, Tom Burns, Ulrike Gampig, Viola Krynksi.

I would also like to thank the companies, which allowed me to test and improve the material with the help of their practical experience, the Peace Corps for their intensive previous work in the intercultural field and the Eurpean Commission for their financial contribution.

Mechatronics

Module 2: Project management and organsiation (Part 2)

Trainerguideline
(concept)

Andre Henschke

Henschke Consulting Dresden,
Germany

EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

www.tu-chemnitz.de/mb/WerkzMasch

Bildung und Kultur

Leonardo da Vinci

Teach ware concept working out and proving project partners

- Chemnitz University of Technology, Institute for Machine Tools and Production Processes, Germany – Project Management
- Corvinus University Budapest, Institute for Information Technologies, Hungary
- Stockholm University , Institute for Sociology, Sweden
- Wroclaw University of Technology, Institute for Industrial Engineering and Automation Technologies, Poland
- Henschke Consulting Dresden, Germany
- Christian Stöhr Unternehmensberatung, Germany
- Neugebauer and Partner OHG Dresden, Germany
- Korff Isomatic sp.z.o.o. Wroclaw, Poland
- Euroregional Chamber of Industry and Commerce Jelenia Gora, Poland
- Dunaferr Metallwerke Dunajvaros, Hungary
- Knorr-Bremse Kft. Kecskemet, Hungary
- National Institute for Vocational Training Budapest, Hungary

Teach ware concept:

Manual, exercises and solutions books for

- Module 1: Fundamentals
- Module 2: Cross-cultural Competencies, Projectmanagement
- Module 3: Fluidics
- Module 4: Electrical Drives and Controls
- Module 5: Mechatronic Components
- Module 6: Mechatronic Systems and Functions
- Module 7: Commissioning, Safety, Teleservice
- Module 8: Remote Maintenance, Diagnosis

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Trainerguidline of module project management and organisation

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Trainerguidline of module project management and organisation

Description of seminar/industry allocation:

Mechatronik

Training aims:

The participants learn and understand the substantial aspects to the following topics

- Work on the project in the trend
- A project; Conditions and characteristics
- Kinds of project
- Project management - definition, purpose
- A project and its phases
- Project organization
- Direction of the project
- Project planning
- Steps and measures to project success
- Risk management

Conditions:

none

Participant circle:

Technical specialists from the ranges construction, assembly, service, and maintenance.

Duration of the seminar in minutes:

1260 minutes

Seminar equipment

Adviser equipment

Coach manual M2 PM/O

Other material for adviser:

Beamer
Whitebord

Seminar documents for the participants per 1 person:

Libretto M2 PM/O? Exercise book M2 PM/O

Other material for participant per 1 person:

Memo pad, pin

Trainerguidline of module project management and organisation

General references and philosophy of the module project management and organization

The available training module project management and organization is conceived as an operational up-to-date seminar consisting of text book and exercises. In addition, it contacts non—university graduates of the specialist area technology, but is usable for other target groups. The training module does not set a focus on the integration of software solutions such as MS Project but dedicates itself to the switching of specific contents and operational sequence of a successful project conversion. By the work with this training module should the participants gain:

- Knowledge of the nature of projects
- Components of a project
- Phases of a project
- Proceeding for the planning of a project
- Conversion of a project and
- Control of the conversion taken place attains.

The exercises to the individual fields of activity examine the understanding of circumstances, on the other hand represent the exercises the possibility for the individual application of the knowledge. Particularly with individual exercises the creativity of the participants is in demand, as it cannot give a formally correct or wrong solution, which is also not on demand. It is left to the argumentation of the participants on the basis the basic conditions given in the text book to find a way to the solution of the task.

Introduction and salutation

Contents in references:

- Conception round
- Program conception
- Expectation inquiry
- Schedule, organization, partners

Special reference:

- Visiting cards exchange
- Conception seminar manual,
- Reference to practical seminar execution,
- Conception of the European master program of „Leonardo da Vinci“

Duration of the chapter in minutes:

30 minutes

1 Work on the project in trend

Contents in references

- Work on the project in the past
- Phases of the development of the work on the project
- Origin of project organization principles

Special reference:

Examples by participants are to be found

Participant documents:
- Libretto M2 PM/O,
- exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

30 minutes

1.1 – 1.3 Work on the project in the past

Deal with the specifics of historical large events. Show the character of a project on the basis large historical achievements like the discovery travels of sailors. Before you use the text book, try to wake enthusiasm for singular and unique enterprises. On this basis you let further examples of singular venture of the past designate. The military origin of principles of organization can be deepened by the white on Carl von Clausewitz „by the war“, which is available in almost all languages of the world.

Carl Philip Gottlieb von Clausewitz (* 1 July 1780 as Carl Philip Gottlieb von Clausewitz in castle close Magdeburg 16. November1831 in Breslau) was a Prussian general and military theoretician. Clausewitz became by its masterpiece „by the war“ admits. His theories about strategy, tactics and philosophy had large influence on the development of the war nature in all western countries. Although his theories mostly of English historians, like Basil Liddell hard or John Keegan were questioned, it is still taught in all important military academies. They apply today also in the management and in marketing. Clausewitz turned against the „System maker“. In his opinion one could not operate war theory as concrete procedural instruction for generals. He wanted instead general principles to point out, which resulted from the study of history and from logical thinking. Even if it treated ideal types, it constantly referred to the reality purchase of its principles. Thus he meant that campaigns could be planned only to a very small degree, since incalculable influences or events, would make so-called „frictions“ that destroy every detailed in advance planning.

1.4 The nine knowledge fields project management

Compile on the basis an example of a present-referred project the nine action field's project management. Result should be a diagram in the following way:

Task 1:

Call 10 examples for important „historical" projects:

Solution (example solution) to task 1:

- Building of the pyramids in Egypt
- Course Alexander's to India
- Building of the Hadrian wall in England
- Building of the Peter cathedral in Rome
- Course of the Napoleon army to Russia under first use of new logistic means as well as durable dose food
- Building of the railway connection between east and west coast Americas
- Development of the Otto engine
- Expedition to the moon
- Hiking of the Mount Everest
- Establishment and start-up of the first atomic power plant

Task 2:

Designate the nine knowledge fields project management

Task 3:

Differentiate the knowledge fields „integration management", „risk management" and „personnel management" and point you out to the connection of the three knowledge fields on the basis of an example even selected.

Solution to exercise 3:

Page 3, 1.4. The nine knowledge fields project management

2 A project - conditions and characteristics

Contents in references:

- DIN 69,901
- Conditions
- Targets
- Singularity
- Possibility for the arrangement
- Project-specific organization

Special reference:

Group exercises

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

30 minutes

Deal with the character and structure of standards. Mention thereby the background of the DIN standard as well as the ISO standard. The DIN standard defines 69,901 a project in DIN. Deal with the nature and the kind of a definition. Definitions will play an important role in the later applications of projects, since an accurate demarcation is important to alternative representations. Define on the basis examples characteristics of projects and compile to the DIN 69,901.

Task 4:

Which seven project conditions mark a „project“ according to DIN 69901?

Solution to task 4:

Page 4, 2.1. DIN 69,901

Task 5:

Mark with five of the 1st historical examples of a project designated in task at least in each case five project conditions according to the following pattern. Use for the representation of each project an extra sheet!:

Solution to exercise 5: (on the basis an example)

Project 1: Building of the pyramids in Egypt

Condition:

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3 Kinds of project

Contents in references:

- Structure of
- Investment projects
- Research and development projects
- Organization projects
- Versus projects
- At a working system
- At a work article
- At business premises
- Project phase models

Special reference:

Group exercise

Participant documents:

Libretto M2 PM/O,
excersisebook M2 PM/O

Seminar equipment:

Notebook,
trainerguidline M2 PM/O,
Whiteboard

Duration of the chapter in minutes:

30 minutes

Give the three kinds of projects (organization projects, research and development projects as well as investment projects). Let the participants find examples of the individual kinds of projects. On the basis a table with three columns (in each case a kind of project) and the line entries of the examples of a project you develop however position characteristics of the individual kinds of project. Lead outgoing from examples to the definitions.

3.4 Project phase model

Compile by an example of a kind of project a rough project phase model in each case. Represent the project phase models one above the other thereby the differences in the expiration become clear.

3.5 Characteristics in the international project management

Discuss the trend of the internationalization with the participants. Deal with personal experiences of the internationalization. The positive view is important on an increasing internationalization, in which chances for innovative and future-oriented specialists work. Do not permit a principle discussion about globalization against personal prosperity, since this discussion would lead away from the topic! The goals of the internationalization should be given by you and taken up by the participant. Examples can be compiled together.

3.5.3 Influences of the sociology in the international project management

Let the participants their personal opinions for the topic field of the sociology enumerate. Let the participants a definition of the sociology and their emphasis and/or action fields represent. They will notice that the understanding of the sociology in general, one strongly deviates from actual contents. Make clear on the basis of examples of the internationalization the importance soft Skills, so called soft factors, those on personal, human level over success and/or failure of a project. Deal with the meaning of different mentalities. Make the importance of a certain empathy clear. As example for it a sentence of Professor Nida-Ruemelin can be considered: „economic success depends on cultural bases and conditions for education, which do not adjust themselves automatically, which must embody themselves often only over generations away and those, in my view a do not only play role in knowledge, but requires sensitivity, and the ability to deal with someone else, and to understand what the other one actually wants, to orient himself in different cultural environments. That particularly applies to an international economy, in which we are confronted with completely different culture-backgrounds and different mentalities and personalities, old-fashionably, certain virtues are developed, for virtues of the consideration, the projecting ability, the stability, the reliability, the truthfulness, the confidence.“ „humans are successful of they make at least a substantial part of their activity from interest in the thing, because they want to make well and not, because they would like to reach thereby something else. This is connected with self-respect, we can not instrumentalism our behaviour without loosing the own identity, or self-respect. And they communicate in the most favourable case, and interact from only one attitude, from the attention, the respect, the confidence.“ Initiate on the basis of this statement a discussion for the topic of values and standards in 21st Century. Deal thereby with the importance of the sycamore value canon.

Task 6:

Designate three kinds of project and outline for each kind of project two fundamental characteristics!

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Solution to exercise 6:

- Investment projects
  - High purchase sum
  - High-quality products
  - Long service life

- Research and development projects
  - Planning and control-intensive project form
  - Characterized by the development of new procedures, new systems

- Organization projects
  - Application to expiration within an organisational structure
  - Organisational structure-spreading co-operation of different ranges

Task 7:

Give of each kind of project 2 examples from your personal action field and outline them by these examples by characteristics to the respective kind of project.

Solution (example solution) to exercise 7:

- Investment projects
  - Purchase of a grinding machine
  - High purchase price
  - Very long service life
  - New building of a freight elevator
  - High-quality and safety-relevant fastidious product
  - Long service life

- Research and development project
  - Construction of an engine for alternative fuels
  - Very planning-intensive procedure
  - High tuning need of the construction team
  - New procedure
  - New procedure of the cleaning of escalators

- Planning-intensive procedure
  - Optimization of the total costs
  - Construction of the cleaning technology/machine

- Organization project
  - Conversion of the computer network work of Microsoft Windows to LINUX
  - Co-operation of all departments involved
  - Common resources employment and/or joint conversion of all PC's in a department
  - Organization of the start-up of a again built building
  - Integration of all ranges
  - Integration of the line level into the planning process
  - Frequent consultation for conversion in time

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Task 8:

Which goals of the internationalization are well-known to you?

Task 9:

Describe on the basis of an example even selected, goals of the internationalization of a project. Deal thereby with the special characteristics of the kind of project and the corresponding goals of the internationalization.

Solution to exercise 8 and 9:

- Economic goals
  - Safety device and growth oriented goals
  - Entrance into a new market with a product of the past homeland market (organization project)

- Non-economic goals
  - Prestige props
  - Development of the influence and power base
  - Fair appearances and (organization project)

- Defensive goals
  - Stabilization of an endangered market situation
  - Production for the lowering of the costs due to strong push of rivals (investment project, organization project)

- Offensive goals
  - Use of a national/regional advantage (technology leader shank) at the international market
  - Skimming strategy for introduction new products (e-Ink) organization project

- Resource-oriented goals
  - Safety device of the raw material basis
  - Production in raw material-rich regions, for the example steel market in India

- Production-oriented goals
  - Price advantage with production abroad
  - Start-up of manufacturing plants of considerable car manufacturers (organization project, investment project)

- Paragraph-oriented goals
  - Opening of a foreign address for the better supply of a main customer
  - Penetration strategy for the penetration of a market (organization project)

Task 10:

International projects stand frequently under the influence of the international origin of the project participants. In which form can the knowledge be helpful around sociological characteristics of international project groups during the successful conversion of a project?

Take on the basis an example even selected in addition to position.

Solution to exercise 10:

See page 12, 3.5.3. Influences of the sociology in the international project management on the basis of the examples represented in task 8and 9 a derivative in examples should be possible. The integration of the definition of the mentalities is important as „prevailing thinking and behaviour pattern within a group of humans“.

4 Planning and goal horizons of project management

Contents in references
- Operational project management
- Tactical project management
- Strategic project management

Special reference:
- project exercise systematic acting;
- Conflict management with the definition of goal horizons

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

30 minutes

On the basis examples let represent the possible planning horizons of project management. Define strategic, operational and tactical ones as temporal and idealistic planning horizons.

Task 11:

Which three goal horizons of the project management are well-known to you? Indicate in each case two practical examples!

Solution task 11:
- Operational project management:
  - Preparation and execution of a removal into a new office building
  - Decision making on the basis of offers with investment projects
  - Line and tracking with F+E projects

- Tactical project management
  - Discussion of the allocation of the areas in the apron of the introduction into a new office building by the responsible department managers
  - Selection of the possible suppliers for an investment project from the whole of the market offered present

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- Strategic project management
  - Decision making to the new building of an office building
  - Decision over the necessity for an investment
  - Definition of the requirement profile

5 A project and its phases

Contents in references:

- Project idea
- Goal definition
- Feasibility study
- Order for project
- Rough arrangement and definition of the task of project
- Fine structuring
- Project planning
- Project supervision
- Project evaluation

Special reference group work:

Structuring on the basis given examples of a project

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

270 minutes

Give the nine phases of a project. Place underneath the nine phases with the definitions.

5.10 Project management groups of processes

Describe the alternative away of an organization on the basis of groups of processes. Make clear that this form of the organization is only meaningful, if several involved ones participate in the project conversion, since only then, groups of processes can be formed. Define the individual groups of processes and their tasks.

Task 12:

Call nine phases of the implementation of a project.

Solution to task 12:

Page 14 FF.

6 Project organization

Contents in referents
- Pure project organization
- Staff organization
- Matrix organization

Special reference:

Group exercises

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

90 minutes

The project organization is often reflected at the actually lived form of the enterprise organization. Place in the discussion with the participants those different experiences with different organization forms. In order to avoid leeways into an uncontrolled form of the discussion, give the three forms of the organization designated here as patterns. Deduce the special cases of the individual cases of enterprise of the discussion from the given main forms. Deal in each case with advantages and disadvantages!

Task 13:

As example the building is to serve a new workshop. The building resounds as an investment project is classified. Which phases of the implementation of the project are for the investment project mentioned relevantly, and as these could according to your opinion are converted:

Solution to task 13:

Relevant project phases:

Project order

1. A production hall with special on-masses shall be built
   project order (certain/project definition become project object) at a place X. Exit situation to this is a certain need to which the hall shall do justice.

2. Definition of the project aims
   At the time of Y the hall must be completed. All technological plants must be able to work in the hall at this time. The hall must be attached to all supply media at this time. The access ways are also completed at this time.

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3. Project organization
   It makes sense for this project to go back to an experienced project team which has looked after construction projects in the past. Therefore the pure project organisation is suitable with this.

Rough planning

4. Taking the complete project to pieces into work packages preparation of a project structure plan

5. Specification of the responsibilities

6. Estimate and coordination of the capacity and the costs

7. Definition and termination of project intermediate results representation of a Gant plan

8. Judgement and assessment of the risks, revision of the planning

9. Organization and facilities of the project information and documentation

Fine planning

10. Taking apart of the work packages in activities and distribution to the ones involved

11. Determination of the required capacity and duration of the activity

12. Analysis of the dependences

- Integration of the dependence conditions into the Gant plan
- Identification of the critical path

13. Determination of the beginning-/ closing dates

14. Determination of the essential critical aims

15. Calculation/specification of the required costs

Control/supervision

16. Planning of the control methodology

- Using the control group
- Determination of a Backstopping group (support according to a technical conceptional company.)

17. Information about not planed events

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18. Collection and representation of the information agreed on

19. Debit-being comparison

20. Introduction and check of control measures

Task 14:

Which kinds of a project organization are well-known to you? Outline them graphically!

Solution to task of 14:

See page 21, 22, 23; Pure project organization, staff organization (project co-ordination), Matrix orgnaisation

Task 15:

Which pros and cons do you see in the application of the individual kinds of the project organization?

Solution to task of 15:

- Pure project organization: See page 21
- Staff organization: See page 22
- Matrix organization: See page 22 and 23

Task 16:

Which kind of a project organization is advisable for the three respective kinds of projects (investment project, f-u-e-projects and organization projects)? Justify your statement!

Solution to task of 16:

Pure project organization:

- Investment projects, since here a large project volume with high degree of details must be administered. All ranges are subordinated to a project manager, since this can steer the whole of the project best. The project manager has here almost the function of a managing director, which with really large projects is quite usual.

Staff organization: - F+E projects, since the co-workers are not only active for a project, and flexibly can be used. The disadvantage of the internal non-affiliation is to be solved as clear executive function of the project manager.

Matrix organization:

- Organization projects, since the co-workers are subordinated to the project manager for the duration of the implementation of the project, on the other hand the specialized division remains subordinated. It must be worked against to the disadvantage of the split affiliation by the integration of the leadership levels of the individual specialized divisions.

7 Direction of the project

Content in reference:

- Area of responsibility tasks
- Personal requirements of the project manager
- Minimum authority
- The project team

Special reference:

Project exercise systematic acting;

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:

- Notebook,
- trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

120 minutes

The project manager is the person most important in the project. Therefore the largest attention is entitled to the selection of the project manager. Note! Not all participants of your group will possess the abilities to the project manager. It is to be assumed that only approx. 5-10 % of humans possess all guidance abilities. A representation of the qualifications enumerated here can lead easily to the depression and inferiority complexes. If the individual realization of the individual abilities is important, then the division of the group in leaders and non—leaders in no case in this phase of the seminar should take place. Practically this will show up in the group exercises and the distributed roles of the implementation of the project. Individual participants will take over better, others more badly the part of the project manager.

On the basis even individually experienced projects the participants should recognize, which meaning the individual sub points of 7.1.1, 7.1.2 and 7.1.3 should be measured out. Deal with practice and particularly on the point of the authenticity! The authenticity is the crucial qualification of each guidance personality, i.e. only the ability for undistorted self reflection secures the ability for the leading impartially and fairly to judge and its way to coordinate. Deal if necessary with the different styles of leadership. In addition should

- Authoritarian style of leadership
- Cooperative style of leadership
- Laissez fair style of leadership count.

Make the shift from authoritarian style of leadership clear to Laissez fair style of leadership on the basis of the complexity and higher individuality of the task. That means, projects with small individuality are rather to be led authoritarian, complex and highly individual with large creativity portion can be led cooperatively and freely.

The meaning of the project team as synergistically working unit must be obtained in point 7.2. Deal in the discussion with experiences (as with positive like negative) of teamwork.

Task 17:

Mark seven areas of responsibility of a project manager.

Solution to task of 17:

See page 24, 7.1.1. Areas of responsibility of a project manager

Task 18:

Mark seven tasks of a project manager:

Solution to task of 18:

See page 25, 7.1.2. Gave up a project manager

Task 19:

Mark seven personal requirements, which must become fair a project manager:

Solution to task of 19:

See page 25, 7.1.3. Personal requirements of the project manager

Task 20:

An organization project is to be accomplished in form of a matrix organization. Two departments of a production location are to be folded up. Discuss on the basis of your knowledge pros and cons of the matrix organization the areas of conflict, in which the project manager will be active. Deal thereby with the tasks of areas of responsibility of the project manager.

Solution to task of 20 (example solution):

Disadvantages of a matrix organization:

Authority conflicts between line organization and project manager.

Solution through:
Adherence to of the guidelines, the procedure and work instructions for the necessary tuning internally and externally project documentation and document administration clear goal definition and task distribution communicative abilities ability of high one social authority of the project manager.

(Repeat this exercise if necessary on the basis of the staff organization and the pure project organization)

8 Project planning

Content in reference:

- Goal planning
- Planning effects
- Arrangement of projects
- Kinds of project plans

Let find the special reference examples by participants

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

90 minutes

This chapter is the most important chapter of the entire seminar. Take sufficiently time around the individual points to discuss them and present them by examples. Only if the project planning takes place really accurately, all details are considered, can a project actually successfully be converted.

8.1 Goal planning

Deal with the dimensions of goals. Make sure, that the chances of success possesses of a project are only realistic if the individual components of a project are actually attainable!

The following example should be stated only if necessary and appropriate training of the participants. The necessary mathematical bases in addition are in the module „bases mathematics“.

Deal on the basis the explanation of a variation with repetition with the mathematical aspect of planning. Clarify on the basis of an example as in the following:

The organization of a garden celebration is planned with the following components:

The garden celebration is to take place in June outdoors.

The beer to this celebration is to be provided by a sponsor.

The volume is to arise likewise free of charge.

In addition the following basic conditions apply:

1. In the past years the weather was continuous sunny in the month June. The probability for a sunny June can be set therefore in this year with 95 %. 2. The beer was placed with the preceding celebrations from a brewery to the order, which pursues marketing-political goals with this Sponsoring. Therefore it can be assumed that with 99% security, some Sponsoring also in this year effected. 3. The band was not won free of charge ever for an appearance. Discussions with 5 different bands are led at present, the probability for a successive thereby with maximally 50 %.

Deal with the assignment of the probabilities of realistic sizes, and point out at the economical „minimum value principle“, i.e., all profits as low as possible are accepted, all losses as highly as possible. Thus the planning risk is minimized, and/or is each planning on this basis of a „Worst Case planning“ and includes the worst case into the consideration. In accordance with the definition of the variation with repetition V=nk and/or V = n1 x n2 x n3 x nk. In our example this means: Since probabilities are not multiply able, mathematical use conversion of 95% is to be made as 0.95. From this follows:

V garden celebration - successfully = 0.95x 0.50 x0.99:= 0.47 from it follows under the given circumstances a successful conversion of the garden celebration is to be accepted only to 47%, or differently expressed: in 47 cases of 100 cases planning of this kind the project conversion will be successful.

An extension of this planning can take place, into which individual probabilities still importance's are measured out, i.e., if good weather is important to 100 % for the success of the garden celebration, the sponsored free of charge beer likewise to 100 % to the success contributes, the free band appearance however is involved only to 70 % in success, since those can be replaced in an emergency by can music, then arises the following computation:

V garden celebration - successfully = 0.500.70 = 0.57 from it follows 0.951 x 0.991 x: Under the given circumstances a successful conversion to 57 of 100 is to be accepted equal stored cases.

This more complex form of the representation can be necessarily regarded with complicated cases of decision. However the danger with each computation, which becomes counted a project „dead“, exists. Is the result of the preliminary decision too?

If the result of the in advance decision is bad, the project is not realized, only because the per cent acceptance were too pessimistic.

8.6 Critical path method

The critical path method represents didactically and also content wise the most difficult part of the seminar. Therefore, according to structure of the seminar group is to be weighed in which form and which circumference the net plan technology finds entrance in the seminar. A condition for the understanding of the topic critical path method is a deep mathematical understanding and analytic abilities. Before the explanation of the mathematical connection deal with similar examples, which clarify systematic of the critical path method descriptive? Examples of the everyday life and/or the planning of a comparable project like the renovation of a dwelling with differently distributed tasks and temporally parallel running actions can serve for the elucidation of contents.

Particularly the identification of the critical way also without including mathematical models is the most important characteristic of the network plan. Make clear that the critical way is the single criteria for success and failure of a project. Sketch network plans on the basis models and projects even selected and derive critical components from it. The network plan should become more complex thereby with each example project. Let the participants additionally compile to the individual exercises of the exercise book of network plans and discuss the critical points and/or their influence on the total process.

9 Steps to project success

Content in reference:

- Components of the risk management
- Risk identification
- Risk evaluation
- Development from measures to the risk accomplishment
- Risk pursuit
- Use from measures to the risk accomplishment

Special reference:

Examples by participants to be found

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:

- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

180 minutes

Point 9 represents a summary of the preceding chapters. Hence, the contents should be confessed in detail and must be explained no more. Point out on the basis of examples to the connection of the components. The matching practise in form of a table should serve for the exemplary desegregation of the single project components. Pay attention in this segment to the clear separation of the project steps and the matching methods. Make the necessity of the detailed knowledge of the single methods clear!

Project order:

Here the separation from other projects muss be regarded! Because often a plan is named fast to a project, should be exactly cleared that a project must fulfil necessary conditions according to DIN69 901!

Coarse planning:

The production of a project structure plan is the most important part of a project planning. Pay attention to the division of the tasks and working parcels in this subject! Without precise separation of these working parcels and definition of the interfaces a conversion is not possible. Leave (provided that it admits the time) with a homogeneous task force also single working parcels themselves compile to make the importance of realistic time planning clear. If it admits the equipment, give the task of a cost calculation, and let estimate the participant's costs on the Internet.

Fine planning:

Make with the help of point 13 clear which buffers an inalienable component of the project planning are. Without built-in buffers and under circumstances redundant process structures at critical places a project are not realizable!

Control and supervision:

A project - thus it concerns a complicated project - never can be carried out without obstacles. That's why not only the planning is important, but also the problem solution. Show participants on the approach oriented to solution the problems. Draw the attention, to the 90%- syndrome.

Controlling:

A project will never be realisable without hindrances. By this reason planning is not only important for a successful realisation of projects, it is also important for solving of problems. Discuss with the participants solution orientated! Tell the participants about the 90%-syndrom:
This means that after 30% of the work the feeling approaches that already 90% of the work is done, and a misalignment of the working intensity on the project end occurs, although still 70% of the work is to be done. The control nature of a project can take place on the basis of characteristic numbers. Since the topic of leading represents its own field of knowledge by characteristic numbers, is not to be dealt herewith it further.

10 Risk management

Contents in references:
- Components of the risk management
- Risk
- Identification
- Risk evaluation
- Development from measures to the risk accomplishment
- Risk pursuit
- Use from measures to the risk accomplishment

Special references of examples by participants to be found

Participant documents:

Libretto M2 PM/O,
exercise book M2 PM/O

Seminar equipment:
- Notebook,
- Trainerguidline M2 PM/O,
- Whiteboard

Duration of the chapter in minutes:

180 minutes

In the chapter risk management the opportunity should be given for the discussion for each kind by danger estimation regarding a successful implementation of the project. With reference to point 8.1 goal planning and the form of the feasibility analysis already described where also the risk analysis can take place.

Important is that here risks are always found with need. Every project is to be equipped with arbitrarily risks, so that a conversion can never occur. Make to the participants clear that project management also signifies independent and with it enterprise as well as creative work. Every enterprise one with it each project is to be equipped with risks, so that a conversion can never take place. Make clear for the participants that project management means also independent business and as well as creative working. Meaning each business or economic acting means to calculate with dispose of few goods, which way is the most effective and which thereby the most efficient. A safe estimation of risks is NEVER possible, occurs this safe case, then it concerns no risk. That excrement-rise up is a law which can be found in Germany.

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Kontrag

Pay attention in the case of the risk discussion to a realistic representation of the situations! Deal thereby with experiences which grew with the participants. Only with the background of personal experiences in similar situations can a meaningful risk calculation can take place. It should be clear that only that person can lead projects, who processes the necessary specialized authority, and who, possesses the necessary social authority and authenticity, his lack of the specialized knowledge is be recognized and technically compensated by project participants.

Consider thereby one of the simplest guidance definitions:

Lead is called to make it redundant!

In the discussion of examples should therefore become clear, how wrong decisions can be, whom this without experience were met. At the same time experience should flow as component indispensable in the project. If you succeed the participants to mediate the fact that risk management means the exact analysis of a problem and means the release of a problem into the dismantling into individual tasks, then you obtained the chapter risk management well. (a task is characterized by the fact that between starting situation and goal situation an expiration exists, which admits and is established, and thus a reliable solution makes possible. A problem does not possess a secured way between output and goal situation. Therefore the art consists of transferring the way between the starting situation and goal situation of the problem into well-known subtasks in order to minimize the risk of a miss.

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Summarizing group exercises:

1st group exercise:

A.)

Discuss which of the following tasks as a project can be understood or have had to and you made your choice after which aspects. Why can't some tasks be understood as project, others as a project?

- New development of a vehicle engine for the foreign market
- Construction one annual accounts
- Restructuring of a sales department in an enterprise
- Acquisition of a new computer network in an enterprise
- Construction of a new production hall for the expansion of the industrial capacity abroad
- Rearrangement to the use of alternative administration software
- Standard delivery of products to international buyers
- Processing of orders to a rush hour (Christmas)

B.)

Divide up the projects identified by you into project ways known to you and discuss why you have carried out this assignment.

C.)

You discuss the usefulness and the aims of international enterprise orientation examples with the predefined one.

D.)

Define the planning horizons of the projects.

Coordinate your results with your seminar leader!

Solution for the 1st group exercise:

F+E project:
Development of a vehicle engine (strategic project)

Organization project:
Restructuring of a sales department in an enterprise (tactical project)
Acquisition of a new computer network in an enterprise (operative project)
Rearrangement to the use of alternative administration software (operative project)

Investment project:
Construction of a new production hall for the expansion of the industrial capacity abroad (strategic project)

The internationalization aims shall orientate themselves to chapter 3.5..

Trainerguidline of module project management and organisation

2nd group exercise:

Prepare a project structure plan for the project „acquisition of a new computer network in an enterprise."

Discuss the alternative representation of the project expiry in the form of process groups. Decide in an estimation of your own which of the form of the project structuring is more suitable.

Derive a fitting model of the project organization from your results.

Determine the project manager of your project.

Prepare the additional project plans on the basis of the project structure plan.

You summarize your planning, into the in an overall plan

- Methods,
- Project steps,
- Responsibilities,
- Responsibilities and
- Critical points of the project planning are represented risks/.

Prepare this plan also as a time schedule (Gantt).

Solution for the 2nd group exercise:

The project structure plan should orientate itself to capital 8.5.. The overall plan consists of the project structure plan as well as chapter 9th steps for the project success.

3rd group exercise:

Prepare a project structure plan for the project „development of a vehicle engine".

Discuss the alternative representation of the project expiry in the form of process groups.

Which special decisions have to be taken into account particularly at strategic projects?

Which differences at the division of the responsibilities do you see?

Decide in an estimation of your own which of the form of the project structuring is more suitable.

Derive a fitting model of the project organization from your results.

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Determine the project manager of your project.

Which tasks of the project manager have been there opposite the solution of the first task?

Prepare the additional project plans on the basis of the project structure plan.

You summarize your planning, into the in an overall plan
- Methods,
- Project steps,
- Responsibilities,
- Responsibilities and
- Critical points of the project planning are represented risks/.

Prepare this plan also as a time schedule (Gantt).

Don't let you stay during the discussion about the individual planning steps by technical details of the engine development but consider the task an exercise to the project management topic not you as a construction task ().

Solution indication for the 3rd group exercise:

The project structure plan should orientate itself to capital 8.5.. The overall plan consists of the project structure plan as well as chapter 9th steps for the project success. The representation into process groups orientates itself to 510th project management process groups.

In addition to the 2nd task the area of responsibility of the project manager was extended by challenge of the very coordination intensive work of an F+E project. Besides logistical and organizational tasks the project manager must either take on the leadership of the project technically or put informed advisers for him aside. A model production of an engine is additional to take a variety of critical ways into account in the F+E project work, since (as in this case) the punctual completion and check of all influencing components meant.

4th group exercise

Prepare a project structure plan for the project „restructuring of a sales department in an enterprise".

Discuss the alternative representation of the project expiry in the form of process groups.

Decide in an estimation of your own which of the form of the project structuring is more suitable.

Derive a fitting model of the project organization from your results.

A restructuring project in an enterprise is always accompanied by personal decisions in favour of and contrary to wishes of employees.

Which special framework conditions can be seen in the context of a sensitive planning or which influence sociological points of view take in such a project?

In the enterprise, can or must project steps and putting into action steps be converted under the stipulation of the acceptance differently than in the first discussed organization project?

Discuss your opinions. Determine the project manager of your project.

Prepare the additional project plans on the basis of the project structure plan.

You summarize your planning, into the in an overall plan
- Methods,
- Project steps,
- Responsibilities,
- Responsibilities and
- Critical points of the project planning are represented risks/.

Prepare this plan also as a time schedule (Gantt).

On which special influence sizes does the successful putting into action depend in the reality, (i.e. in an enterprise working really)?

Solution indication for the 4th group exercise:

The project structure plan should orientate itself to capital 8.5.. The overall plan consists of the project structure plan as well as chapter 9th steps for the project success. The representation into process groups orientates itself to 510th project management process groups.

Special framework conditions are given by the psychological load of the employees in this situation. In this case employees must choose from their colleagues and the aims of the management between the loyalties. A good leadership integrated sociologically is based on the photo of these problems and the solution connected with that of the conflict in the project. Without an innate leadership fortune tasks don't have to be solved in this area. In this case an emphatic for right and wrong decisions is an existential prerequisite for every project manager.

The successful putting into action of the conviction of all employees therefore depends in an enterprise working really that the planned restructuring processes are to the advantage of everyone. Blockades the himself have to devotedly either be or be analyzed in the front-end due to grown structures by be divided previous structures cleared out. Last variant is more economical, however, divides the enterprise into final battery separators and persons affected horizontally.

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5th group exercise

Prepare a project structure plan for the project „construction of a new production hall for the expansion of the industrial capacity abroad“.

Discuss the alternative representation of the project expiry in the form of process groups.

It is an investment project.

Must which unusual features be taken into account taken into account at a construction project be in your opinion abroad?

Decide in an estimation of your own which of the form of the project structuring is more suitable.

Derive a fitting model of the project organization from your results.

Determine the project manager of your project.

Prepare the additional project plans on the basis of the project structure plan.

You summarize your planning, into the in an overall plan

- Methods,
- Project steps,
- Responsibilities,
- Responsibilities and
- Critical points of the project planning are represented risks/.

The production centre shall be integrated into the supply system of the existing company structure abroad.

Which planning steps are necessary outside the pure construction project to make the connection with the enterprise?

Prepare a project structure short plan also to this.

Solution indication for group exercise 5:

The project structure plan should orientate itself to capital 8.5. The overall plan consists of the project structure plan as well as chapter 9 steps for the project success. The representation into process groups orientates itself to 5.10 project management process groups.

Foreign investments cause the attention of a variety of unusual features. Besides differences in the exchange rate in not EU countries and different habits at dealing with public administrations and its financing mentality differences have primarily to be taken into account. The picture of the German abroad is indicated as a „The German Bulldog“ or „The German tank“. It has proved therefore when very positive to show restraint and modesty abroad particularly as a German to not encourage prejudices of a latent German power inclination. To this you take „intercultural competence“ from the module details.

6th group exercise

Prepare a project structure plan for the project „rearrangement to the use of alternative administration software“.

Discuss the alternative representation of the project expiry in the form of process groups. Decide in an estimation of your own which of the form of the project structuring is more suitable.

Go from your own experience into problems of acceptance at the use of new software.

Which specific reservations can derive you from experience of their own from use with new software?

Under which circumstances can a failure of a software rearrangement be foreseen in every case?

Sociological and intercultural action countries are what at the introduction of new software.

Derive a fitting model of the project organization from your results.

Determine the project manager of your project.

Prepare the additional project plans on the basis of the project structure plan.

You summarize your planning, into the in an overall plan
- Methods,
- Project steps,
- Responsibilities,
- Responsibilities and
- Critical points of the project planning are represented risks/.

Prepare this plan also as a time schedule (Gantt).

Define risks of the software introduction which go beyond the pure time schedule of the implementation and assess possible results of the single risks.

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Solution indication for the 6th group exercise

The project structure plan should orientate itself to capital 8.5. The overall plan consists of the project structure plan as well as chapter 9 steps for the project success. The representation into process groups orientates itself to 5.10 project management process groups.

Introduction problems are frequently connected to the lack of understanding of a change of the existing solution at new software. New software generally is found too complicated. Reason for it is usually a material and so to speak natural lack of understanding in questions of the software. Software isn't understood in its depth but is reduced to few known and required processes in the use. For a certain time period, the acceptance of new versions diminishes since these known processes are changed. Since the integration of new media and technologies is carried out no longer completely as of a certain age group, a complete connection qualification isn't always possible either.

7th group exercise

Judge way the predefined critically.

With a project management different ways always lead to the aim. You have found an alternative way, the also have led and have no fundamental fault made or no risk at your project implementation you overlooked, you also can consider your way an excellent way so.

Solution indication for the 7th group exercise:

The critical judgement of the work of one's own is important in the context of an authenticity-related work. Test the participants at the admission of their faults or weak points and attach special importance to the realistic evaluation of the work. Die openly the self-assessment and/or overestimation without person reference to the difficulties, however.

Conviction grows from experience, lives to education,
personal and unteilhaft remain at the events.
Opinion is mass, conviction man.
(Stefan Zweig)

Mechatronics

Module 3: Fluidics

Solutions
(concept)

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EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

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1 Pneumatics

1.1 Compressed air supply

Exercise 1 *How does the temperature of a gas change, when the gas is compressed?*

The temperature of the gas rises up.

Which compressor types are frequently used?

The reciprocating piston compressors and the screw compressors.

Which frequently used possibilities for drying of compressed air are there?

The cold drying and the absorption drying. The diaphragm dryers are used at the maintenance units.

What is the order of flow passing through the single components of a maintenance unit?

The flow passes through the filter first, then through the pressure control valve. The last component is the oil mist lubricator.

What does the arrow indicate, that passes through the spring in the symbol of a pressure control valve?

The arrow means, that the spring's force is adjustable. This is used to change the pressure at the pressure control valve.

What is the purpose of the ventilation hole in a pressure control valve, and what happens when it is closed?

The ventilation hole passes the excessive pressure after the pressure control valve to the surrounding area. When the ventilation hole is closed, the pressure can not be reduced any more with the pressure control valve.

Which functions does the compressed air storage container have?

The compressed air container supplies compressed air covering the consumption peaks. The compressed air is cooled in the container after the compressor directly. This allows a part of the water contained in the compressed air to be separated.

1.2 Operating of a single-action cylinder

Exercise 2 A single-action cylinder should run out when a push button is pressed and run in immediately after releasing the button.

Complete the circuit diagram!

Questions *How should the diagram be changed so that the cylinder is normally driven out and runs in only after pressing the button?*

A valve with passing rest position must be used. The passing rest position can be realized in many valves applying the compressed air to connection port 3.

In this case, what should be taken into consideration concerning the directional control valve?

The used directional control valve should allow applying of compressed air to connection 1 or 3. This is usually possible with spool valves. But there are also seat valves with passing rest position.

Why does the single-action cylinder carry out work in one direction only?

The backstroke is performed by the force of the built in spring only. This force is not enough to carry out any additional work.

What is the purpose of the ventilation hole in the piston rod chamber of a single-action cylinder?

The ventilation hole prevents a pressure buffer from appearing in the piston rod chamber when the cylinder runs out, which acts as a force opposing to the motion direction. When the cylinder runs in the air passes through the hole preventing the buildup of negative pressure.

What should be taken into consideration concerning the operating force in a seat valve that applies different pressure values?

The operating force in seat valves depends on the applied pressure. The higher the pressure the larger the operating force.

Didactic tips

Before connecting the components in the circuit diagram the working principle of a maintenance unit should be reviewed. The adjusting of the pressure should be demonstrated.

The students should be notified, that pipes with unconnected ends may be dangerous when the pressure is applied to the other end.

The circuit diagram is represented in figure 1. It should be implemented with a seat valve and a spool valve successively. The different operating forces at different pressure values should be demonstrated.

Since the connections 1 and 3 in a 3/2-directional control valve of spool type can be interchanged, the circuit diagram should be accordingly changed, so that the cylinder is driven out when the valve is not activated.

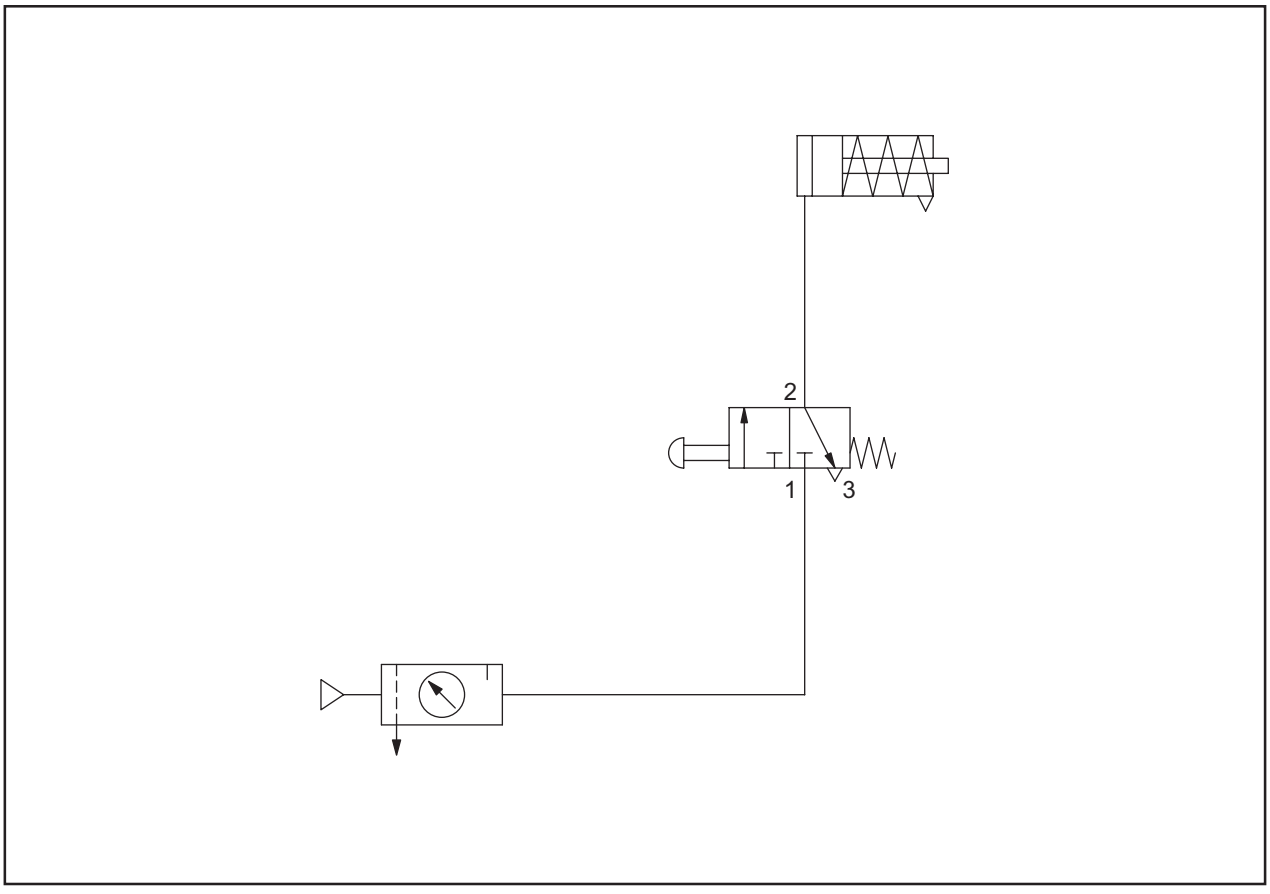

Figure 1: Operating of a single-action cylinder

1.3 Operating of a double-action cylinder

Exercise 3 A double-action cylinder should run out when pressing a button and run in immediately after the button is released.

Complete the circuit diagram!

Questions *What does the end position damping in a cylinder cause?*

The end position damping prevents strong impacts of the piston from happening at the end positions. It is required first of all in cylinders used to move large masses. External shock absorbers can be also used as alternative to end position damping.

Why is a ring magnet required in the piston?

The ring magnet allows to fix the piston at a certain position without direct contact. Cylinder switches are frequently arranged at the end positions of a cylinder. The cylinder switch generates a signal when the cylinder reaches its end position.

Which position does a normal double-action cylinder take, if the pressure is applied to both connections?

In a normal cylinder the piston's area is larger than the ring-shaped area of the piston at the side of piston rod. When applying the same pressure to both connections the force in moving out direction is higher due to the larger piston's area. Therefore, the cylinder will run out.

How much is the air consumption in a double-action cylinder higher than in a single-action cylinder? (Approximately)

The air consumption in a double-action cylinder is approximately two times higher. The cylinder is operated by alternate filling of the piston's chamber and the piston rod chamber with compressed air.

What is the difference between single and double arrows in a directional control valve?

Double arrows mean that the valve can pass in both directions. Single arrows indicate that there is only one passing direction.

Didactic tips

The cylinder should be operated with a 5/2-directional control valve first. The students should be notified that interchanging the connections 2 and 4 makes the cylinder in “driven out” position when the valve is not activated.

The functioning of the end position damping should be demonstrated. This is made by adjusting the screws of the end position damping chokes while the cylinder runs in and out. It should be also shown, that at a very strong throttling the end position can not reached any more.

After that the cylinder should be operated by means of two 3/2-directional control valves. The 3/2-directional control valve at the piston rod side should be connected in the passing rest position. Two 3/2-directional control valves have the same function of one 5/2-directional control valve.

However, it is also possible to apply pressure to both cylinder chambers or to leave them pressureless by operating of one directional control valve only. The possibility of pre-ventilation and the resulting increase of the piston’s speed must be also shown.

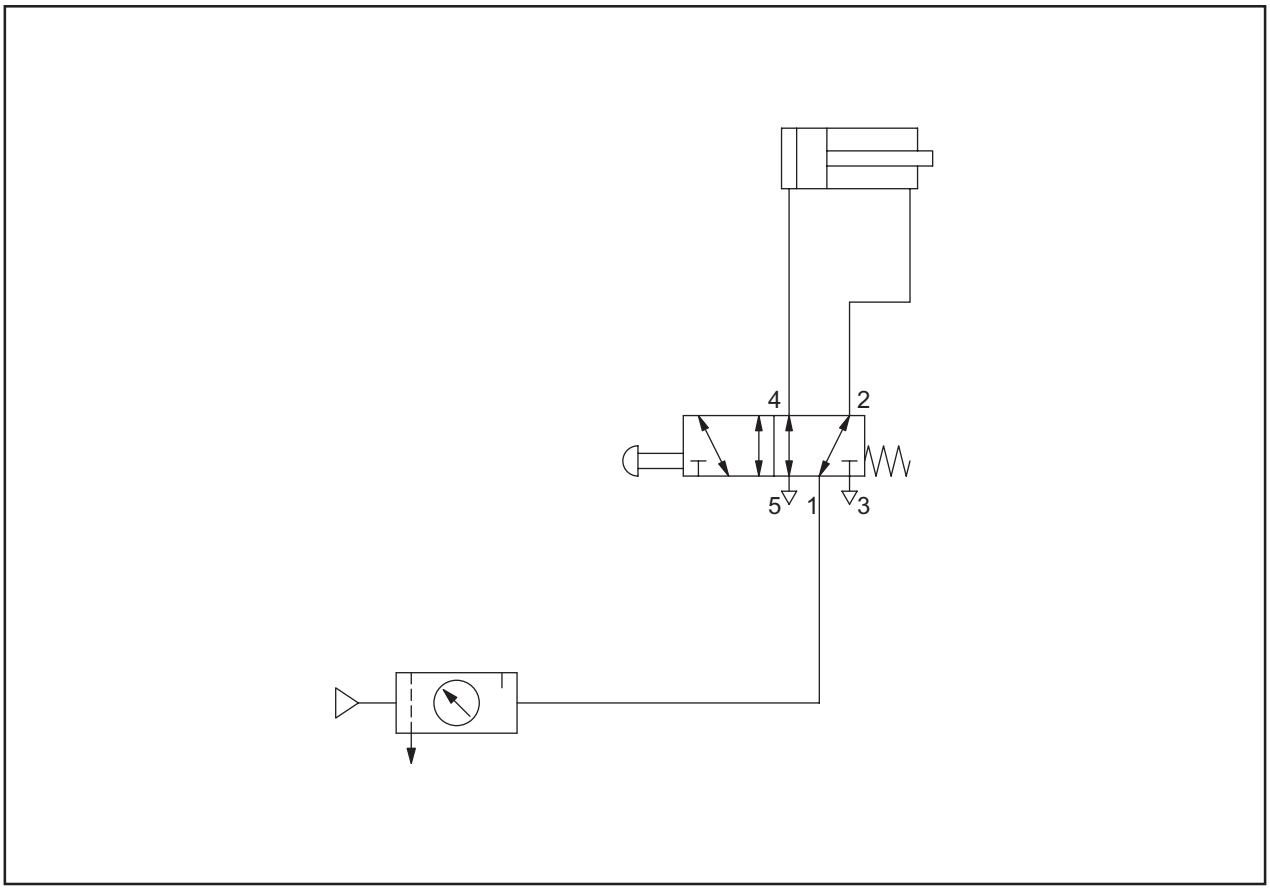

Figure 2: Operating of a double-action cylinder

1.4 Indirect operating of a cylinder

Exercise 4 A double-action cylinder should run out when pressing a button and run in immediately after the button is released. The directional control valve, which is used to activate the cylinder, should be operated pneumatically by pressing of a button.

Complete the circuit diagram! Indicate all connections of the valves!

Questions *In which case is the valve, that drives the cylinder, indirectly operated?*

Cylinders with large volumes are operated by means of large valves. In the indirect operating small valves can be used as switches. These switches can be arranged at some distance from the main valve.

What is the maximal allowed distance between the switch and the operated valve?

The switch and the signal elements in general should not be located at a distance exceeding 10m from the operated valve. Longer connection pipes cause high wastes in the signal strength.

Why is a pneumatically operated directional control valve unable to switch to other position when the applied control air has a pressure of about 1,5 bar?

The pressure is too low to switch the valve considering the surface area of the operating piston. The force produced by this pressure is smaller than the force of the return spring of the valve. Therefore, the valve is unable to switch.

What is the position of the 3/2-directional control valve in a pilot control?

The 3/2-directional control valve in a pilot control is located directly at the main valve. Therefore, the control signal connection is very short.

What is the pilot control used for?

The pilot control allows to operate the main valve applying very small operating forces. It is used first of all with the electrically operated valves. Since the required forces are low, it is possible to use small magnet coils with low energy consumption.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram. The difference between the signal elements and the actuators should be clarified.

The students should be also notified that the control connections are indicated with dashed lines. Pipes of different colour can be used to indicate the control connections on the experiment board.

After that a pressure control valve can be mounted in the incoming line of the switch. Reducing of the control pressure shows that a pneumatically operated 5/2-directional control valve needs a certain minimal pressure that should be applied to the control air connection.

The fact that the force of the air spring is dependent on the valve operating pressure should be also clarified. The required control pressure at different pressure values applied to the main valve should be also defined.

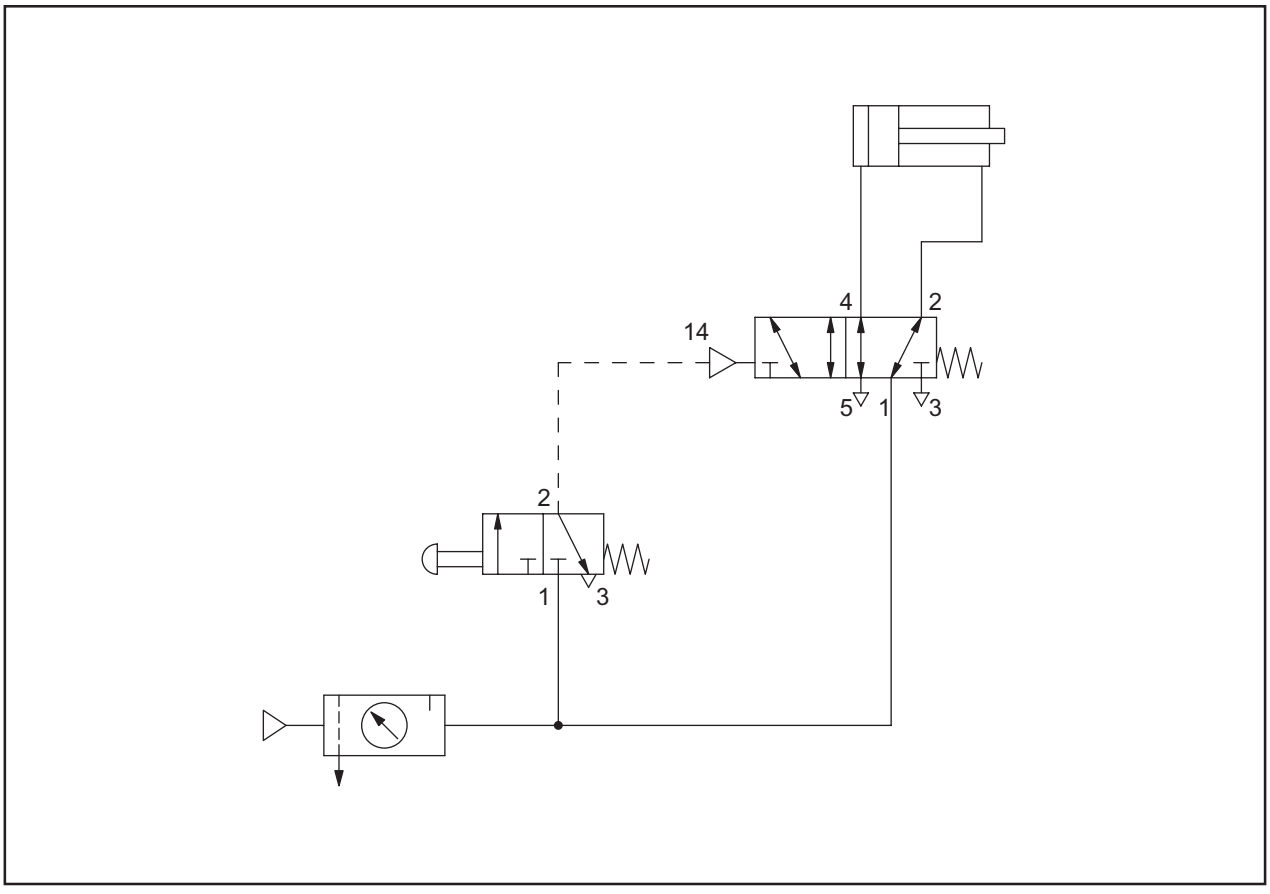

Figure 3: Indirect operating of a double-action cylinder

1.5 Operating of a cylinder using an impulse valve

Exercise 5 A double-action cylinder should run out when pressing a button and must still driven out after the button is released. The cylinder should run in again only after a second button is activated.

Complete the circuit diagram! Indicate all connections of the valves!

Questions *What happens if the second button is pressed when pressing the first button?*

The signal of the second button is unable to switch the impulse valve as long as the signal of the first button is still applied.

What is the initial state of the impulse valve at which the compressed air is applied without pressing any of the buttons? What is the position of the cylinder in this case?

Since the impulse valve doesn't have a certain initial state it can be switched to any of the both possible positions. Therefore, the cylinder may run out immediately after switching the compressed air on.

Which type of impulse valves provide different priority for the control air connections?

Impulse valves with differential pistons have a control piston with different surface areas. When the same control pressure is applied to both connections, the signal applied to the control connection with the larger piston surface area has a higher priority.

A single-action cylinder should be operated by means of an impulse valve. There are only 5/2-directional control valves available. How can this control be performed?

Closing one of the both output connections turns the 5/2-directional control valve to a 3/2-directional control valve. When a 3/2-directional control valve with blocking rest position is needed the cylinder should be mounted to the connection number 4.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram.

Activate each of the buttons for a short time in order to set the cylinder in motion.

Both possible positions of the impulse valve should be demonstrated. This is made by moving the cylinder to the “driven out” position and then switching the compressed air off. Then the cylinder should be driven in by hand. After switching the compressed air on again the cylinder will move immediately to the “driven out” position. Hereby, the position of the impulse valve should be pointed out.

Activating of both buttons shows that the impulse valve is unable to switch as long as there is pressure applied to the other control air connection.

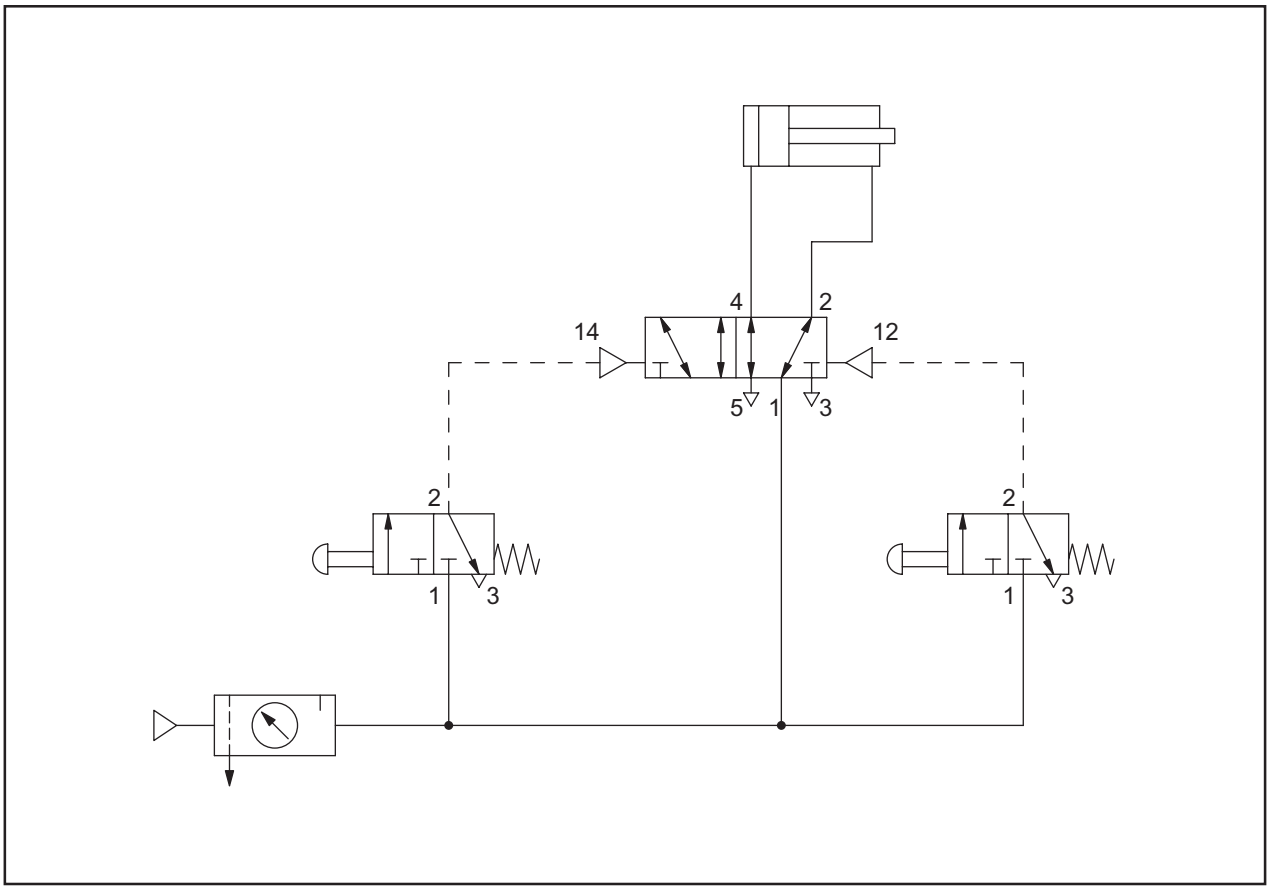

Figure 4: Operating of a cylinder using an impulse valve

1.6 The speed control of a cylinder

Exercise 6 A double-action cylinder should run out when pressing a button and must still driven out after the button is released. The cylinder should run in again only after a second button is activated. The speed of moving out can be reduced by means of a check choke valve. The back stroke should not be throttled.

Complete the circuit diagram!

Questions *Why is the symbol of a check choke valve surrounded with a dash-doted line?*

The check choke valve consists of a choke and a check valve. To show that both components are placed in one housing their symbols are surrounded with a dash-doted line.

Why is the outgoing air throttling preferred to the incoming air throttling?

When using the outgoing air throttling the pressure is applied to both sides of the piston. This makes the cylinder move considerably smoother, specially at low speeds. On the other hand, the incoming air throttling can cause a slip stick.

When should the incoming air throttling be used?

The incoming air throttling should be used only with very small cylinders and single-action cylinders. In single-action cylinders the spring damps any possible non-uniform movement.

Which component is used to increase the speed of a cylinder?

The speed is increased using a quick exhaust valve. The pipe connecting with the quick exhaust valve must be as short as possible.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram.

The moving out speed is reduced by means of the outgoing air throttling. The choke should be adjusted so that the cylinder's speed is clearly reduced.

After that the check choke valve should be used for the incoming air throttling and the difference with the outgoing air throttling should be clarified.

The types of check choke valves that can be screwed in the cylinder connections should be pointed out. The influence of the connection length between the cylinder and the check choke valve must be clarified. The chokes that can be built directly in the outgoing air connections of a directional control valve should be also mentioned.

When demonstrating the increase of the cylinder's speed by means of a quick exhaust valve the connection between the cylinder and the quick exhaust valve must be as short as possible. The most optimal is using of quick exhaust valves that can be screwed directly in the cylinder's connection.

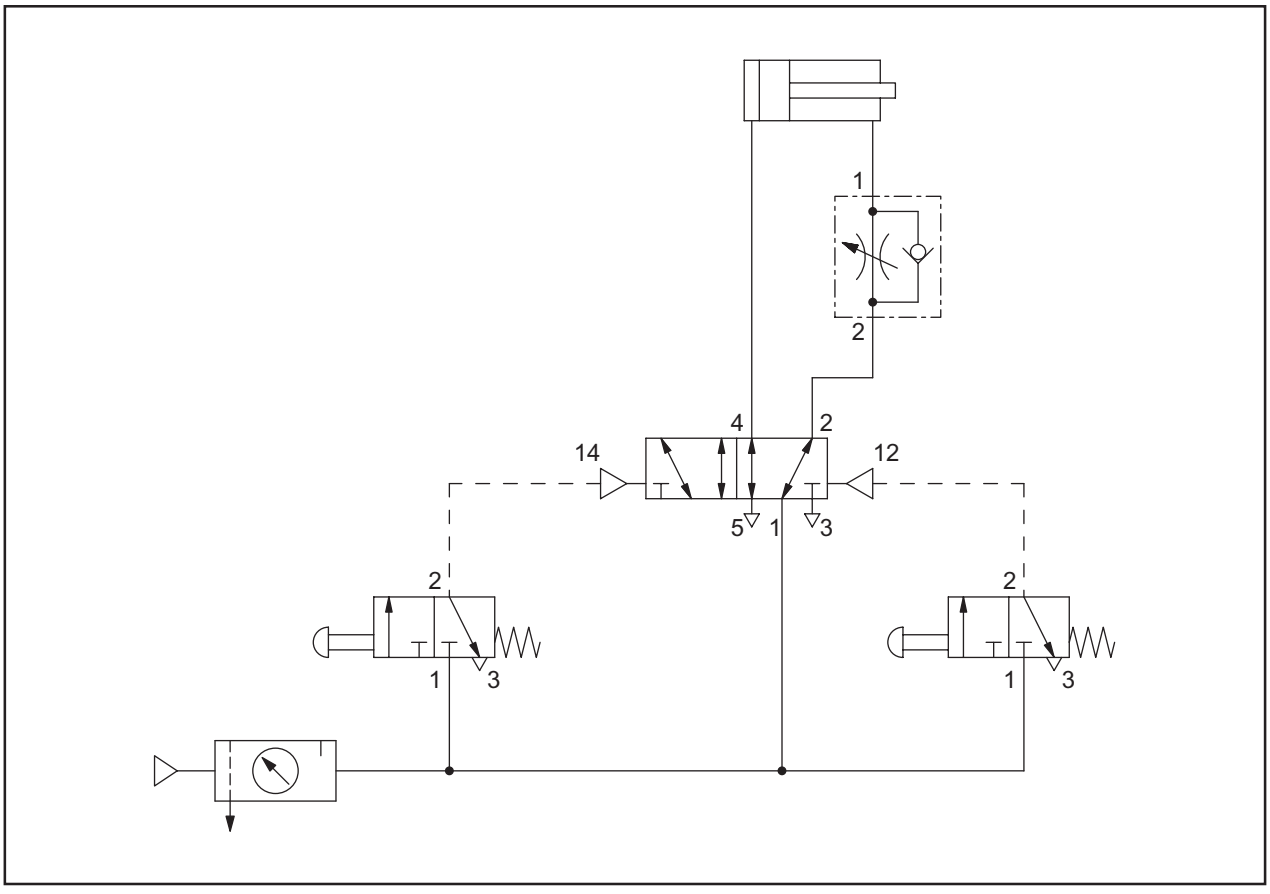

Figure 5: The speed control of a cylinder

1.7 The stop-control of a cylinder

Exercise 7 A double-action cylinder should run out when pressing one button and run in again when a second button is activated. The cylinder moves only while a button is pressed. The cylinder's speed must be adjustable in both directions.

Complete the circuit diagram!

Questions *What are the usual middle positions of the 5/3-directional control valves in the pneumatics?*

Besides the blocking middle position described in the exercise there are also two other usual middle positions in the pneumatics. In the blow-through middle position pressure is applied to both outlet ports of the directional control valve. Whereas in the ventilated middle position the outlet ports are connected with the ventilation holes. Therefore, the cylinder connections are pressureless.

Which middle positions can be also realized using two 3/2-directional control valves?

The blow-through and the ventilated middle positions can be also realized using two 3/2-directional control valves. These are also switched in such a way that either pressure is applied to both cylinder connections at the same time or they are both pressureless.

Which device allows to fix the cylinder mechanically in a certain position?

Locking units are used to fix cylinders mechanically at a certain position. The locking unit is not used for slowing down the cylinder's motion. The cylinder is stopped by means of a 5/3-directional control valve.

Which feature should a check valve have, when it must be connected to the inlet pipe of a cylinder?

The check valve must be unlockable. In order to unlock the check valve in the blocking direction pressure is applied to the control connection.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram.

Activate each of the buttons for a short time in order to set the cylinder in motion.

The speed should be adjusted using the check choke valves so that several stops of the cylinder within a stroke are possible.

When possible, this experiment should be also implemented with a cylinder which runs out downwards. A mass attached to the piston rod can represent a pulling down load.

It is possible to monitor the pressure inside the piston chamber mounting additional manometers in the connections between the check choke valves and the cylinder. The students should be notified that the pulling load produces additional pressure.

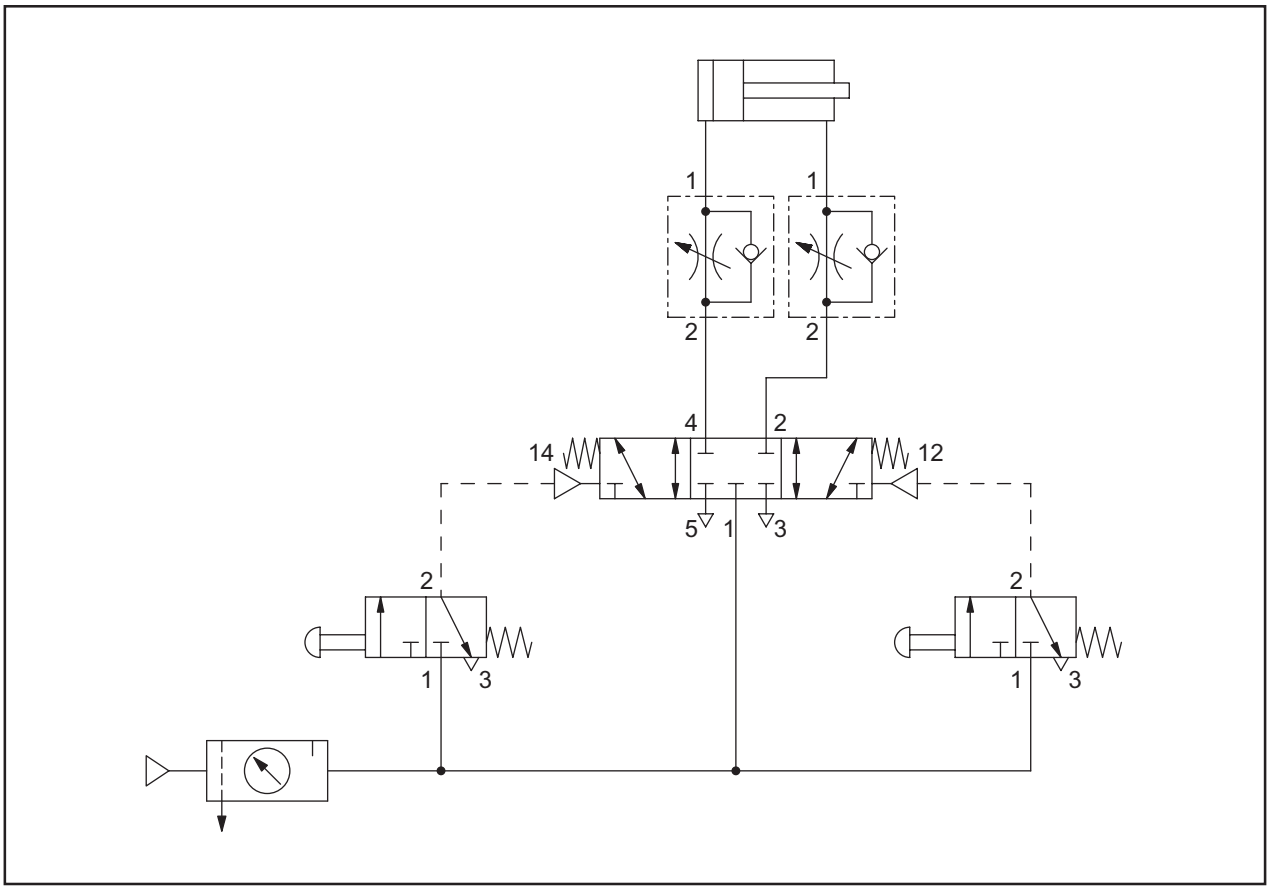

Figure 6: The stop-control

1.8 Stroke-dependent control

Exercise 8 A double-action cylinder should run out when pressing a button and must run in again immediately after reaching the “driven out” end position. The running out is only possible when the cylinder stands at the “driven in” end position.

Complete the circuit diagram! Indicate the single components!

Questions *How can the stroke be shortened?*

The follower roll makes the cylinder run in again after it reaches the “driven out” position. In order to make the cylinder run in earlier the roll should be placed closer. The cylinder doesn’t reach its “driven out” end position. The cylinder’s speed should not be very high. In this case the roll can be passed through, and the generated signal is too short and not enough to switch the impulse valve.

What happens if the starting button remains continuously pressed?

While the button is pressed the cylinder will continuously move but and ben between both end positions. A new moving outwards can start only after the cylinder is completely driven in, because the follower roll at the “driven in” position and the start button are switched one after another.

What happens if the follower roll of the “driven in” position jams and remains continuously active?

When the follower roll at the “driven in” position remains continuously active and the start button remains pressed at the same time, there will be a continuous signal applied to the connection 14 of the impulse valve. In this case, the signal of the follower roll at the “driven out” position is unable to switch the impulse valve and the cylinder remains driven out.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram.

The students should be notified that the symbols of the directional control valves are located in the lower part of the diagram near the signal elements, although the follower rolls are arranged on the piston rod.

The indication of single elements and the activated follower rolls in the diagram should be clarified.

The start button should be activated for a short time to set the cylinder in motion.

The follower roll at the “driven out” end position can be shifted in order to change the stroke length. If this roll was positioned too distant from the cylinder no back stroke will be carried out.

The correct positioning of the follower roll at the “driven in” end position should be also clarified. An incorrect positioning can prevent the cylinder from moving out.

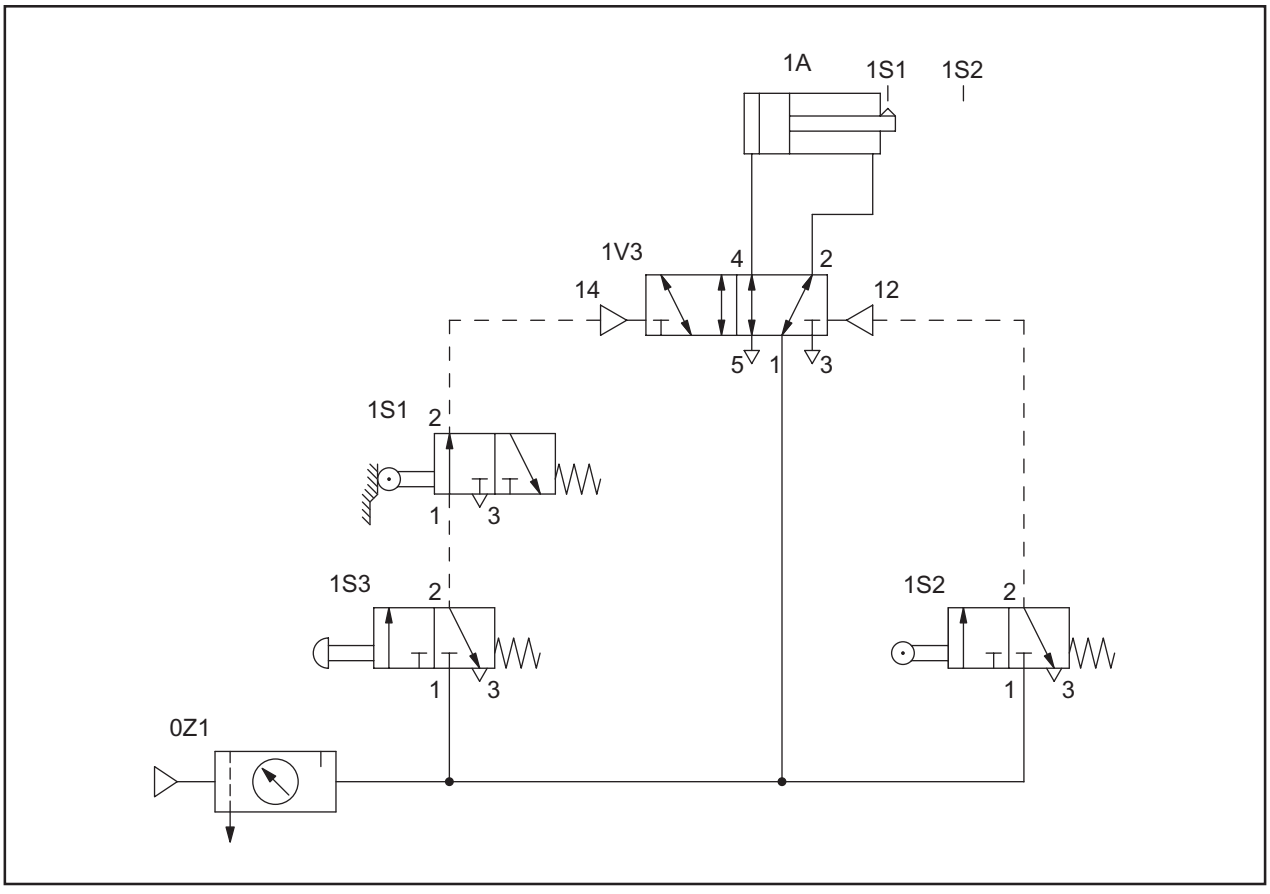

Figure 7: Stroke-dependent control

1.9 Logical combination of signals

Exercise 9 A double-action cylinder should run out when pressing one of two different buttons. The cylinder can run in only after it reaches its “driven out” end position and another button is activated.

Complete the circuit diagram!

Questions *How do we call the logic combinations with alternating check valves and dual-pressure valves?*

Alternating check valves can be used for OR-combinations. If both or one of the input signals is present the output signal will be also set on. The dual-pressure valve represents an AND-combination. The output signal is set on only if both input signals are applied at the same time.

A cylinder must run out only when four signals are present. How many dual-pressure valves are needed?

Since a dual-pressure valve has two input ports, we need two dual-pressure valves for four signals. The output ports of both dual-pressure valves should be connected to the input ports of another dual-pressure valve. Therefore, three dual -pressure valves are required. The number of required valves in general is always one less than the number of input signals.

Two different pressures are applied to a dual-pressure valve. Which pressure is applied to the output?

In dual pressure valves the smaller input pressure is always applied to the output. Specially when placing several dual-pressure valves one after another, the smallest pressure will be applied to the output. To prevent this from happening the dual-pressure valve should be replaced with a pneumatically operated 3/2-directional control valve. Hereby, the smallest pressure will switch the directional control valve, whereas the highest pressure will be applied to the output.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram. The follower roll is placed at the cylinder 's "driven out" end position.

Activate each of the buttons for a short time in order to set the cylinder in motion. This can be also made activating both buttons at the same time.

The students should be notified that a back stroke can start only if the follower roll at the "driven out" end position and the back stroke button are activated together.

The AND-combination using a dual-pressure valve should be compared with a series connecting of two valves.

Other logic functions that can be realized using pneumatic valves should be also pointed out. The possible alternative circuit combinations for alternating check valves and dual-pressure valves should be also clarified.

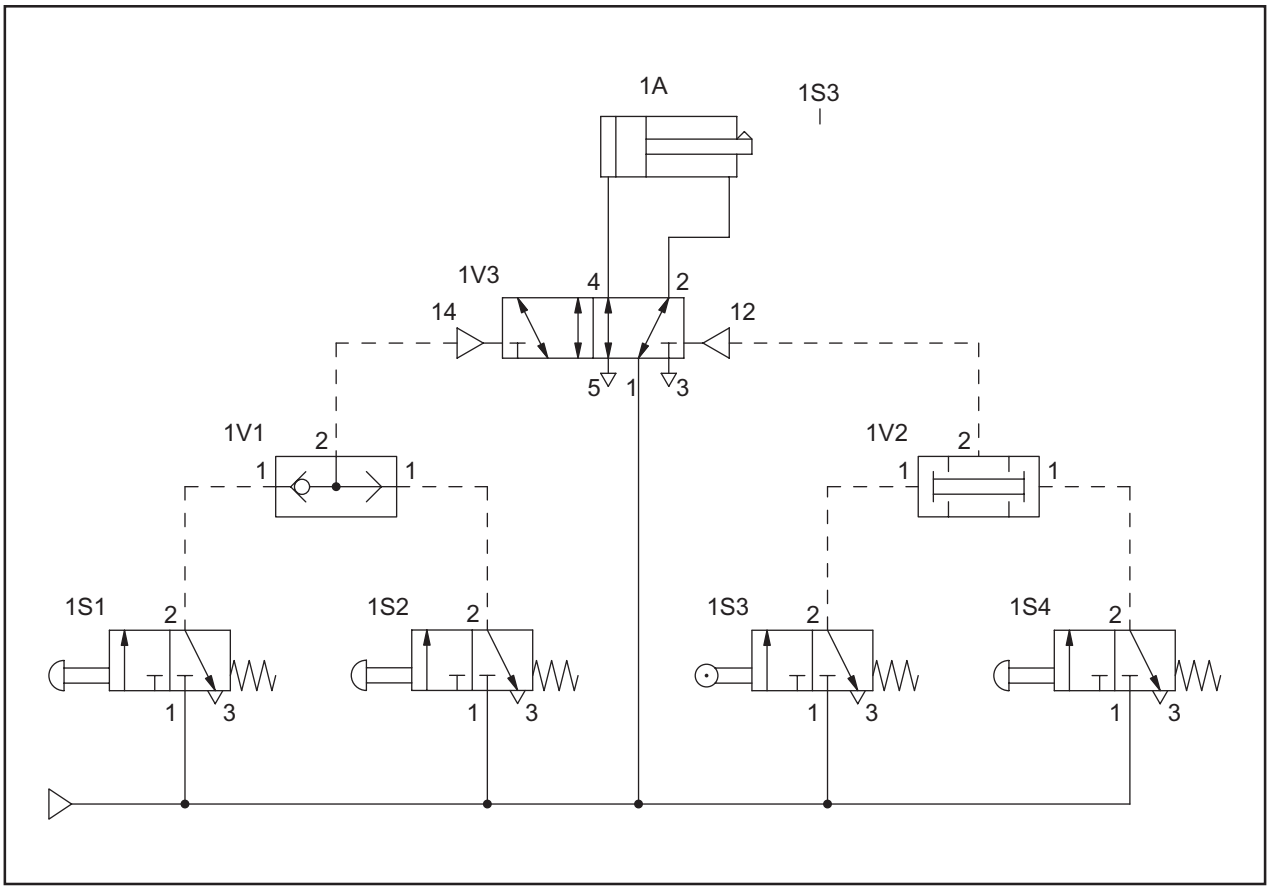

Figure 8: Logical combination of signals

1.10 Time-dependent control

Exercise 10 A double-action cylinder should run out when a button is pressed. After reaching the “driven out” end position the cylinder should remain driven out for 10 seconds and then run in autonomously. The running out is only possible when the cylinder stands at the “driven in” end position.

Complete the circuit diagram! Indicate the single components!

Questions *Which components does the pneumatic time element include?*

The pneumatic time element consists of a check choke valve, a container and a pneumatically operated 3/2-directional control valve. The time element can be built from the single components if required. The container can be a part of the piping connection system in this case.

Which component is used to adjust the time? How can the time period also be increased?

In a pneumatic time element the time length is adjusted by turning the choke’s screw. The more the choke is opened the faster the container is filled with compressed air and consequently switches the directional control valve also faster. The time period can be increased by connecting an additional reservoir to the container, which increases the volume and the amount of compressed air that can flow in and makes the pressure rise slower. The time element switches consequently later.

Which additional component allows to make the functioning of the pneumatic time element observable?

A manometer can be connected to the additional reservoir. The manometer makes the pressure changes inside the container observable. This is very useful at operation start up and at error checking.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram. The cylinder activates the follower rolls.

Activate the start button for a short time to set the cylinder in motion. The time element should be adjusted to 10 seconds first. Then shorter and longer time periods should be tested.

A manometer should be mounted on the time element container if possible in order to watch the pressure.

The possibility of switching signals off by means of time elements should be clarified. This can be made in the passing rest position by applying the signal to connection 3.

A time element can be additionally assembled from single elements.

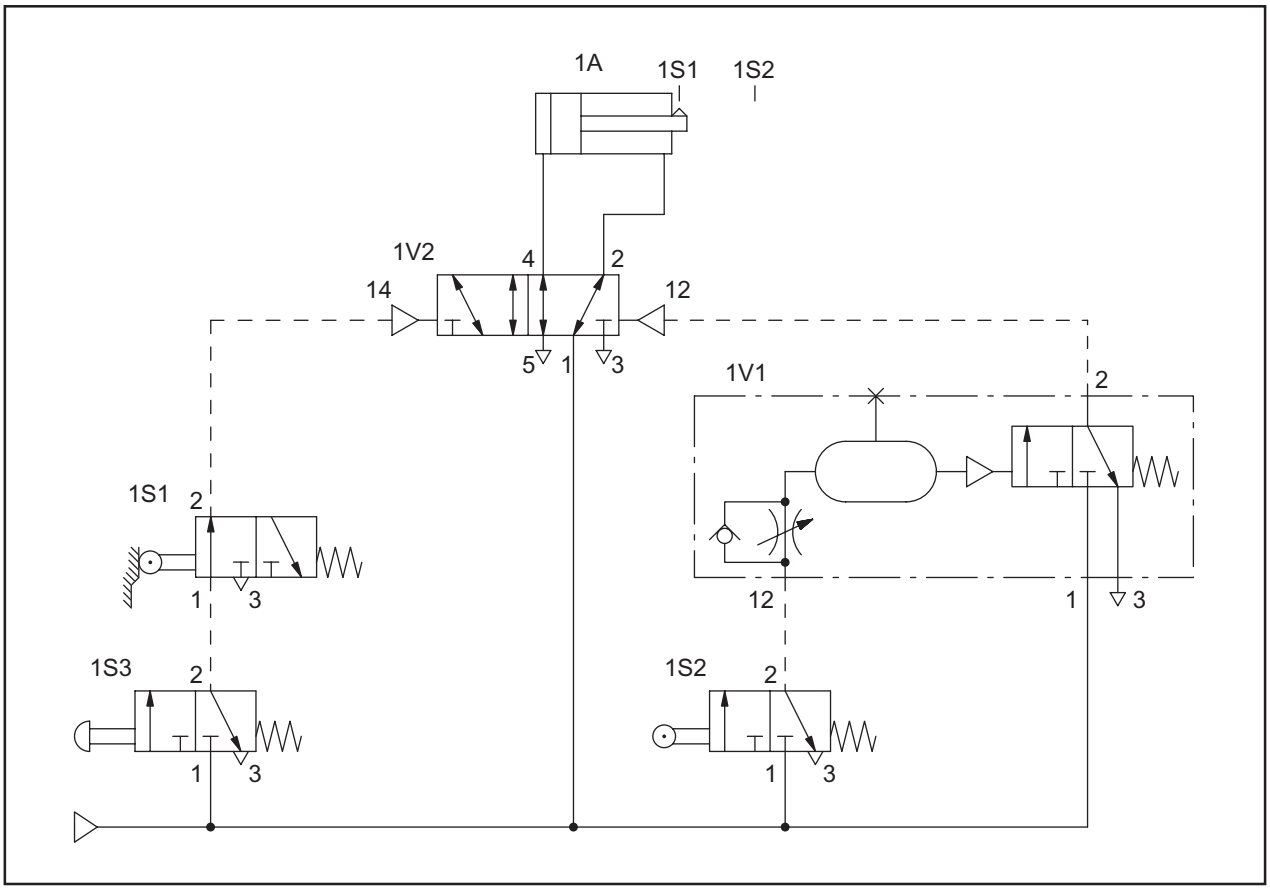

Figure 9: Time-dependent control

1.11 Sequence control

Exercise 11 A double-action cylinder should run out when a button is pressed. After reaching the “driven out” end position a second cylinder must run out. The first cylinder must run in again after the second is driven out. After that the second cylinder must also move back to its starting position. The system may start only when the first cylinder stands at the “driven in” end position.

Draw the function diagram!

Complete the circuit diagram! Indicate the single components!

Questions *What is the state called, at which in a sequence control, the signal is applied to both control air connections of an impulse valve?*

If a signal was applied at once to both control connections of an impulse valve within a control process, a signal overlapping results.

How can be ensured, that an impulse valve stands in the correct position at the beginning of the control function?

Many simple control systems take the starting position automatically after switching the compressed air on. This can start the motion of the cylinder. If the starting position was not taken automatically a setting pulse should be applied to the corresponding control air connection (usually connection 12). The alternating check valve at the control air connection is used to ensure the switching of the valve when a normal control signal or a setting pulse is applied.

Didactic tips

Connect the components and implement the experiment. The components should be arranged like it is shown in the circuit diagram. The cylinders activate the follower rolls.

Start the control process activating the start button. If the process functioning was not correct a systematic error checking is required. Hereby, it is important to control which follower rolls are activated and which valves must be consequently switched.

The function diagram should be clarified.

The students should be notified once again that impulse valves don't have any defined initial position. For that, the compressed air should be switched off within the process and the driven out cylinders should be shifted back by hand. After that the compressed air should be on again. Watch the movement of the cylinders.

The signal overlapping, that happens when pressure is applied to both control air connections of an impulse valve, may be also reviewed. The possible solutions should be demonstrated.

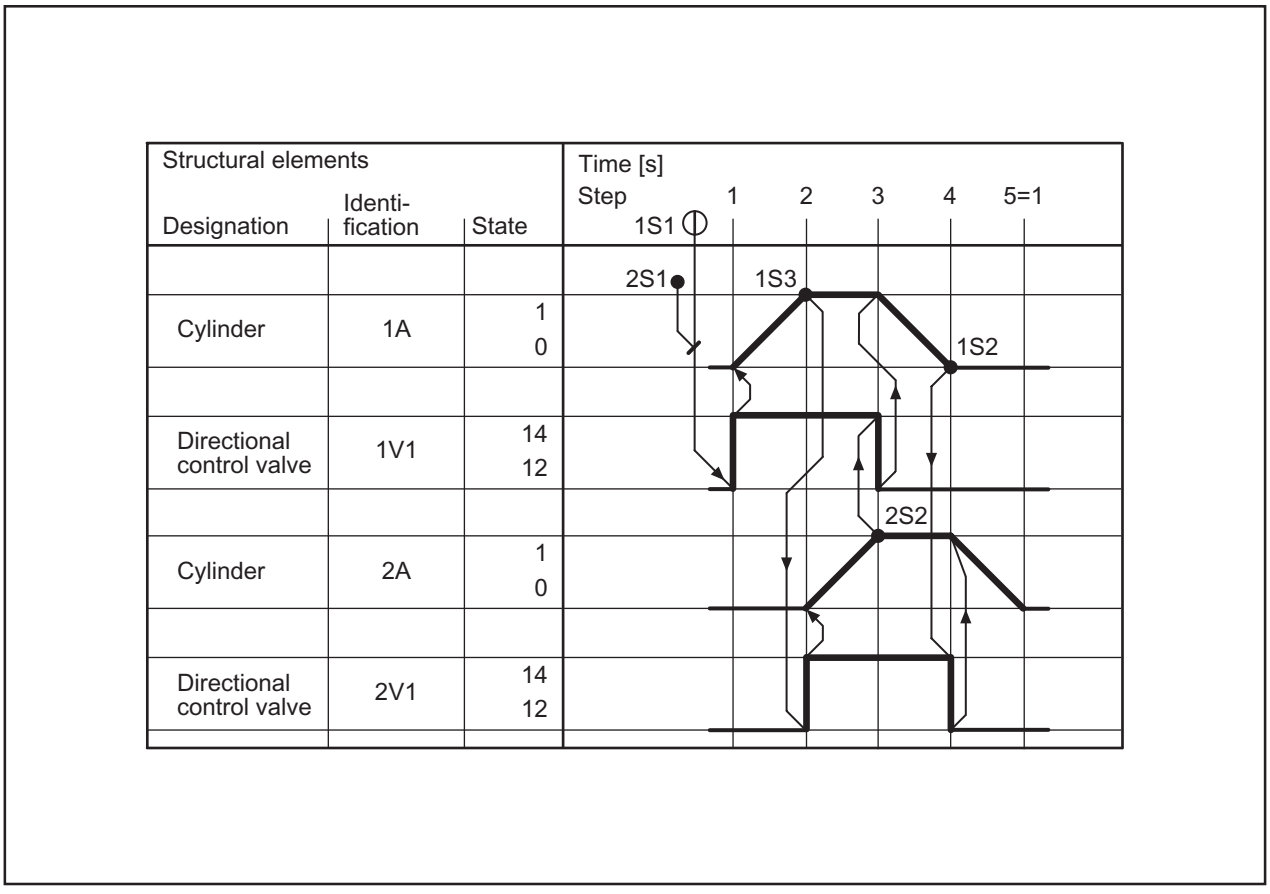

Figure 10: Function diagram

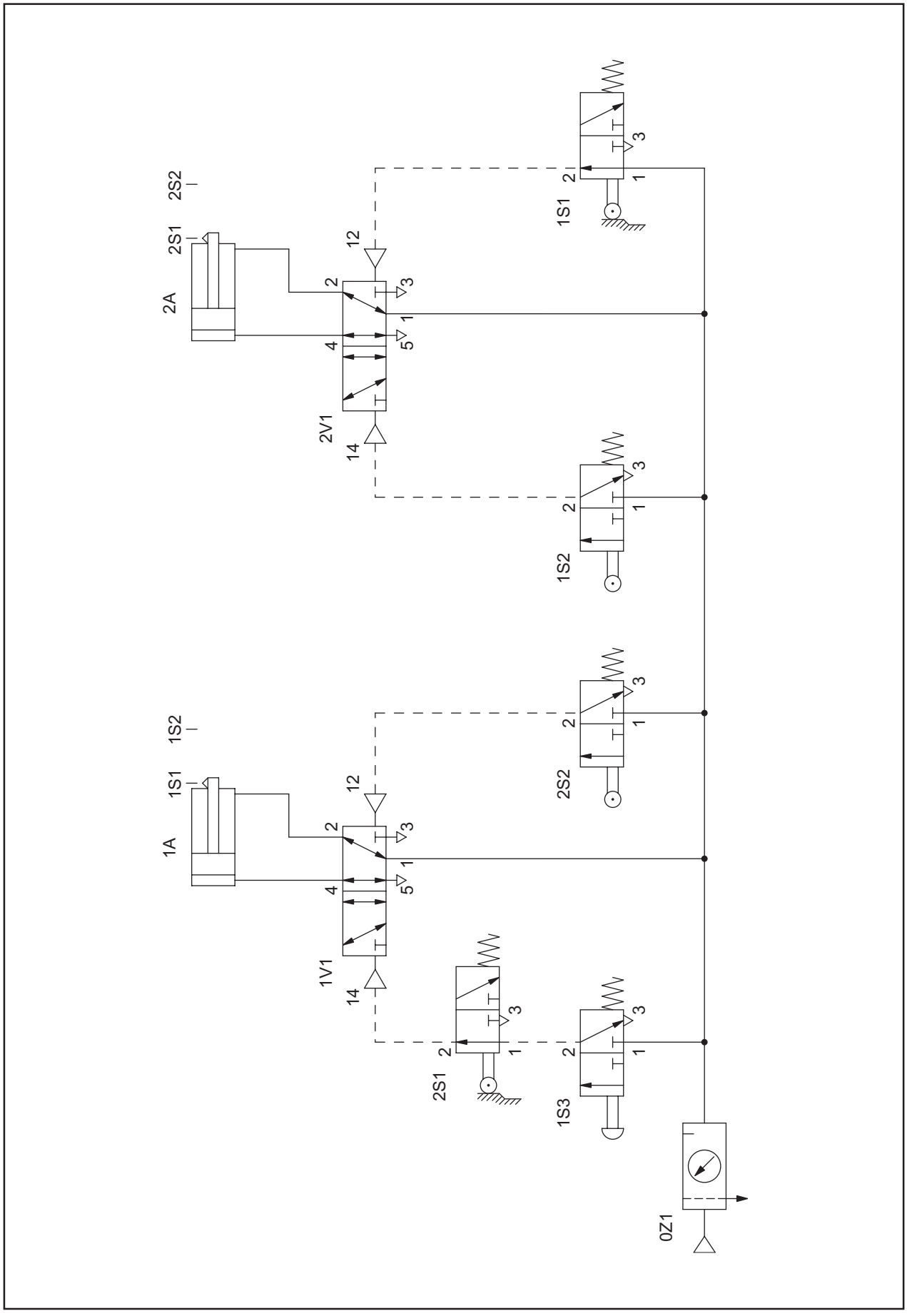

Figure 11: Sequence control

2 Electropneumatics

2.1 General

In these exercises two different forms of energy are used. The electrical energy is used besides the compressed air. The electrical energy may be hazardous for health or even for life.

Therefore, the equipment in these experiments uses a safety-low voltage. The devices are usually operated with 24 V direct voltage. The used power supplies should be short-circuit proof, because even accurately connected circuits may contain errors.

After finishing the exercises, it is not allowed to perform any experiments with the equipment using alternating voltage higher than 50 V or direct voltage higher than 120 V.

The exercises concentrate on the relay technics, which has a wide range of uses. However, there are some exercises concerning the programmable logic controls (PLC). The knowledge of the basics of relay technics is of advantage and some times essential for working with these controls.

The electrical components are connected with laboratory cables of different colours. Cables going to the consumer should be of red colour.

The power supply should be turned on only after all the components are connected together.

In the pneumatic part, the tightness of the flexible tubes and pipes should be checked-out first of all. If a pressurized tube loosens it may be dangerous and cause damage and even injuries because of the whiplash effect.

2.2 Operating of a single action cylinder

Exercise 12

A single-action cylinder should run out when a button is pressed and run in again after releasing the button.

The cylinder is operated by means of a 3/2-directional control valve with magnet coil direct control. The magnet coil is directly operated by a button. The service unit should be also drawn.

Complete the pneumatical and the electrical diagrams!

Questions

In which direction does the bar of the magnet coil move, when the current is applied to the coil?

The bar is pulled into the coil.

What is the name of the contact, which passes current when operated?

This is the normally open contact.

Didactic tips

This first simple exercise should contain briefing about the experimental equipment. The students should be notified of the possible danger when handling with electrical voltages, even if the used voltages do not exceed 24 Volt.

Both electrical and pneumatical energy sources should be turned on when implementing the experiments.

The students should be informed of the technical data of the magnet coils and the possibility of the replacement of coils. It should be explained, that only small valves can be directly operated using magnet coils.

Furthermore, the manual supporting valve operation should be clarified.

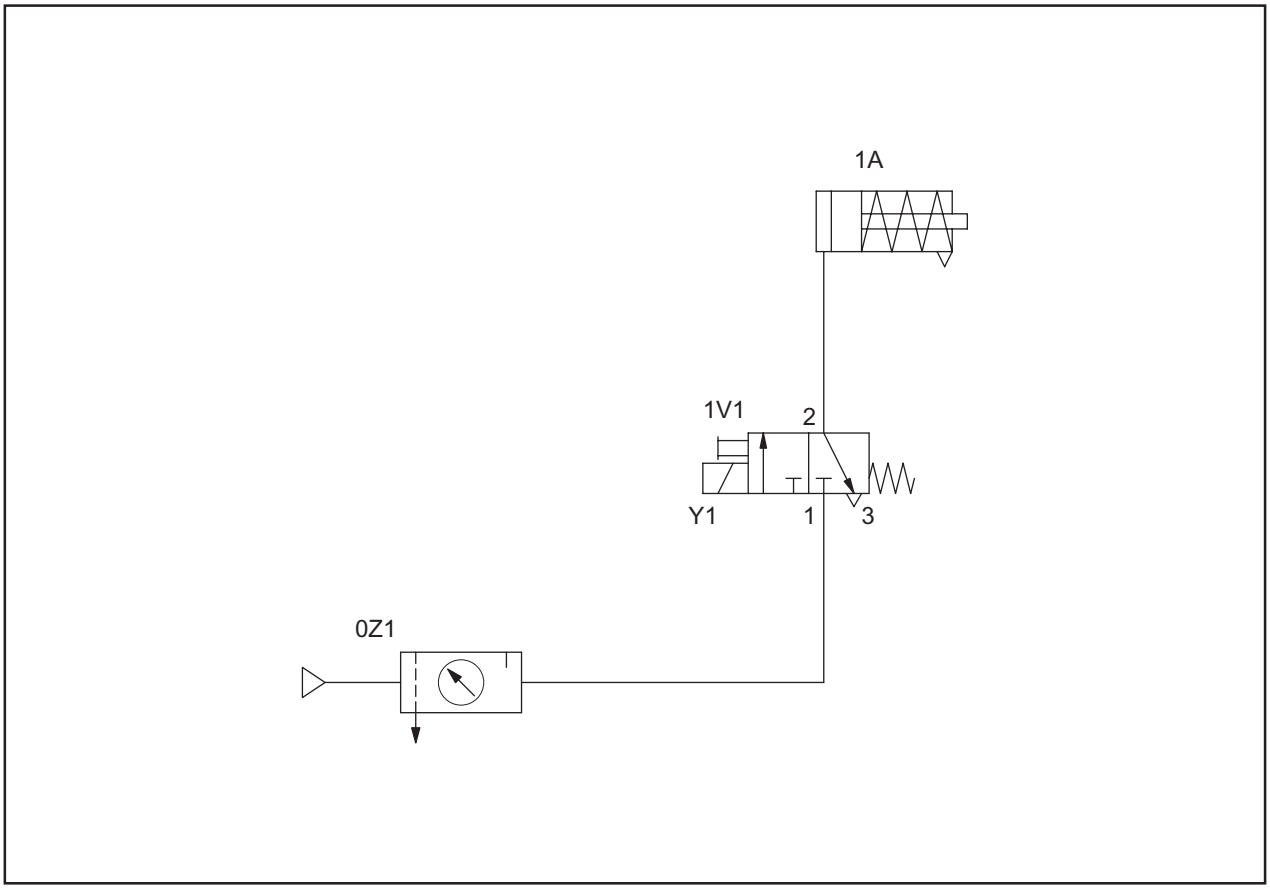

Figure 12: Pneumatic diagram of the single action cylinder

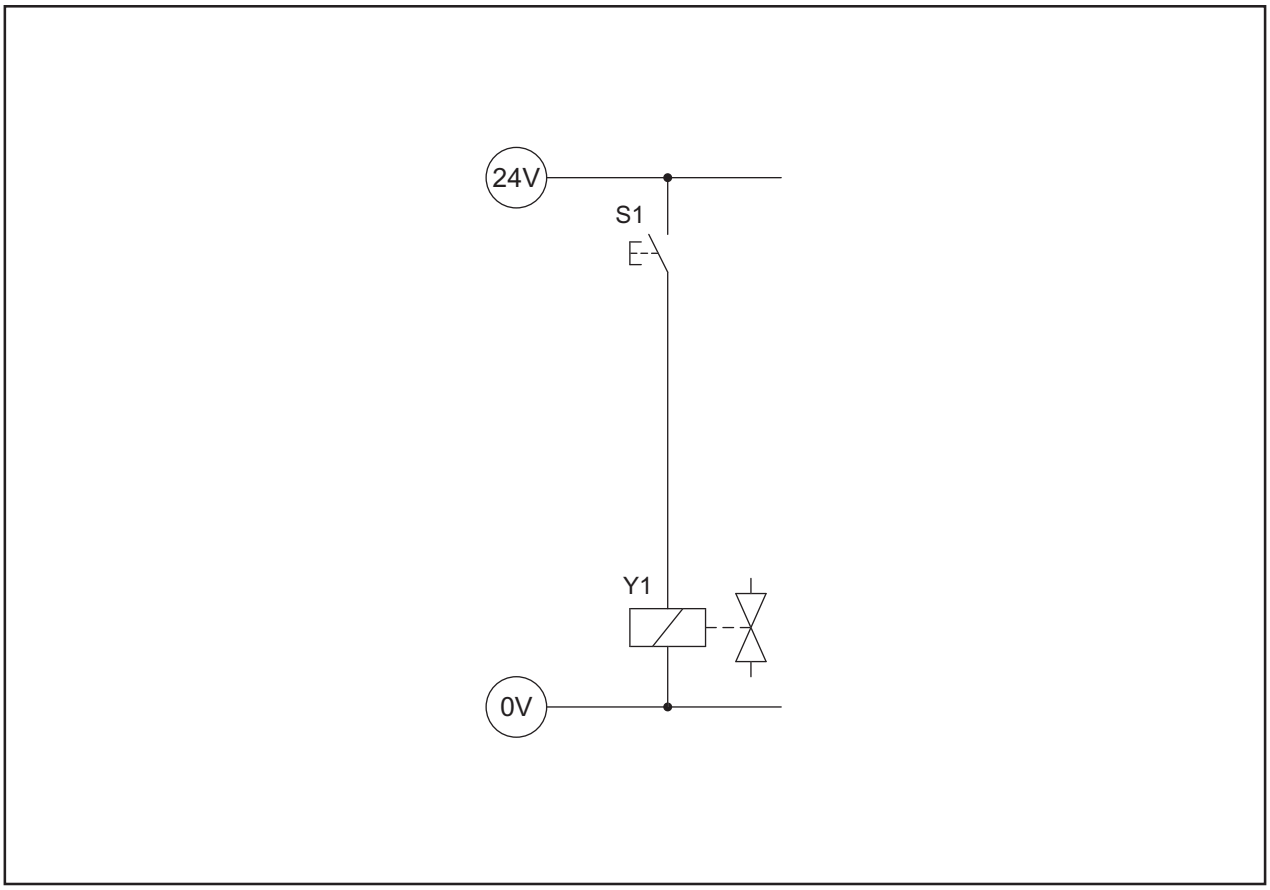

Figure 13: Circuit diagram of the single action cylinder

2.3 Circuits with relays

Exercise 13

A double-action cylinder should run out when pressing a button and must still driven out after the button is released. The cylinder can run in again only after a second button is activated.

Each of the buttons activates a relay. Each relay has one contact, which switches the magnet coils of an impulse valve. The service unit should be drawn in the pneumatic diagram.

Complete the pneumatic and the electrical diagrams!

Questions

Which code letters indicate the relays in the diagrams?

The relays are indicated with the letter K.

Where should the relays be arranged in the current path?

The relays should be always placed at the bottom in each current path.

Didactic tips

This exercise clarifies the functionality of the relays. The technical data of the relays should be determined. Important data, such as voltage value, current type and power of the coils, as well as the possible tension of the contacts should be highlighted.

This experiment can be also implemented without using relays. Therefore, other alternatives, such as contact multiplication and possible different voltage values at the regulation and the power parts should be discussed.

Furthermore, the manual supporting operation of the directional control valve should be demonstrated. Applying of compressed air to the directional control valve is required for the manual supporting operation. The students should be reminded of the functioning of impulse valves.

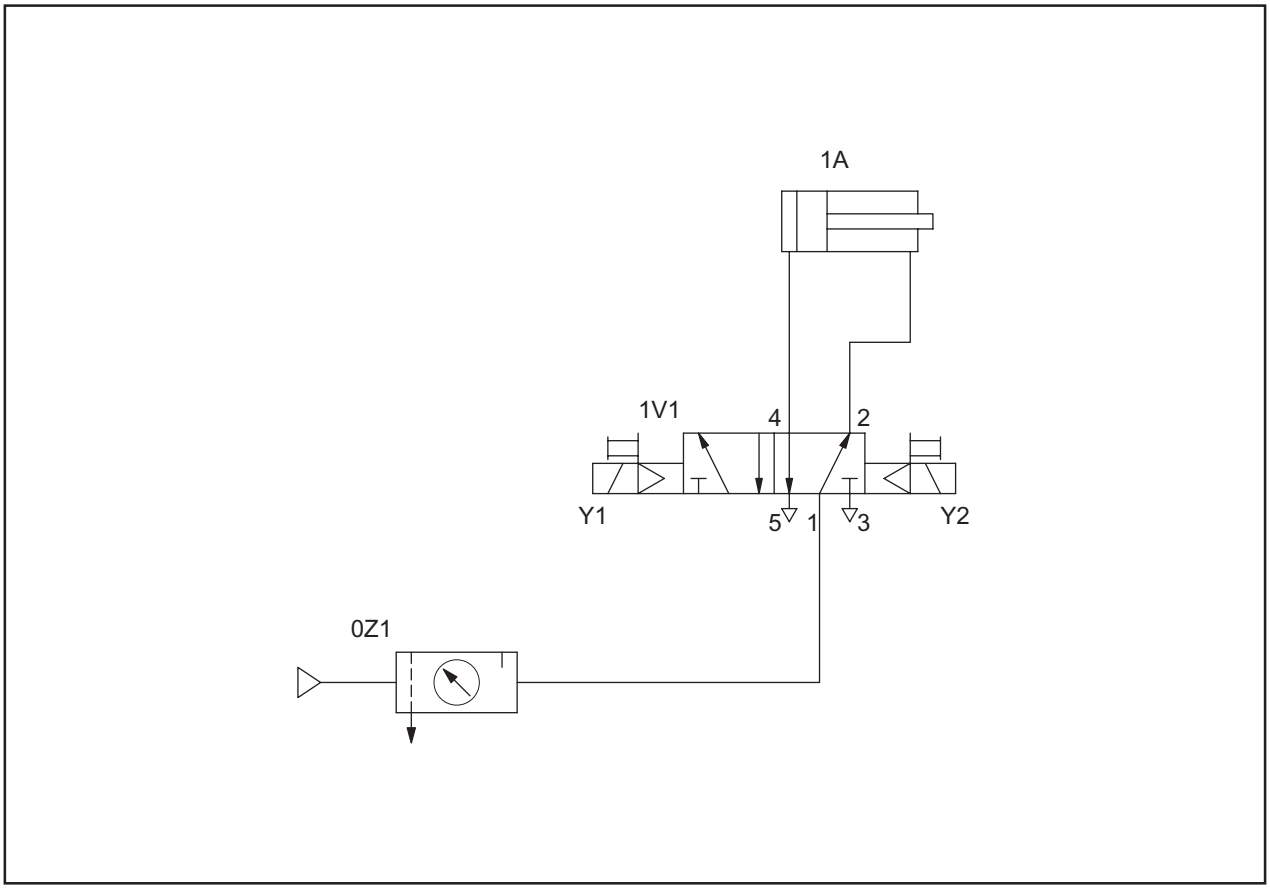

Figure 14: Pneumatic diagram of the double action cylinder

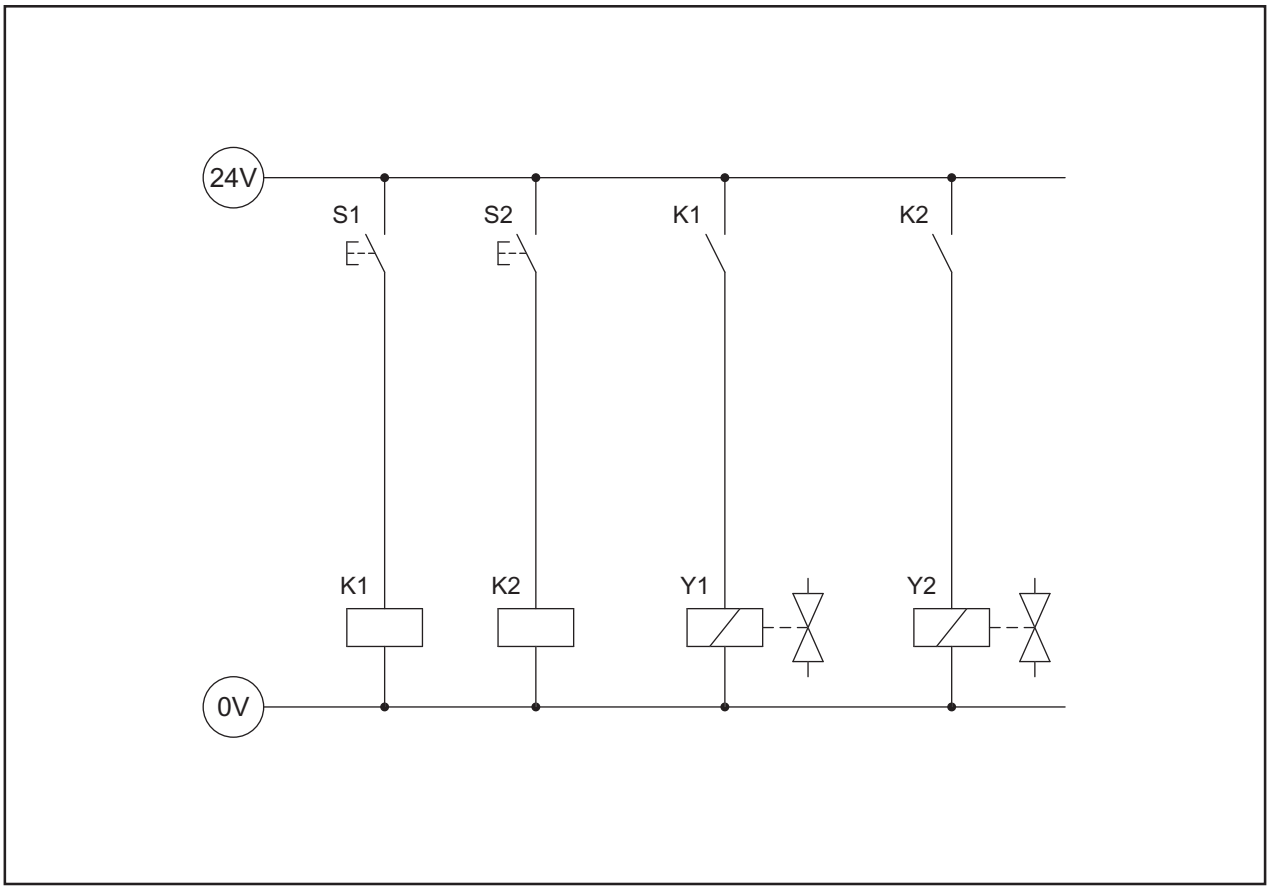

Figure 15: Circuit diagram of the double action cylinder

2.4 Self preservation

Exercise 14

A double-action cylinder should run out when pressing a button and must still driven out after the button is released. The cylinder should run in again only after a second button is activated.

The cylinder is operated by means of a directional control valve with a switchback spring. The signal is stored using a relay with self-preservation. The button, which erases the self preservation, should also turn off the current applied to the magnet coils of the directional control valve.

Complete the pneumatic and the electrical diagrams!

Questions

What are the fundamental types of the self-preservation?

There are the dominating ON and the dominating OFF self-preservation.

What happens to the stored signal in case of electrical energy failure?

The stored signal will be lost in case of energy failure. The spring switches directional control valve back to the starting position.

Didactic tips

This exercise demonstrates the storage of signals using the self-preservation of relays. The circuit diagram represents the dominating OFF self-preservation. However, the dominating ON self-preservation should be also explained and demonstrated.

The functioning of flags and the storage in the PLC-programming can be also explained in this exercise.

It is also useful to discuss safety requirements, such as the protection from uncontrolled switching on in case of a short circuit or cable break.

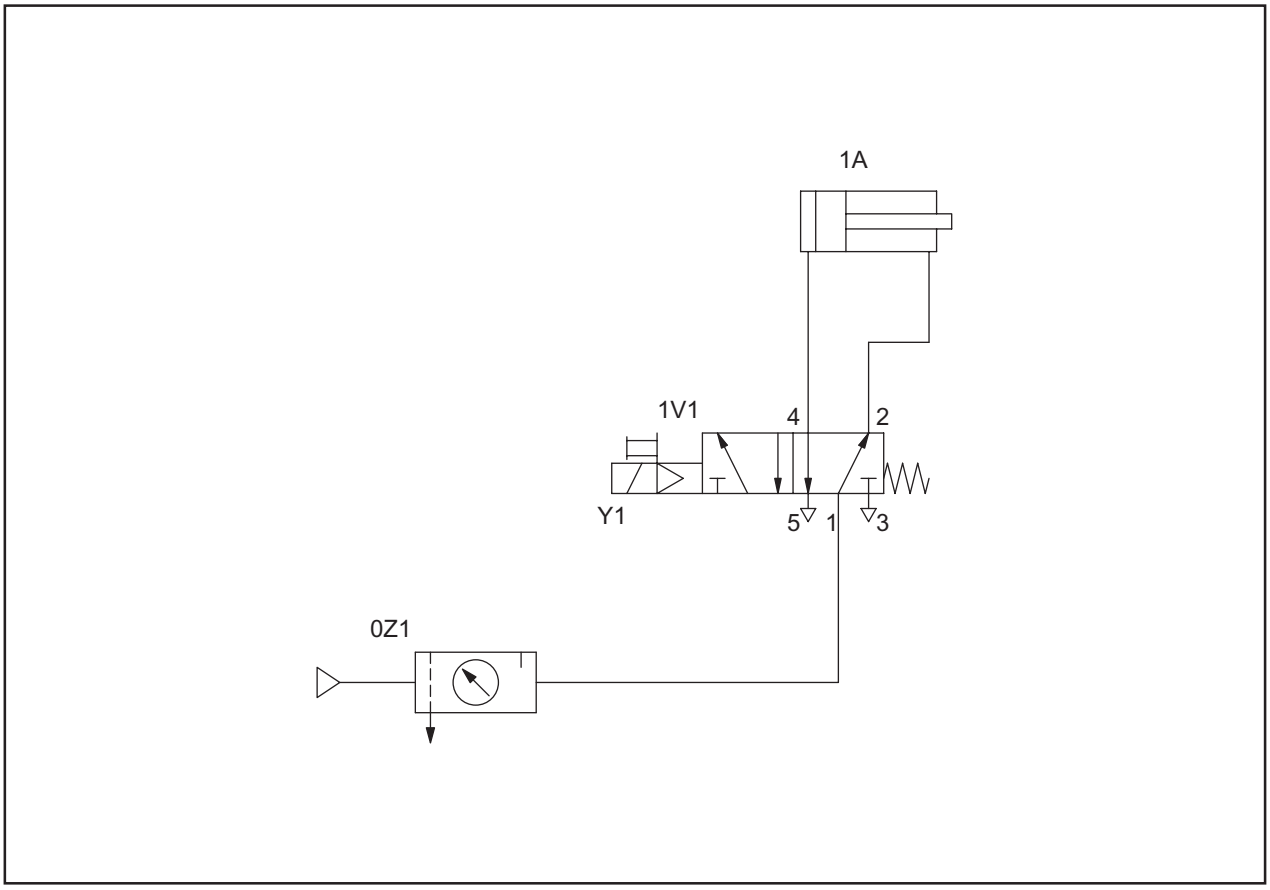

Figure 16: Pneumatic diagram of the self-preservation

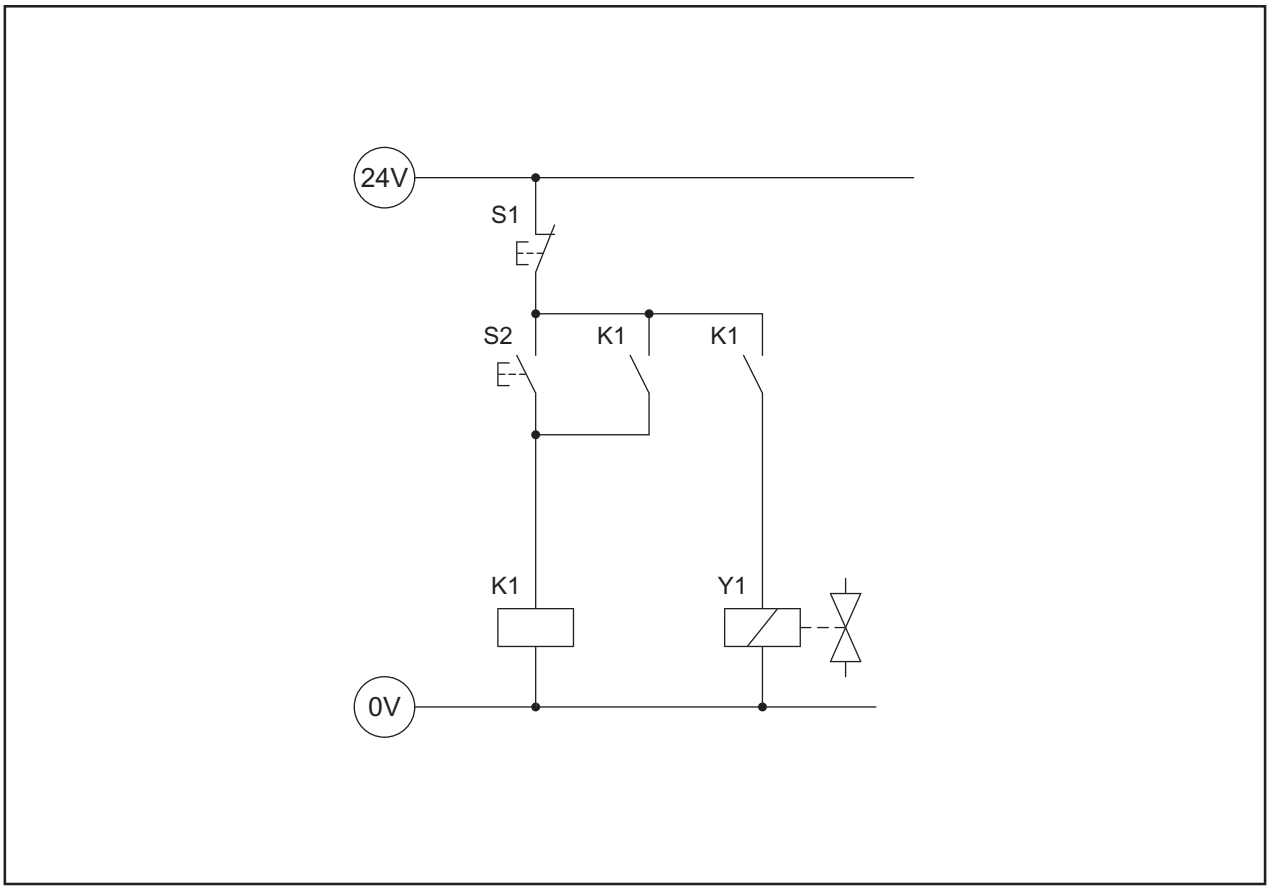

Figure 17: Circuit diagram of the self preservation

2.5 Operating of a 5/3-directional control valve with locking

Exercise 15

A double-action cylinder should run out when pressing a button and run in again after a second button is activated. The cylinder should move only when a button is pressed.

Each button controls a relay. A locking circuit for the relays prevents both magnet coils of the directional control valve from being switched on at the same time.

Complete the pneumatic and the electrical diagrams!

Questions

Which type of contacts is used to break the current path at the correspondingly other side?

A normally closed contact or breaker is used to break the current path at the other side.

Which position does the directional control valve take in case of energy failure, and how does the cylinder act?

The directional control valve switches to the middle position due to the spring-centring. The cylinder remains motionless in its last position.

Didactic tips

The 5/3-directional control valves and the different possible middle positions should be spoken about first of all. The speed of the cylinder motion should be reduced by means of check-choke valves. The positioning accuracy and the possibility of piston rod locking can be also reviewed.

The action of the control system in case of energy failure should be also discussed.

The action of the control system when pressing both buttons together should be tested. The operating of the directional control valve should be compared with an electro-motor, which is switched in the right-handed or the left-handed rotation.

Other alternatives for locking, such as using of two pairs of contacts for the button or arranging of breakers in the conductors to the magnet coils, should be pointed out.

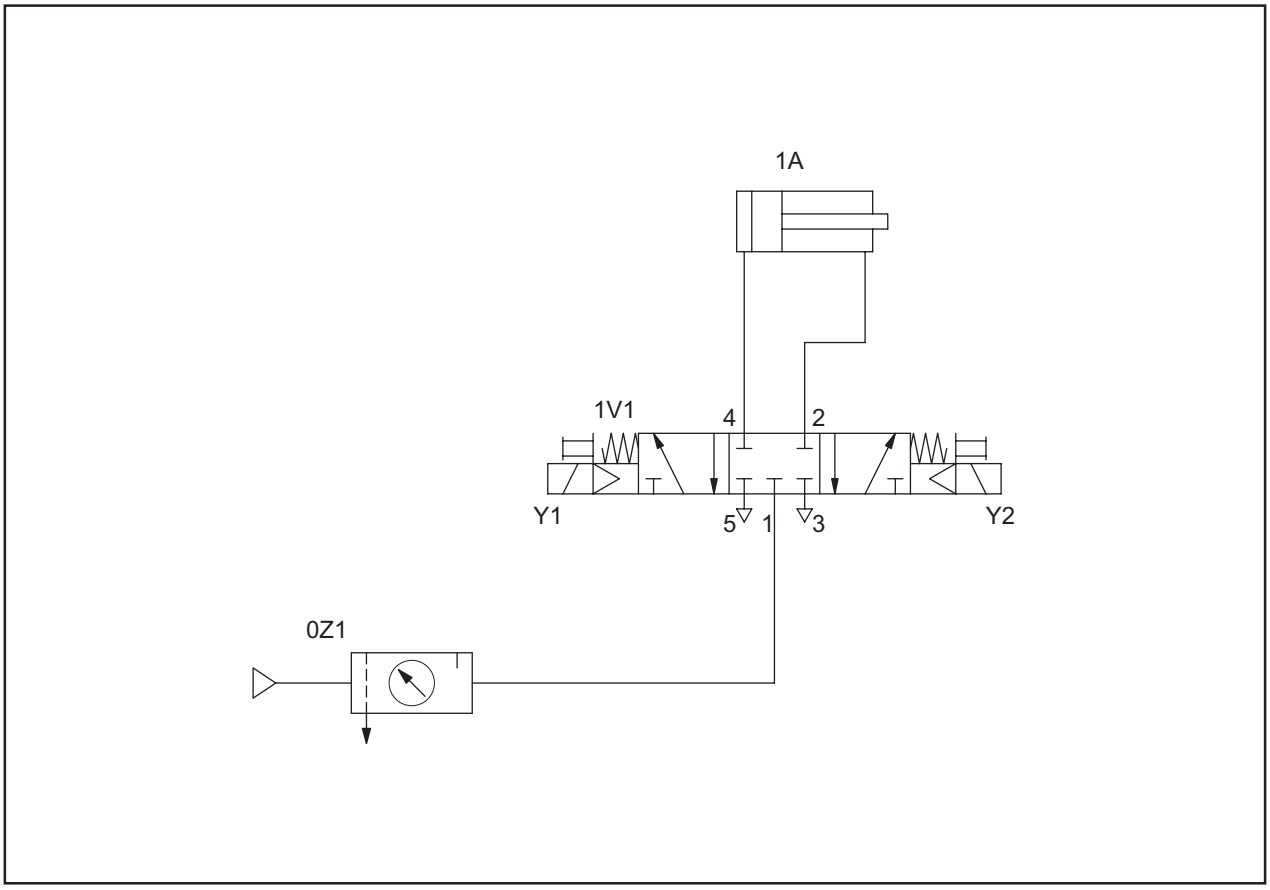

Figure 18: Pneumatic diagram of the stop-control

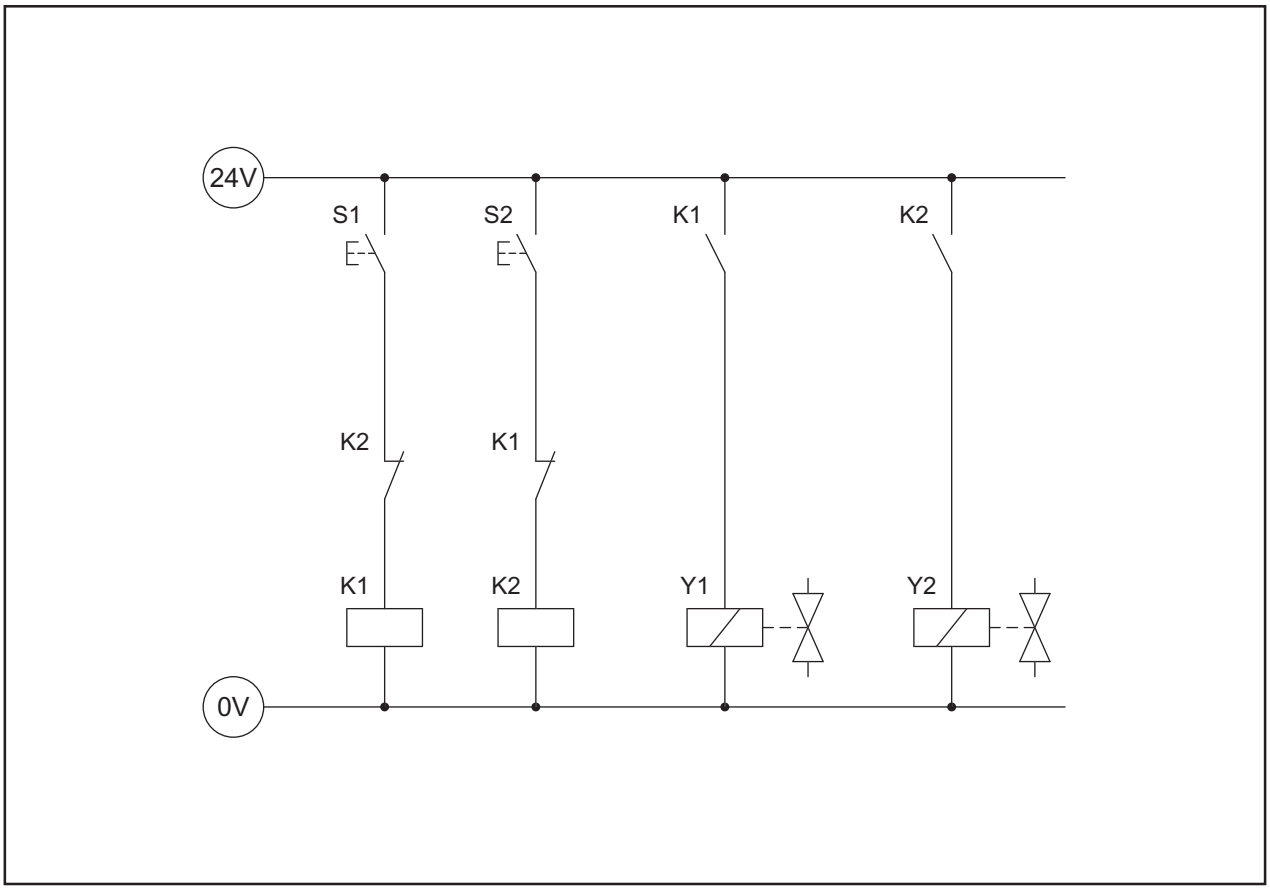

Figure 19: Circuit diagram of the stop-control

2.6 Cylinder switches

Exercise 16

A double-action cylinder should run out when pressing a button and must run in again after reaching the “driven out” end position. The running out is only possible when the cylinder stands at the “driven in” end position.

The cylinder is operated by means of an impulse valve. Two cylinder switches are used to sence the reaching of end positions.

Complete the pneumatic and the electrical diagrams!

Questions

What is used to actuate the cylinder switches?

The cylinder switches are actuated by means of a magnet force. The magnet is arranged in the piston of the cylinder.

Where are the cylinder switches usually arranged in reference to the stroke of the piston?

In most cases, the cylinder switches are arranged at the end positions of the cylinder. Therefore, they are also called the end position switches.

Didactic tips

The function of cylinder switches should be explained. The electronic cylinder switches should be also reviewed besides the reed contacts.

The fact, that reed contacts are vulnerable to short circuits should be also pointed out. The students should be notified, that the contacts may burn out, and that the internal resistance when using reed contacts may be very high.

It should be also demonstrated, that the reed contacts remain functioning with an incorrect polarity of the conductors, but the light diodes of the display will not function any more.

It is also important to point out the indication of actuated cylinder switches in the electric circuit diagram.

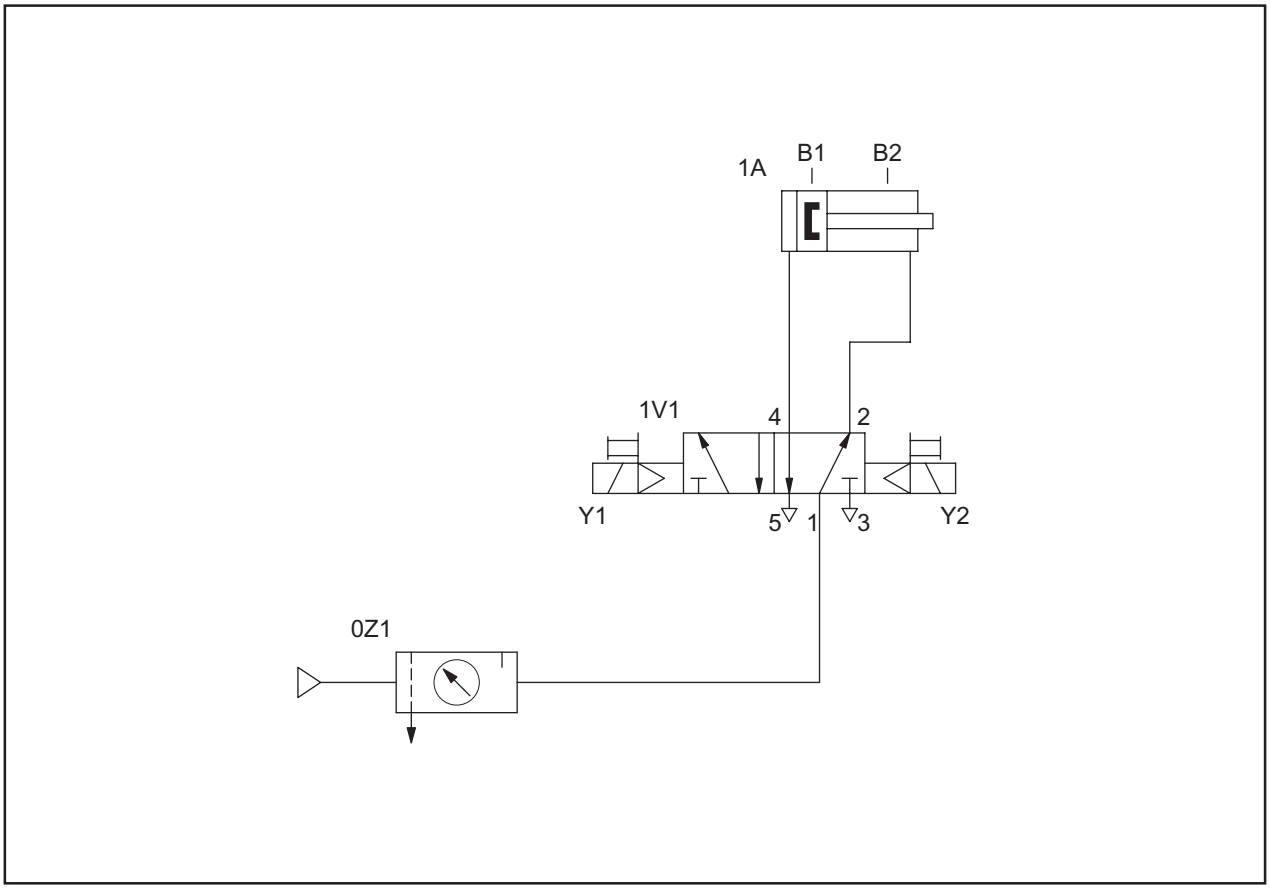

Figure 20: Pneumatic diagram with cylinder switches

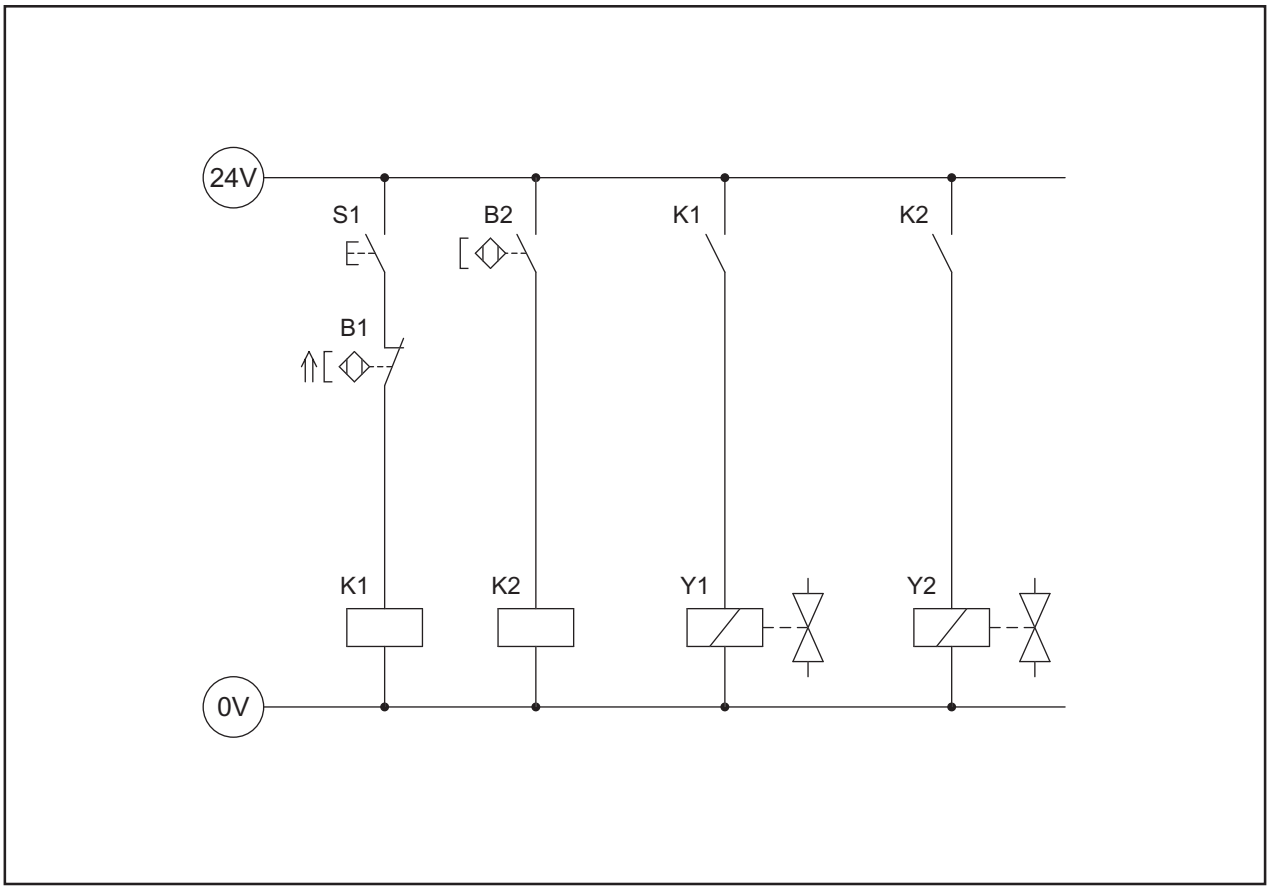

Figure 21: Circuit diagram with cylinder switches

2.7 Pick-up delayed relay

Exercise 17 A double-action cylinder with incoming throttling should run out when a button is pressed. After reaching the “driven out” end position the cylinder should remain driven out for 10 seconds and compress a work piece, then it should run in autonomously.

The cylinder is operated using a directional control valve with a switch back spring. A pick-up delayed relay is used for the timing function.

Complete the pneumatic and the electrical diagrams!

Questions *When does the time measurement start in a pick-up delayed timing element?*

The time measurement starts as soon as voltage is applied to the timed relay. The contacts will switch after the time is elapsed.

What happens if the voltage applied to the timed relay was switched off before the adjusted time is elapsed and switched on again after a short time?

The time measurement will stop and start again after switching on the voltage.

Didactic tips The functioning of the pick-up delayed relay should be explained using a signal state diagram.

The construction principle should be compared with the pneumatic timing element. Hereby, the capacity should be compared with the volume, the resistance with the choke, the diodes with the check valve and the relay with the directional control valve.

The students should be notified of the semicircle at the switching contact, which indicates the delayed switching on.

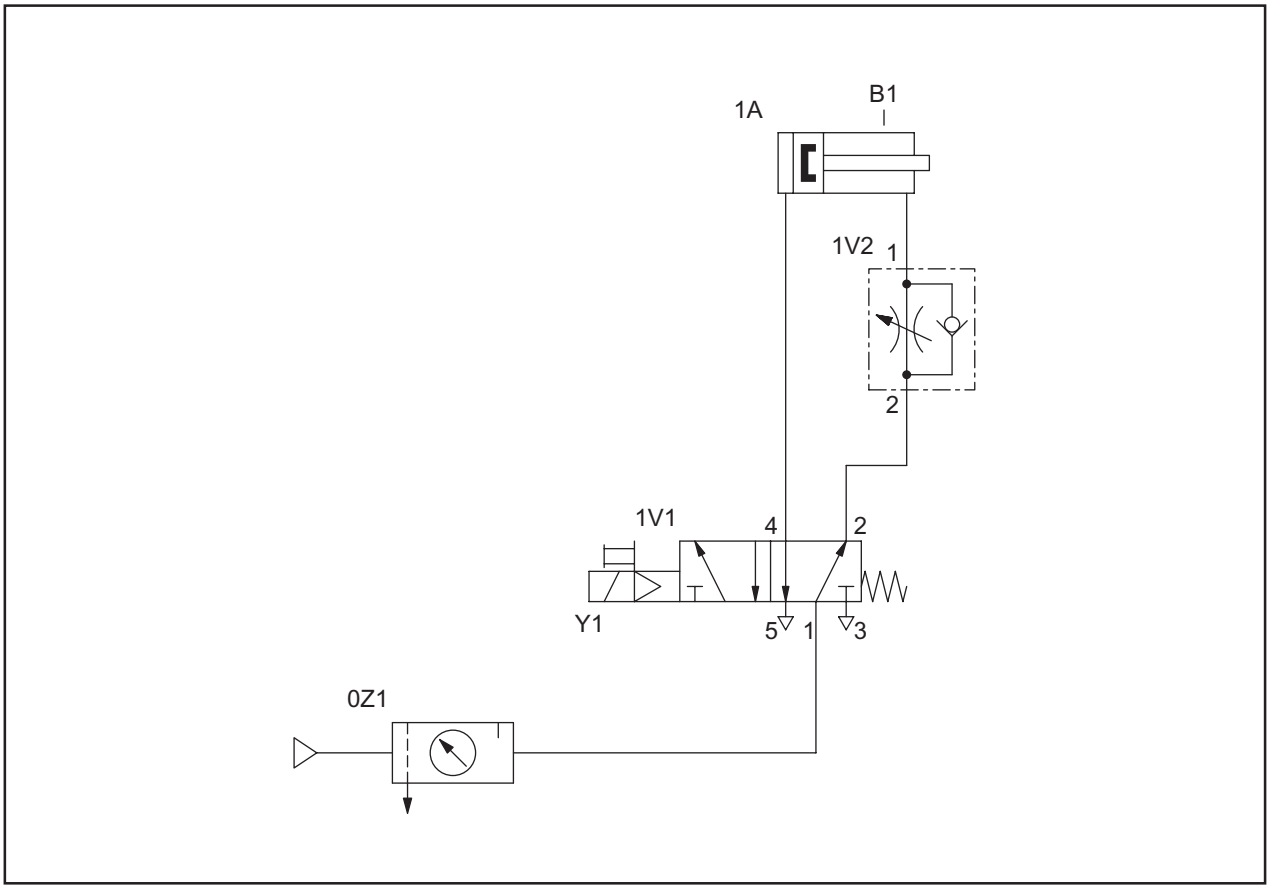

Figure 22: Pneumatic diagram of the time-dependent control

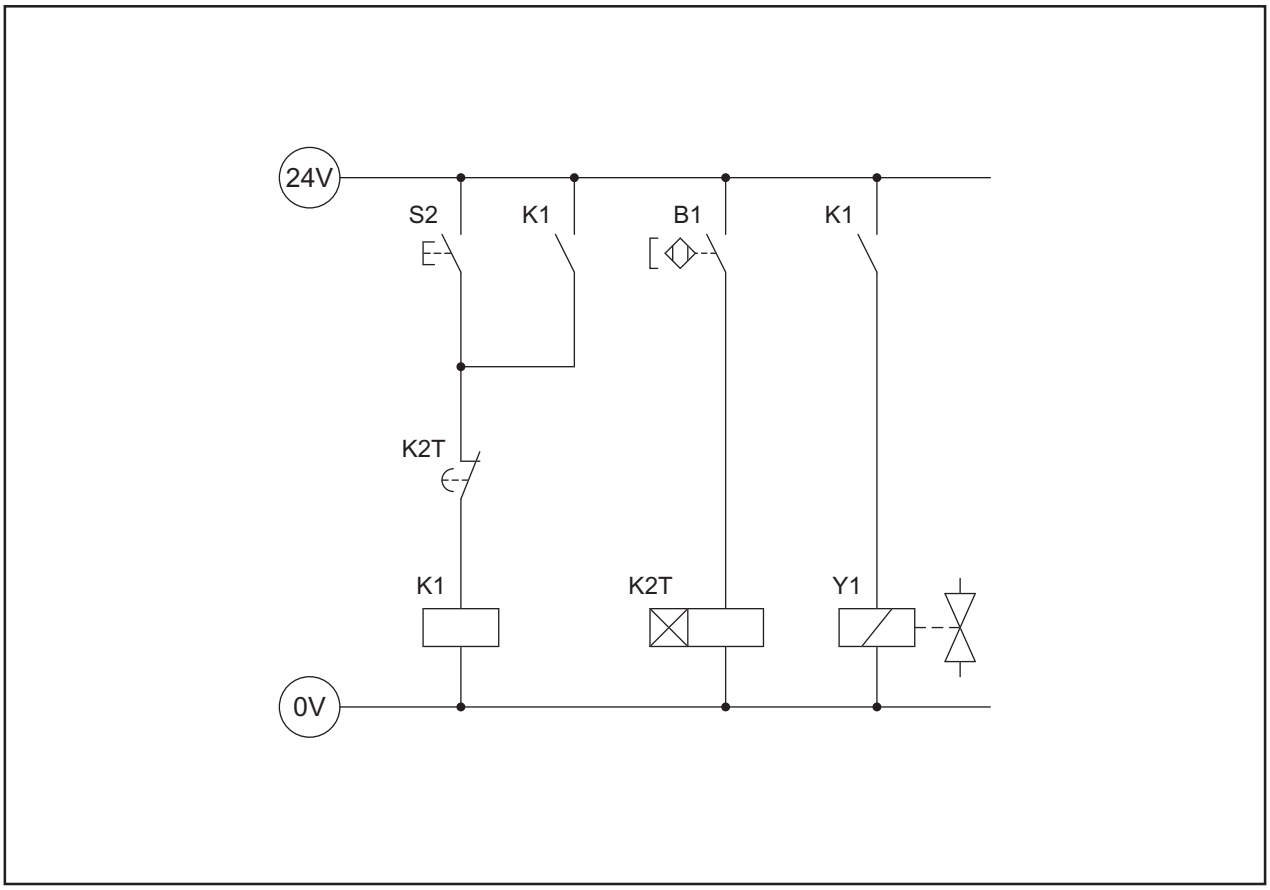

Figure 23: Circuit diagram of the pick-up delayed relay

2.8 Dropout delayed relay

Exercise 18

A double action cylinder should run out and open a door when one of two separate buttons is activated. After releasing the button, the cylinder should remain in the “driven out” position for 10 seconds and then run in autonomously closing the door.

The cylinder is operated using a directional control valve with a switch back spring. A dropout delayed relay is used for the timing function.

Complete the pneumatic and the electrical diagrams!

Questions

When does the time measurement start in a dropout delayed timing element?

The time measurement starts as soon as the voltage at the timed relay is switched off. The contacts will switch back after the time is elapsed.

What happens if the voltage was applied again to the timed relay before the adjusted time is elapsed?

The time measurement will stop and will start again after switching off the voltage.

Didactic tips

The functioning of the dropout delayed relay should be explained using a signal state diagram.

The construction principle should be demonstrated. It should be pointed out, that the dropout delayed relay remains activated within the adjusted time, even if the power supply was switched off. There are no comparable timing elements in the pneumatics.

The students should be notified of the semicircle at the switching contact, which indicates the delayed switching off.

A review of the electronic timed relays is also reasonable. In the PLC-technics the timing functions are also realized by means of timers.

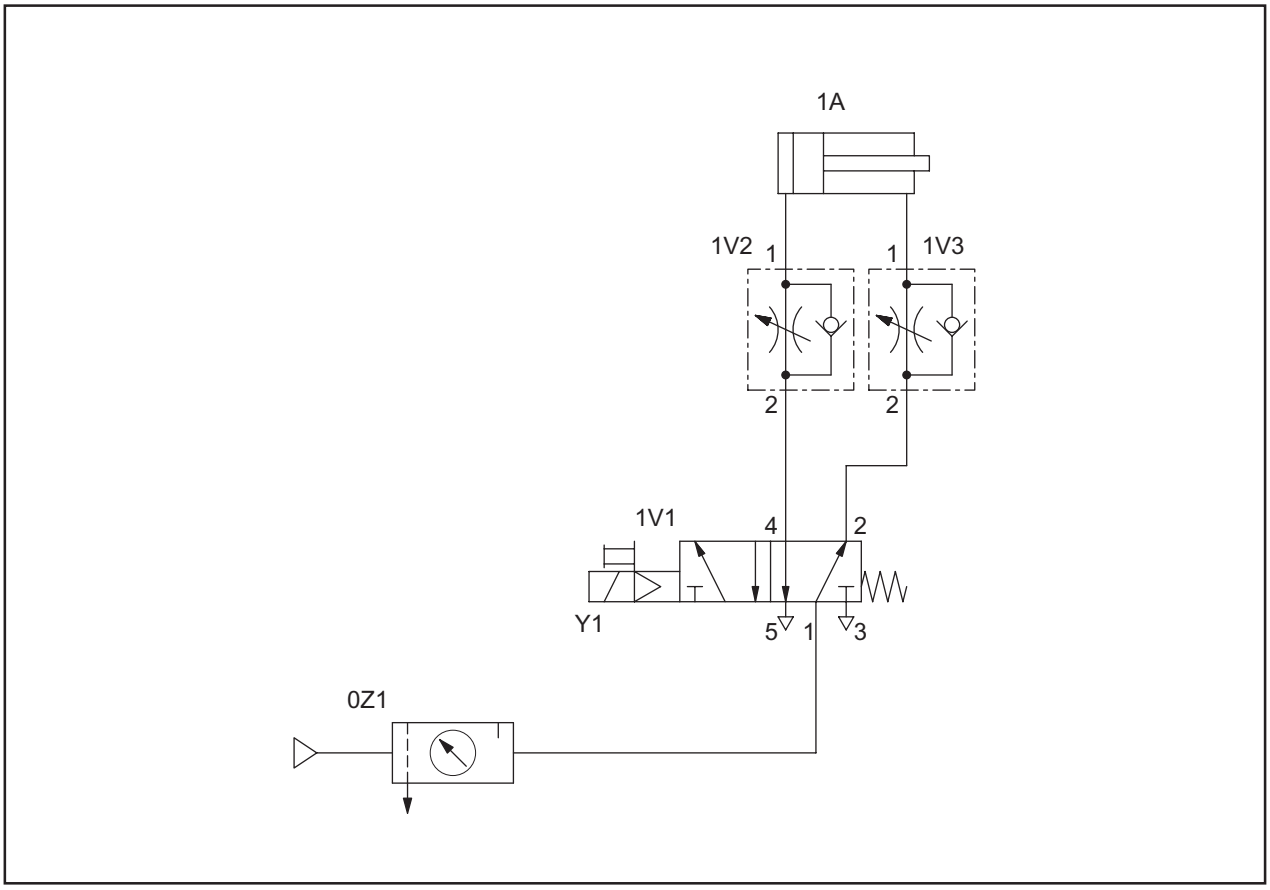

Figure 24: Pneumatic diagram of the time-dependent control

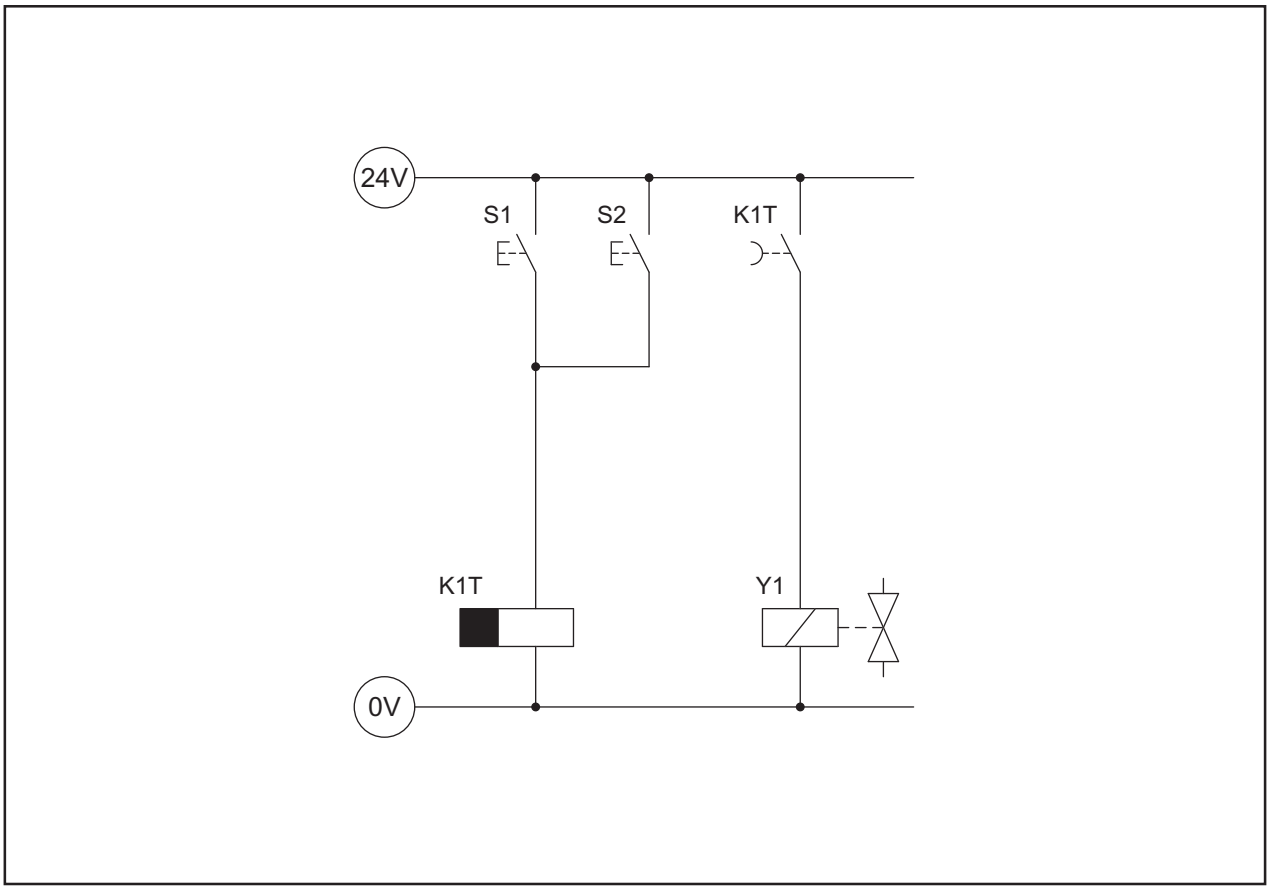

Figure 25: Circuit diagram of the dropout delayed relay

2.9 Combination of signals

Exercise 19

A double action cylinder with incoming throttling runs out and compresses work pieces. The running out of the cylinder can be started with a single-cycle button or a control switch for continuous operation. In addition to that, the running out is only possible when the cylinder stands at the “driven in” end position, and when there are sufficient work pieces in the magazine.

The back stroke starts autonomously only when the cylinder stands at the “driven out” end position and after a minimal pressure of 5 bar builds up in the piston rod chamber.

Complete the pneumatic and the electrical diagrams!

Questions

How should be the contacts connected to perform an AND-function?

The contacts should be connected in series one after another.

How should be the contacts connected to perform an OR-function?

The contacts should be connected in parallel to each other.

Didactic tips

The students should be notified, that in such couplings with incoming throttling the pressure builds up slower. This makes the switching process of the pressure switch more observable.

The pressure switch should be adjusted to several different pressure values. The pressure build up during the running out should be observed by means of a manometer.

The different indications of the pressure switch in pneumatic and electrical diagrams should be pointed out.

The construction and the functioning of the pressure switch should be explained. This also includes information concerning accuracy and switching hysteresis.

The logical functions “AND”, “OR” and “NOT” should be represented with their value tables, and their significance in the field of PLC-technics should be pointed out.

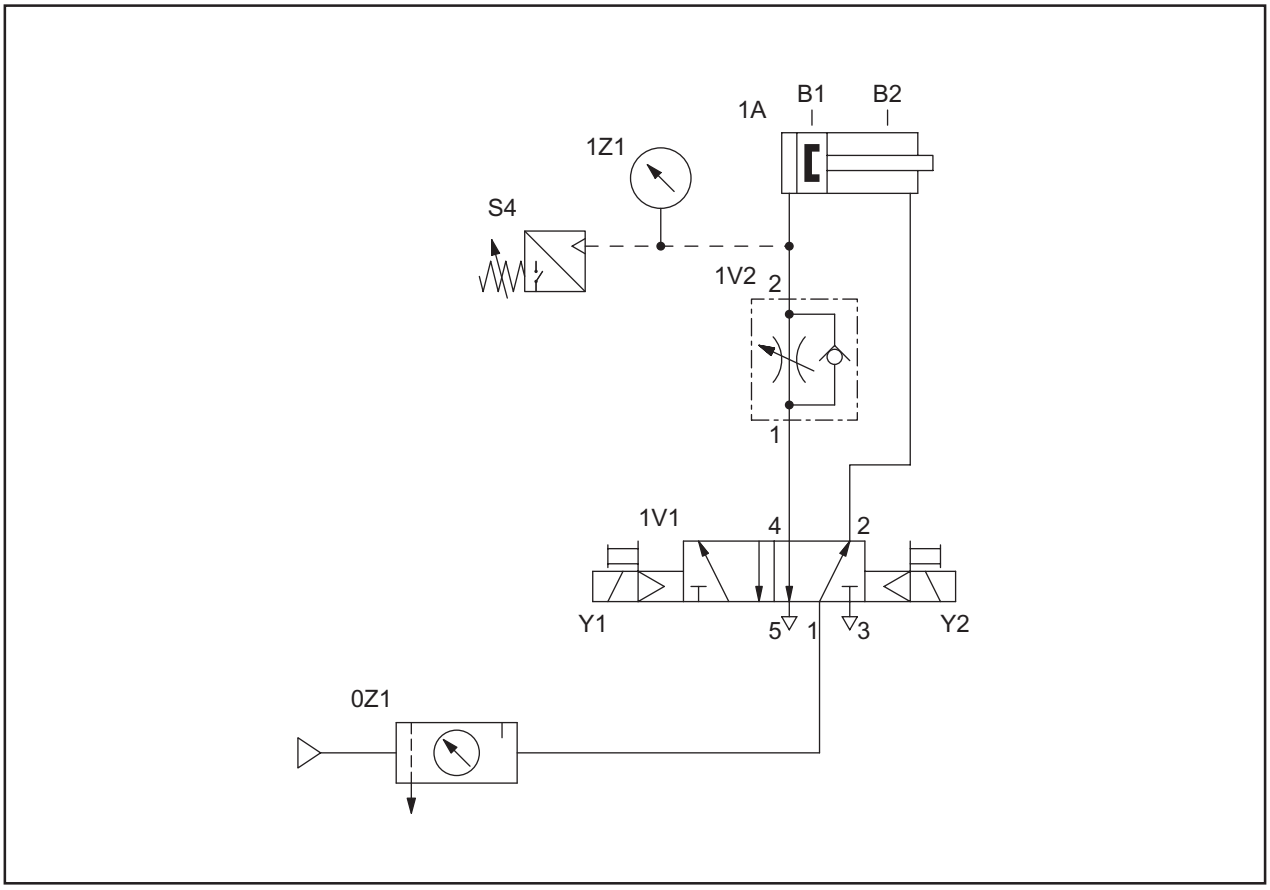

Figure 26: Pneumatic diagram of the logic control

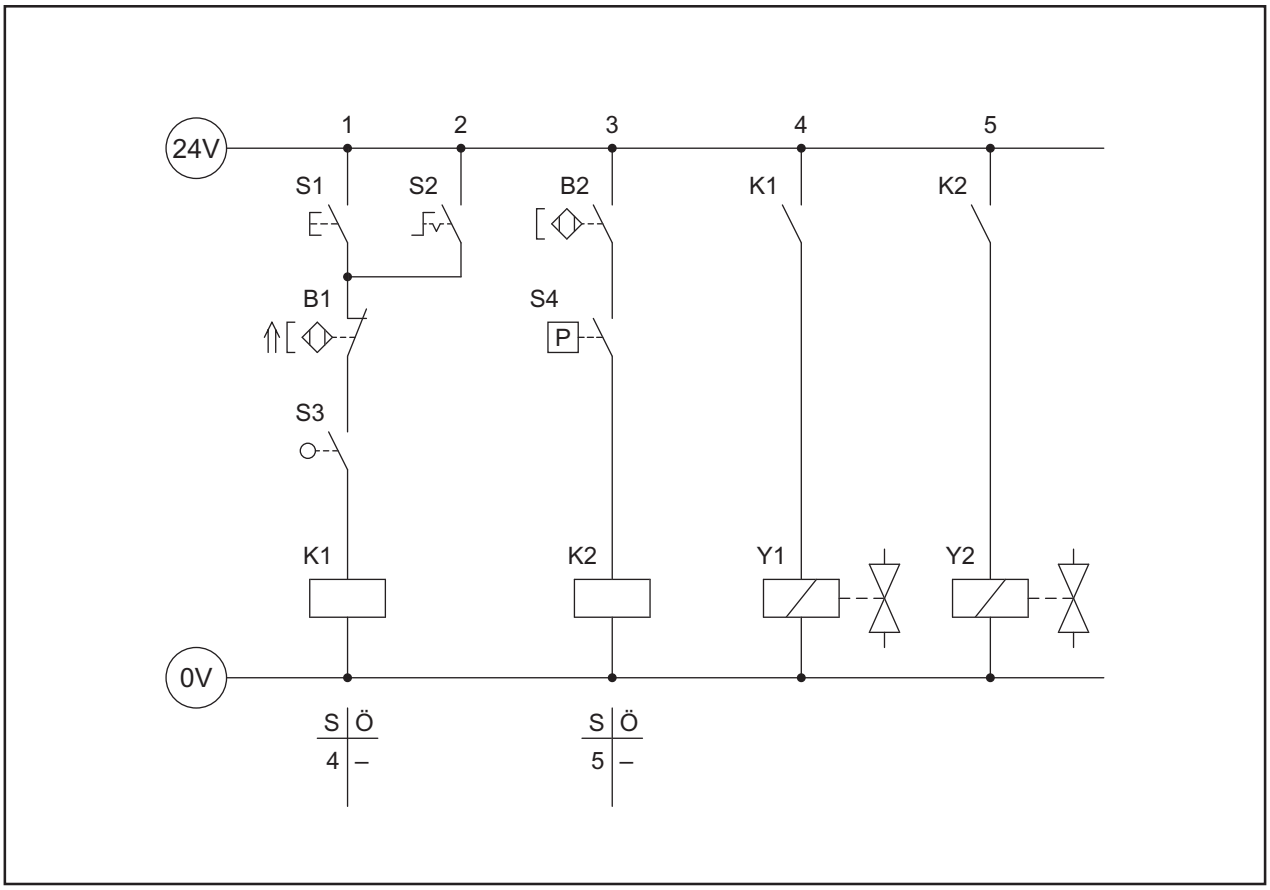

Figure 27: Circuit diagram of the logic control

2.10 Two-hand safety circuit

Exercise 20

A double action cylinder is used to operate a press. The cylinder is allowed to run out only when two buttons are activated together within 5 seconds. When releasing one of the buttons the cylinder should retract immediately.

In this exercise a timed relay is used for the timing function. The cylinder is operated using a directional control valve with a switch back spring.

Complete the pneumatic and the electrical diagrams!

Questions

Within which period of time should both buttons be pressed in order to make the cylinder run out?

Both buttons should be activated within 0,5 seconds.

What happens if one of the buttons was released when the cylinder moves out?

The signal for moving out will be interrupted and the cylinder will move in again.

Didactic tips

This two-hand safety circuit with timed relay is designed exclusively for this exercise and for training purposes. For industrial uses, further constructional characteristics should be taken into consideration. Thereby, the buttons should be deepened and arranged at a certain distance from each other, and the time length should not be adjustable. Industrial type tested modules should be also discussed.

The time length for this exercise should be adjusted to 0,5 seconds and the functioning of the circuit should be tested.

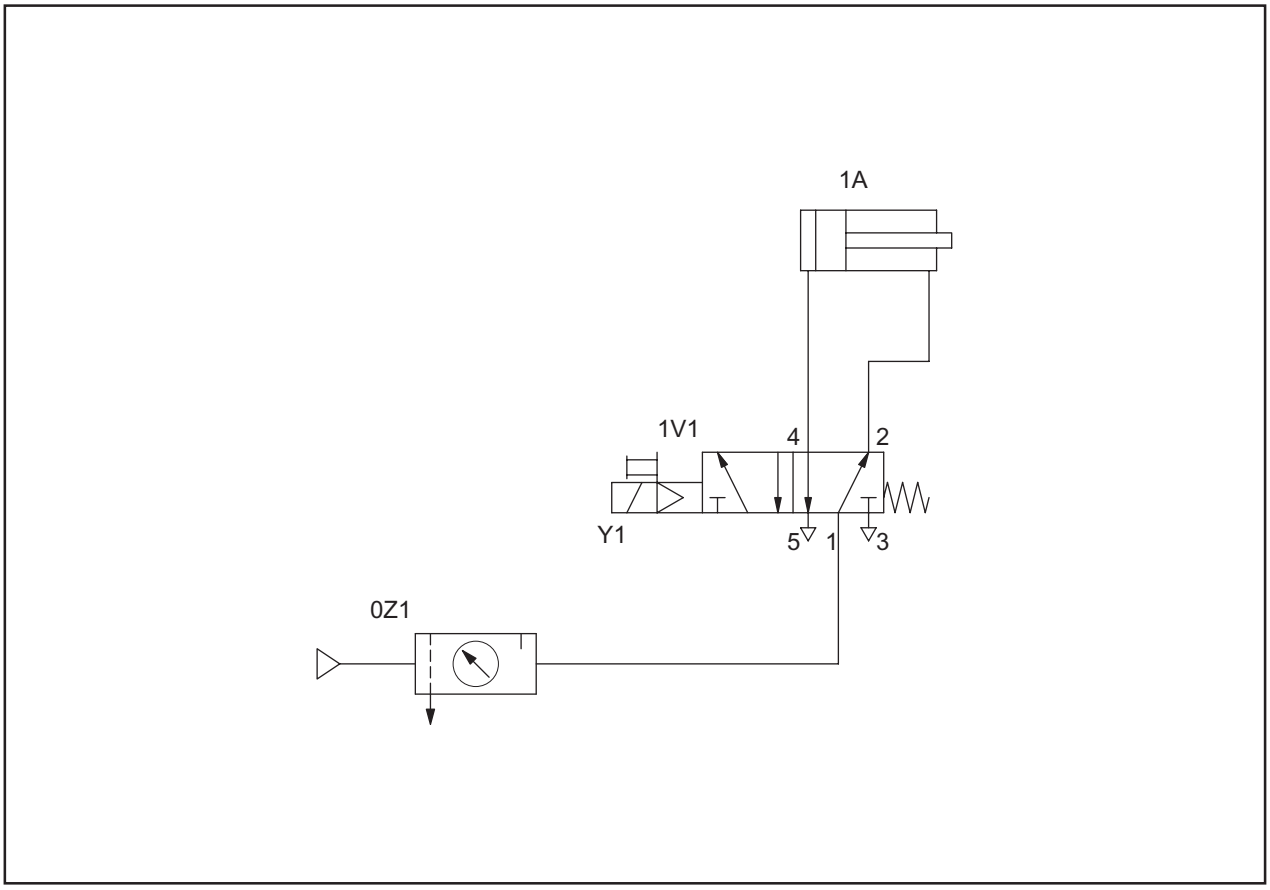

Figure 28: Pneumatic diagram of the two-hand safety circuit

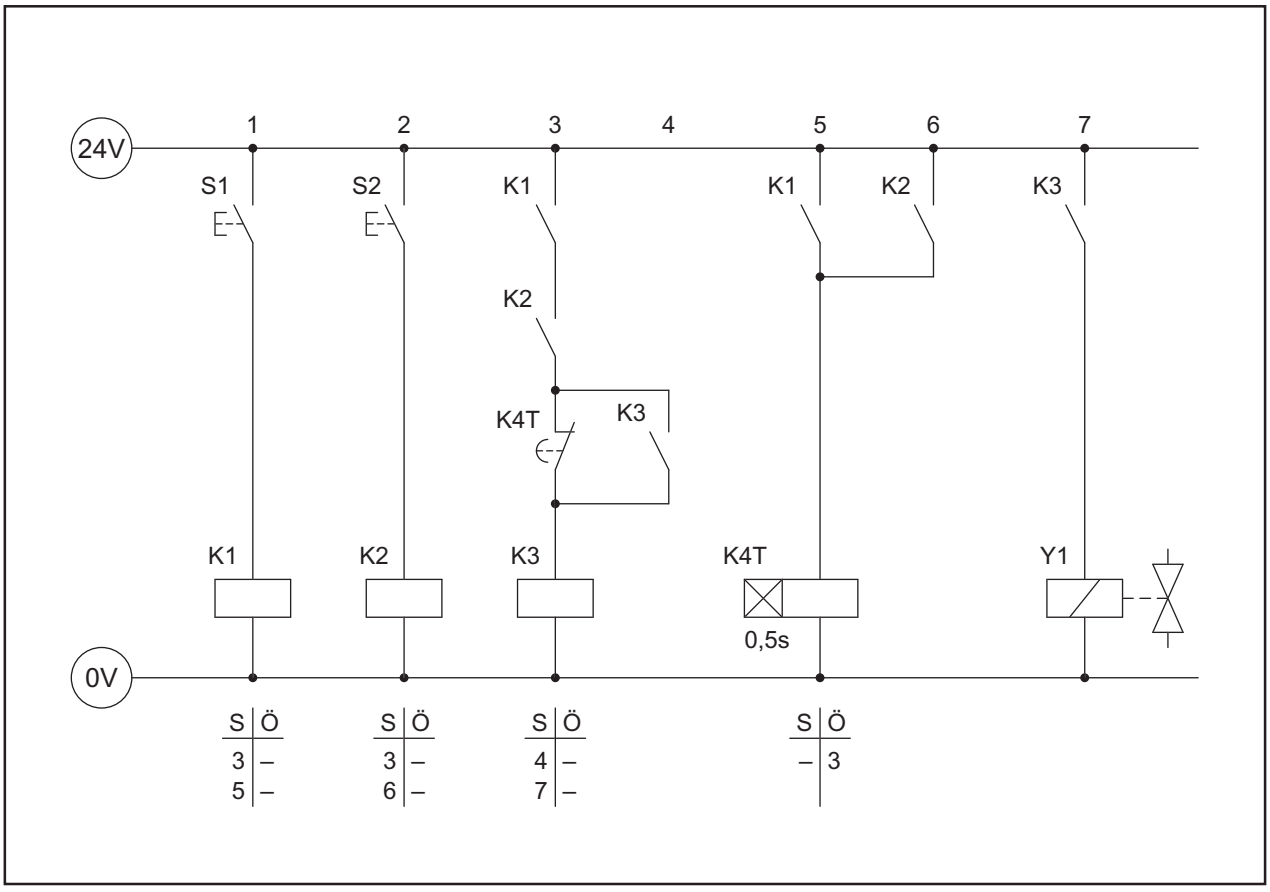

Figure 29: Circuit diagram of the two-hand safety circuit

2.11 Sequence chain circuit

Exercise 21

A double action cylinder should run out when a button is pressed and clamp a work piece. After that, a second cylinder should run out, deform the work piece and run in immediately. At last, the clamping cylinder should run in again.

Both cylinders are operated using directional control valves with a switch back spring. The extending motion is throttled. A continuous step-sequence should be implemented by means of relays.

Complete the pneumatic and the electrical diagrams!

Questions

How do we call the step-sequence, whereby the relays switch on one after another and switch off again after all the steps are completed?

This step-sequence is called the continuous step-sequence.

What should be taken into consideration when impulse valves are operated using this step sequence?

In the impulse valves only one of the magnet coils should be switched on.

Didactic tips

The advantages of methodically prepared coupling diagrams concerning the creation steps and error finding should be pointed out. The difference between continuous and purging sequence should be explained.

When using impulse valves with continuous sequences the problem of signal overlapping should be discussed.

The possibility of dividing the electrical circuit diagram into a control part and a power part should be also spoken about. The cylinder switch B3 can be used as an additional starting precondition.

Furthermore, the conversion of the electrical circuit diagram into a ladder diagram for the PLC-programming should be demonstrated.

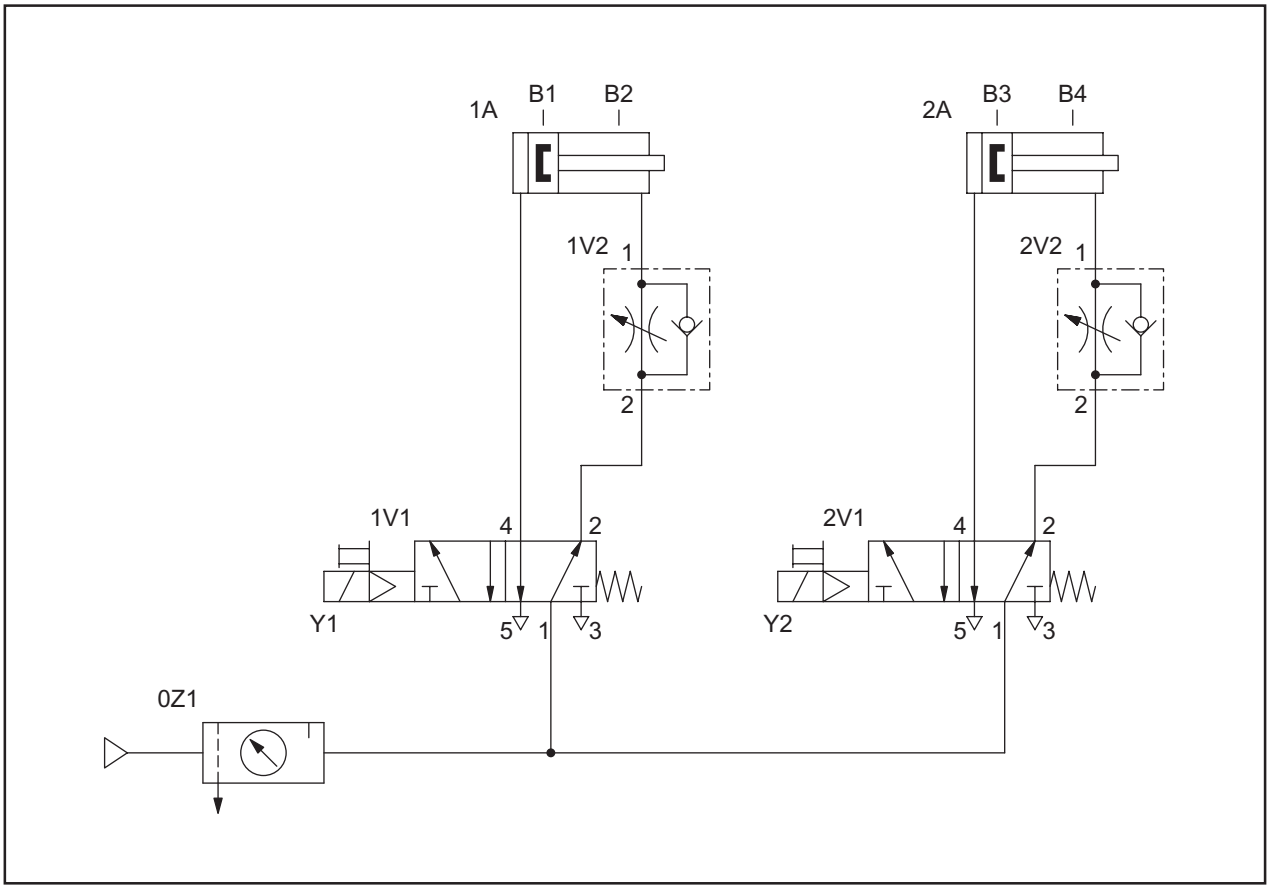

Figure 30: Pneumatic diagram of the sequence control

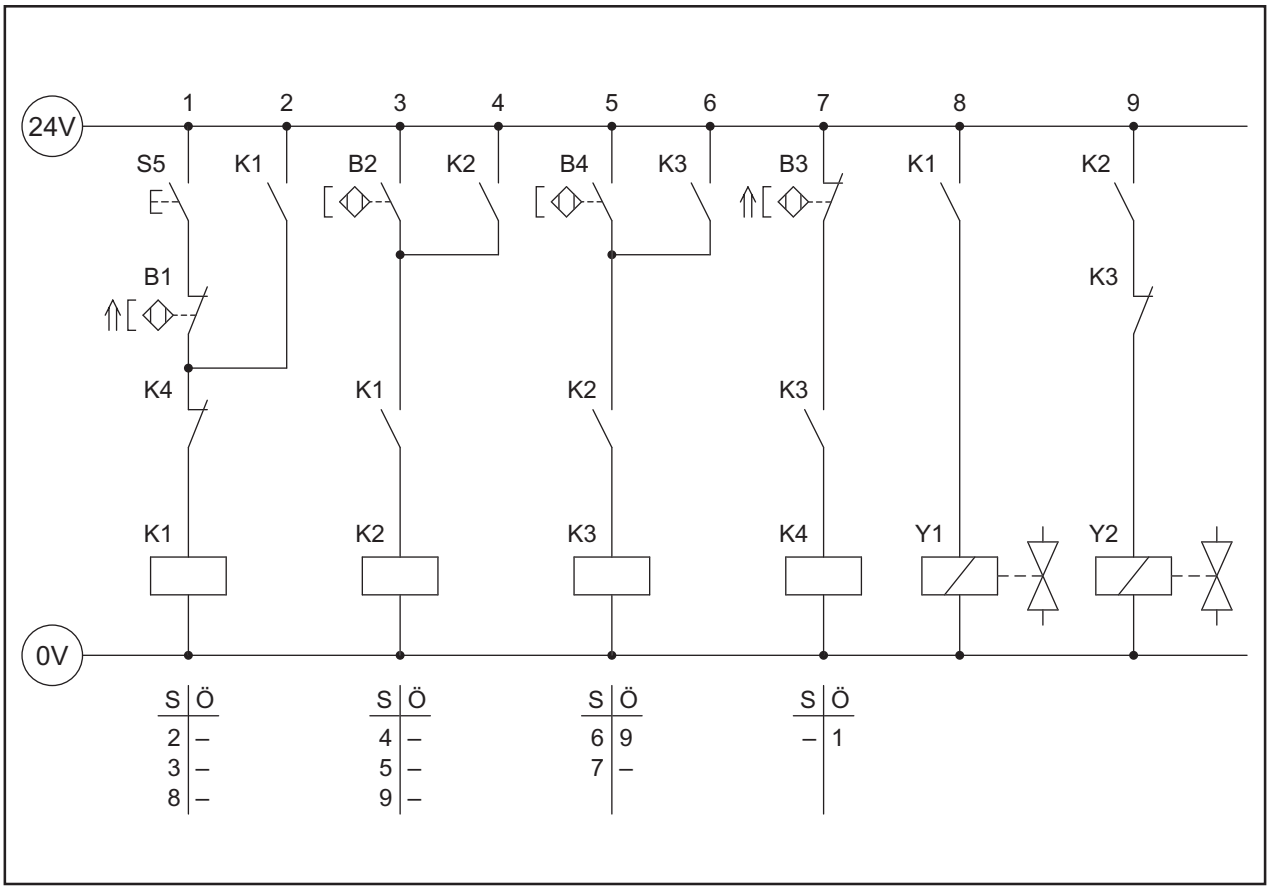

Figure 31: Circuit diagram of the sequence control

Mechatronics

Module 4: Electrical Drives and Controls

Solutions
(concept)

Matthias Römer

Chemnitz University of Technology
Institute for Machine Tools and Production Processes

EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

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- Module 7: Commissioning, Safety, Teleservice
- Module 8: Remote Maintenance, Diagnosis

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1 The fundamentals of electrotechnics

1.2 Voltage, current and resistance

Exercise 1a A current of 500 A flows in an electrical welding machine within a period of 0,8 s. What is the transformed charge? Recalculate the result into kWh!

$Q = I \cdot t$

$Q = 500\ A \cdot 0{,}8\ s$

$Q = 400\ C$

$Q = 0{,}11\ kWh$

A charge of 400 C passes through the welding machine. This equals to 0,11 kWh.

Exercise 1b The filament lamp of an automobile works with a voltage of 12 V. It has a resistance of 3 Ω. Calculate the current, that flows through the lamp?

$R = U / I$

$I = U / R$

$I = 12\ V / 3\ \Omega$

$I = 4\ A$

A current of 4 A flows through the filament lamp.

Exercise 1c A fan heater is supplied with 230 V from the house mains. It consumes a current of 10,5 A. What is it's resistance? What is the current value when the applied voltage is reduced to 220 V?

$R = U / I$

$R = 230\ V / 10{,}5\ A$

$R = 21{,}9\ \Omega$

The resistance of the fan heater amounts 21,9 Ω.

$I = U / R$

$I = 220\ V / 21{,}9\ \Omega$

$I = 10{,}05\ A$

At 220 V a current of 10,05 A flows.

Exercise 1d What is the resistance of a copper conductor with a cross-sectional area of 1,5 mm^2 and a length of 50 m? What is the resistance of a conductor with the same length but with a cross-sectional area of 2,5 mm^2?

$\rho = R \cdot A / l$

$R = \rho \cdot l / A$

$R = 0{,}0175\ \Omega mm^2/m \cdot 50\ m / 1{,}5\ mm^2$

$R = 0{,}583\ \Omega$

The resistance of the copper conductor amounts 0,583 Ω.

$R = \rho \cdot l / A$

$R = 0{,}0175\ \Omega mm^2/m \cdot 50\ m / 2{,}5\ mm^2$

$R = 0{,}35\ \Omega$

The resistance of the copper conductor with the larger cross-sectional area amounts 0,35 Ω.

1.3 Electrical power and work

Exercise 2a An electric grill is connected to 230 V wall outlet. The protection allows a maximal current of 10 A. What is the maximal allowed power, that the grill can have?

$P = U \cdot I$

$P = 230\ V \cdot 10\ A$

$P = 2300\ W$

The grill may have a maximal power of 2300 W. At a higher power value the protection will break the current flow.

Exercise 2b A switch is allowed to pass a maximal current of 0,4 A. The maximal connected power should not exceed 10 W.

The connected component has a resistance of 40 Ω. Is it possible to use the above mentioned switch for the consumer, which should be operated with a voltage of 24 V?

$P = U \cdot I$

$U = P / I$

$U = 10\ W / 0{,}4\ A$

$U = 25\ V$

The value of 10 W is reached at a voltage of 25 V. Since the voltage amounts 24 V only, the switch may be used for this consumer.

$R = U / I$

$I = U / R$

$I = 24\ V / 40\ \Omega$

$I = 0{,}6\ A$

A current of 0,6 A will flow through the resistance of 40 Ω at the voltage of 24 V. This current value is two times higher than the maximal allowed current for the switch. Therefore, the switch can not be used in this case.

Exercise 2c A heating system designed for aquariums is imported from abroad. The power consumption at a voltage of 117 V amounts 75 W. What is the power consumption when using the system at a voltage of 230 V?

$P = U \cdot I$

$I = P / U$

$I = 75\ W / 117\ V$

$I = 0{,}64\ A$

A current of 0,64 A flows through the heating system.

$R = U / I$

$R = 117\ V / 0{,}64\ A$

$R = 182{,}8\ \Omega$

The system has a resistance of 182,8 Ω.

$I = U / R$

$I = 230\ V / 182{,}8\ \Omega$

$I = 1{,}26\ A$

At 230 V the current value amounts 1,26 A.

$P = U \cdot I$

$P = 230\ V \cdot 1{,}26\ A$

$P = 290\ W$

The power consumption of the system at 230 V amounts 290 W.

1.4.2 Connecting of measurement devices

Exercise 3

What are the measuring ranges for direct current on your multimeter? Specify all ranges!

0 … 200 μA, 0 … 2000 μA, 0 … 20 mA, 0 … 200 mA

What are the measuring ranges for alternating current on your multimeter? Specify all ranges!

0 … 10 A

What are the measuring ranges for direct voltage on your multimeter? Specify all ranges!

0 … 200 mV, 0 … 2000 mV, 0 … 20 V, 0 … 200 V, 0 … 1000 V

What are the measuring ranges for alternating voltage on your multimeter? Specify all ranges!

0 … 200 V, 0 … 750 V

What are the measuring ranges for resistance on your multimeter? Specify all ranges!

0 … 200 Ω, 0 … 2000 Ω, 0 … 20 kΩ, 0 …200 kΩ, 0 … 2000 kΩ

What is maximal direct current value and the maximal direct voltage value that can be measured using the lowest measuring range of the multimeter?

maximal direct current value: 200 μA
maximal direct voltage value: 200 mV

A direct voltage with unknown value should be measured. What measuring range should be used first?

The highest measuring range, in the example 0 … 1000 V

A direct current with unknown value should be measured. What measuring range should be used first?

The highest measuring range, in the example 0 … 200 mA

Didactic tip

The measuring ranges differ from one multimeter type to another.

Exercise 4 Implement the following measurement exercise. Take into consideration the learnt rules for dealing with a multimeter!

The following components are required:

Voltage supply device with 24 V direct voltage
Multimeter
Resistance R_1 = 100 Ω
Resistance R_2 = 220 Ω
Resistance R_3 = 470 Ω

The load capacity of the resistances should be 1 W.

Connect the circuit with three resistances as it shown in the figure below. Measure the voltage drops at each resistance.

Draw the symbol of the voltage measurement device in the diagram.

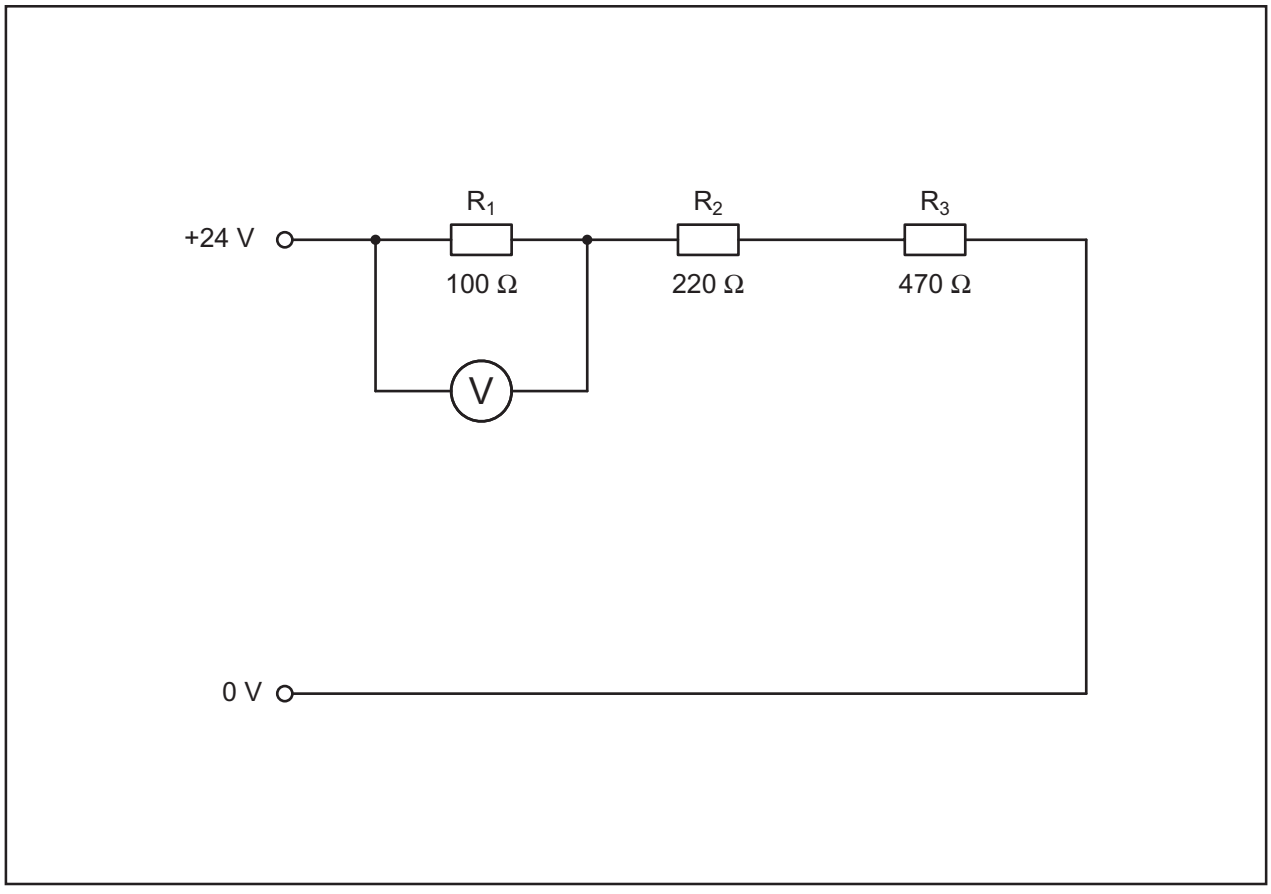


Figure 1: The circuit diagram for voltage measurement

Connect the resistances to the current supply device. The resistances should be serially connected.

Start with the resistance R_1. You should use a measuring range for direct voltages. Select the highest measuring range and connect the measurement device to the resistance.

Determine the lowest possible measuring range by reducing the ranges step by step. Register the measured value.

The determined measuring range: 0 … 20 V

The measured direct voltage: 3,04 V

Select the highest measuring range again and connect the measurement device to the next resistance.

Repeat the measurement procedure with the resistance R_2. Register the measured value.

The determined measuring range: 0 … 20 V

The measured direct voltage: 6,68 V

Perform the measurement with the resistance R_3 too. Register the measured value.

The determined measuring range: 0 … 20 V

The measured direct voltage: 14,28 V

Now determine the voltage value at both resistances R_1 and R_2 together.

The measured direct voltage: 9,72 V

Finally, determine the voltage value at both resistances R_2 and R_3 together.

The measured direct voltage: 20,96 V

Check the voltage value of the voltage supply device by measuring the voltage drop at all the three resistances together.

The measured direct voltage: 24 V

Didactic tip The measuring ranges differ from one multimeter type to another.

Exercise 5 Implement the following measurement exercise. Take into consideration the learnt rules for dealing with a multimeter!

The following components are required:

Voltage supply device with 24 V direct voltage
Multimeter
Resistance R_1 = 220 Ω
Resistance R_2 = 470 Ω
Resistance R_3 = 1000 Ω

The load capacity of the resistances should be 1 W.

Connect the circuit with the resistance 220 Ω as it shown in the figure below. Measure the current, that flows through the resistance. Repeat this procedure for each of the other resistances.

Draw the symbol of the current measurement device in the diagram.

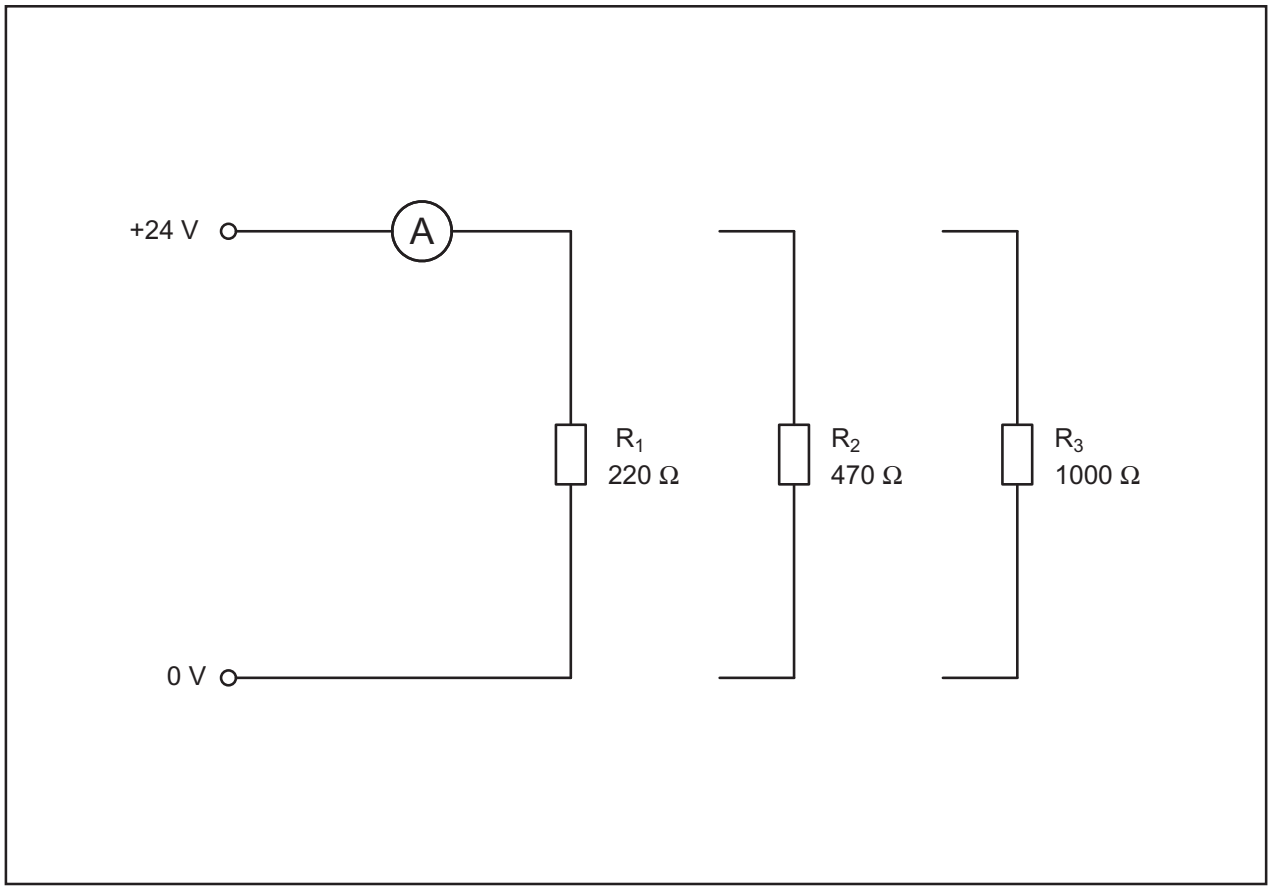


Figure 2: The circuit diagram for current measurement

Connect the resistance 220 Ω with the current supply device first. The other resistances are not required yet.

You should use a measuring range for direct current. Select the highest measuring range and connect the measurement device to the resistance and the voltage supply device.

Determine the lowest possible measuring range by reducing the ranges step by step. Register the measured value.

The determined measuring range: 0 … 200 mA

The measured direct current: 109 mA

Select the highest measuring range again and replace the resistance R_1 with the next resistance R_2.

Repeat the measurement procedure with the resistance R_2. Register the measured value.

The determined measuring range: 0 … 200 mA

The measured direct current: 51,1 mA

Perform the measurement with the resistance R_3 too. Register the measured value.

The determined measuring range: 0 … 200 mA

The measured direct current: 24 mA

Determine the current flow through both resistances R_1 and R_2 together. Connect these resistances in parallel and measure the current flow through them.

The measured direct current: 75,1 mA

The current flow through both resistances is higher than the current flow through the smaller resistance when connected alone.

Didactic tip The measuring ranges differ from one multimeter type to another.

Exercise 6 Implement the following measurement exercise. Take into consideration the learnt rules for dealing with a multimeter!

The following components are required:

Multimeter
Resistance R_1 = 100 Ω
Resistance R_2 = 220 Ω
Resistance R_3 = 470 Ω
Resistance R_4 = 1000 Ω

Connect each of the resistances to the multimeter. Select the highest resistance measuring range and determine the lowest possible measuring range by reducing the ranges step by step.

Repeat this procedure with other resistances. Register the measured values.

Resistance R_1 = 100 Ω
Resistance R_2 = 220 Ω
Resistance R_3 = 470 Ω
Resistance R_4 = 1000 Ω

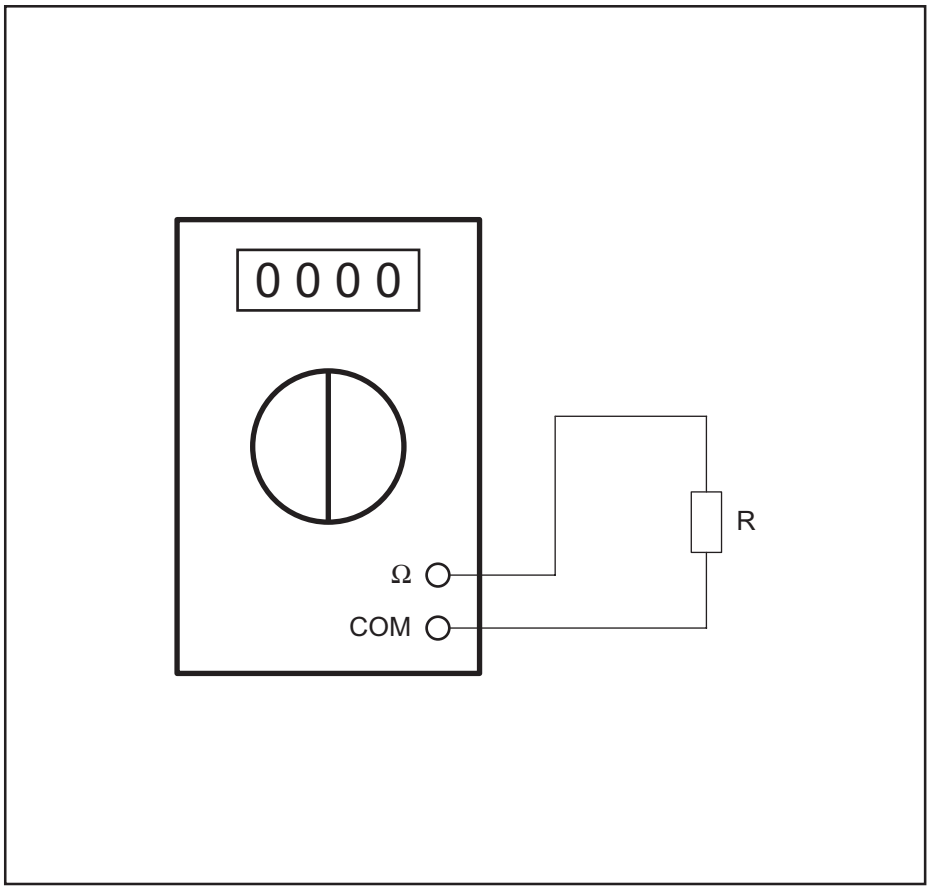


Figure 3: Resistance measurement

Exercise 7 Relay operation analysis.

The following components are required:

Voltage supply device with 24 V direct voltage
Multimeter
Press button
Relay

Connect the circuit according to the diagram. Connect the button and the relay in serial and attach them to the voltage supply device.

Connect the multimeter switched to the resistance measuring range. Some multimeters also have a flow measuring range. These can be used too.

Connect the multimeter to the relay's shutter contacts, which are indicated with 1 and 4.

Activate the button and watch the multimeters display. Repeat the experiment with the relay's break contacts.

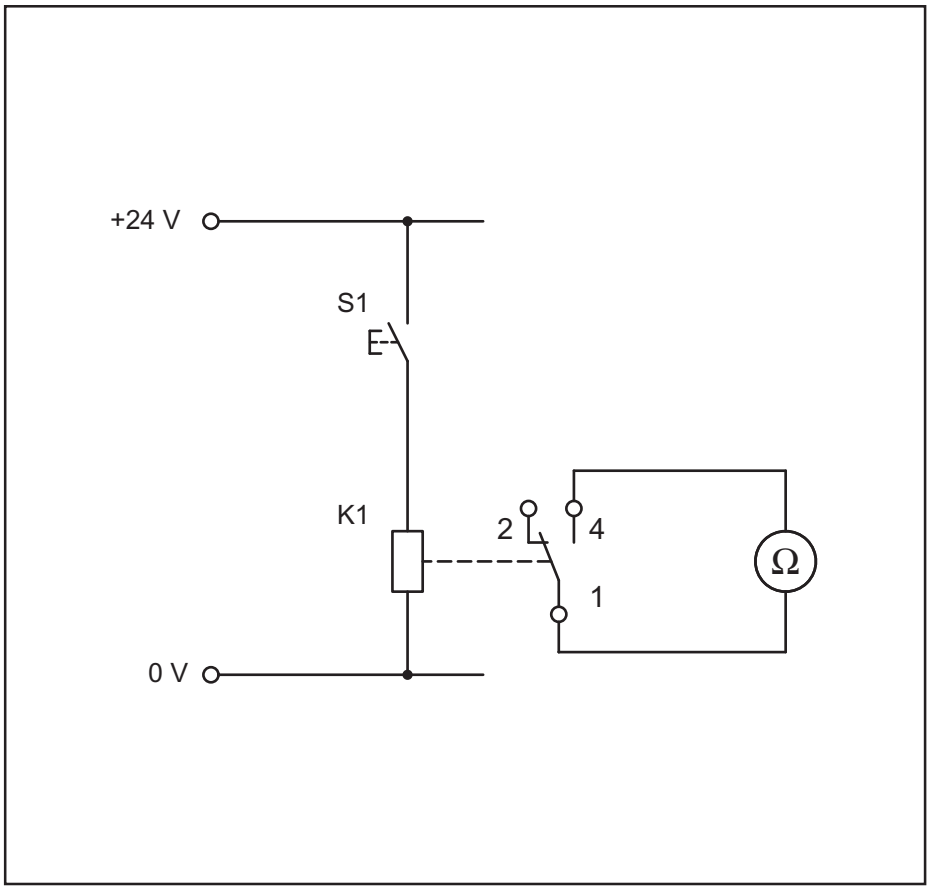
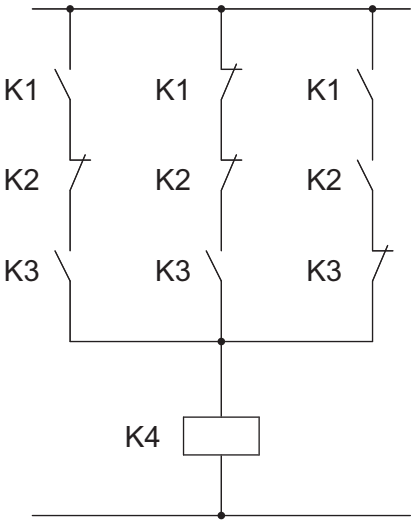


Figure 4: The operation of a relay

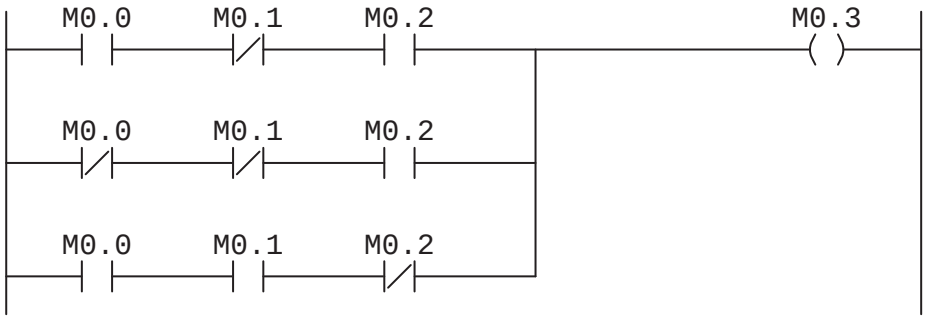
2 Programmable logic controls

Exercise 8 Convert the following electric diagram into ladder diagram. Use flags for the contacts of relays.

Circuit diagram:



Ladder diagram:

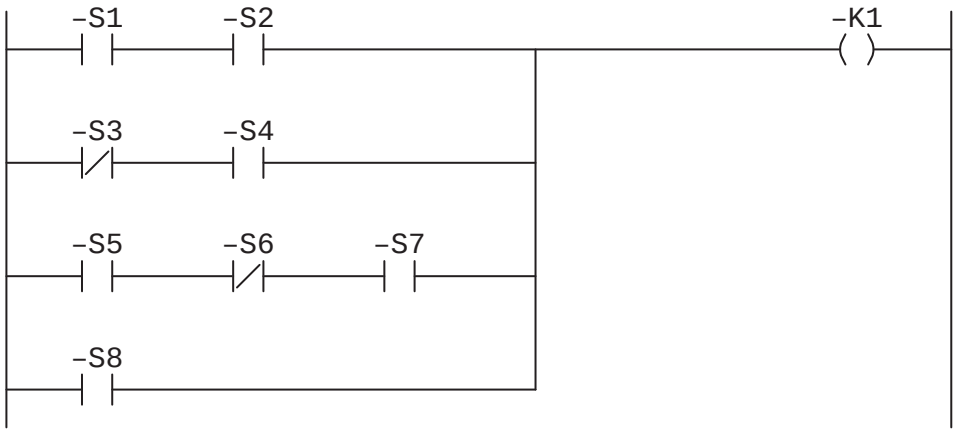


Exercise 9 Convert the following statement list into a ladder diagram and a function plan! In the ladder diagram a new path starts at each OR-gating.

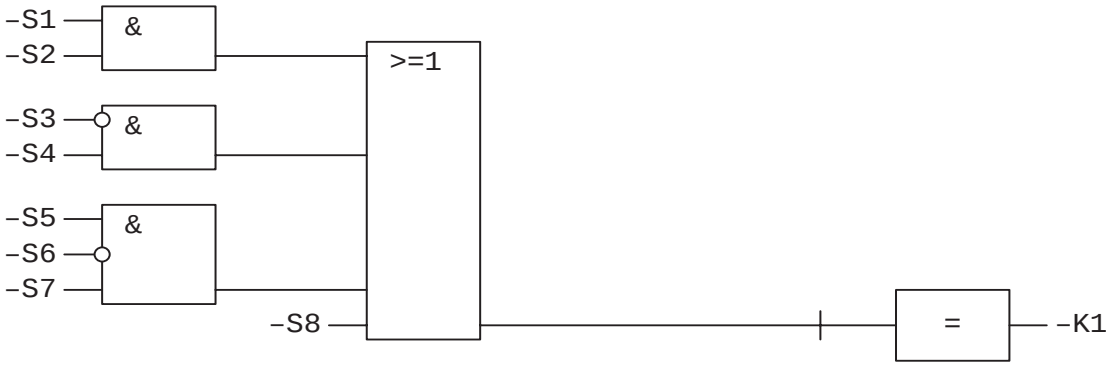
ST:

```
U    –S1
U    –S2
ON   –S3
U    –S4
O    –S5
UN   –S6
U    –S7
O    –S8
=    –K1
```

Ladder diagram:

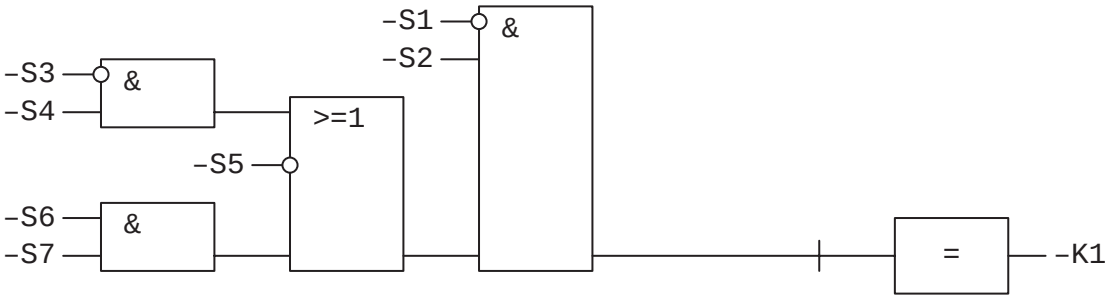


Function diagram:

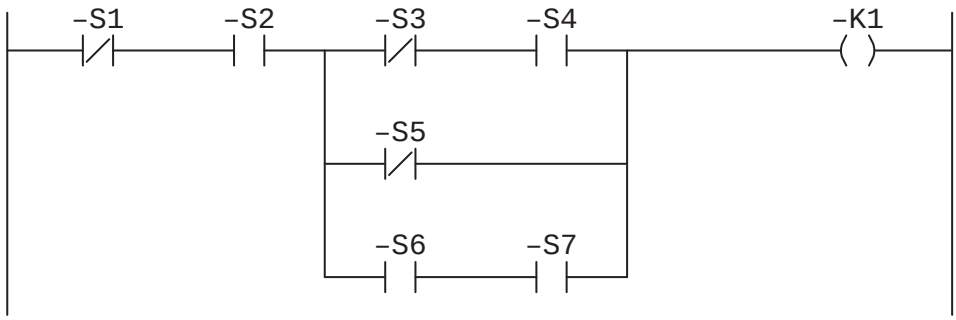


Exercise 10 Convert the following function plan into a ladder diagram and a statement list!

Function plan:



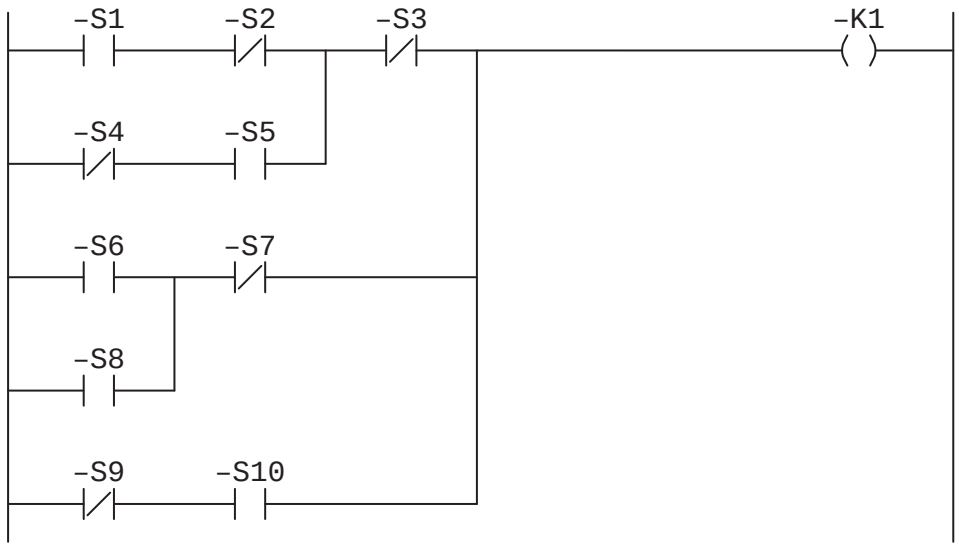
Ladder diagram:



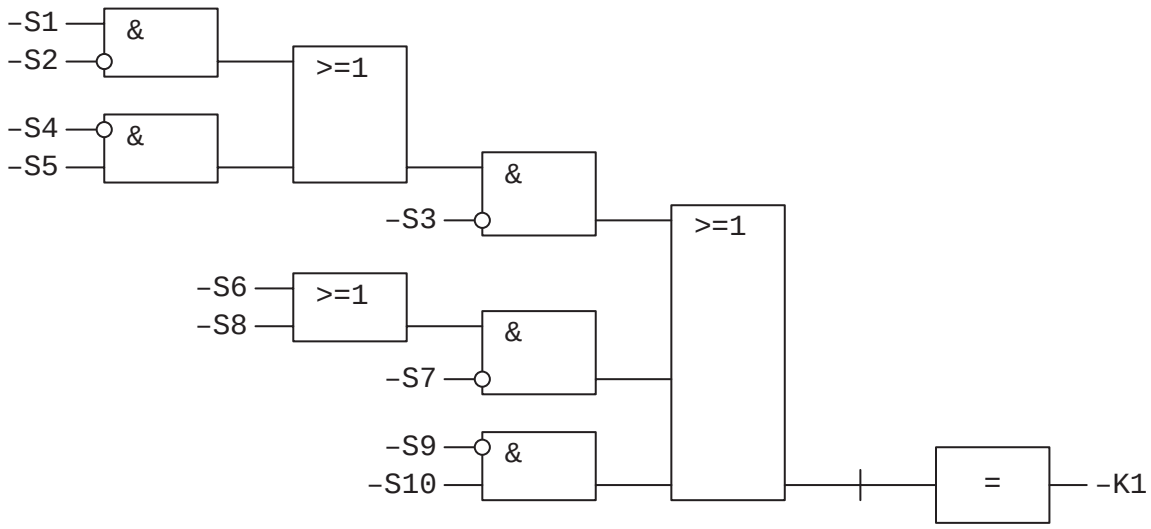
Statement list:

```
UN   –S1
U    –S2
(
UN   –S3
U    –S4
ON   –S5
O    –S6
U    –S7
)
=    –K1
```

Exercise 11 Convert the following ladder diagram into a function plan!



Function plan:



Exercise 12 A PLC should be used to operate three cylinders. The following operational sequence is planned:

The cylinder 1 should run out first and fasten a workpiece. The cylinder 2 should run out next and warp the workpiece. Then, the cylinder 2 must run in immediately. After that, a third cylinder should run out and return immediately too. Finally, the cylinder 1 should also run in and release the workpiece.

Each cylinder is provided with two end position switches for each end position. The operation starts by means of a start button. The starting should be possible only when all three cylinders stand in the “driven in” position.

Create a classification list for the PLC inputs and outputs first.

Device	Indication	PLC address	Comment
Starttaster	–S1	I0.0	shutter
cylinder 1	–B1	I0.1	internal end position
cylinder 1	–B2	I0.2	external end position
cylinder 2	–B3	I0.3	internal end position
cylinder 2	–B4	I0.4	external end position
cylinder 3	–B5	I0.5	internal end position
cylinder 3	–B6	I0.6	external end position
magnet coil 1	–Y1	Q0.0	cylinder 1
magnet coil 2	–Y2	Q0.1	cylinder 2
magnet coil 3	–Y3	Q0.2	cylinder 3

After that, create the PLC-connection diagram. Connect the single inputs and outputs to the corresponding buttons, switches or valve coils.

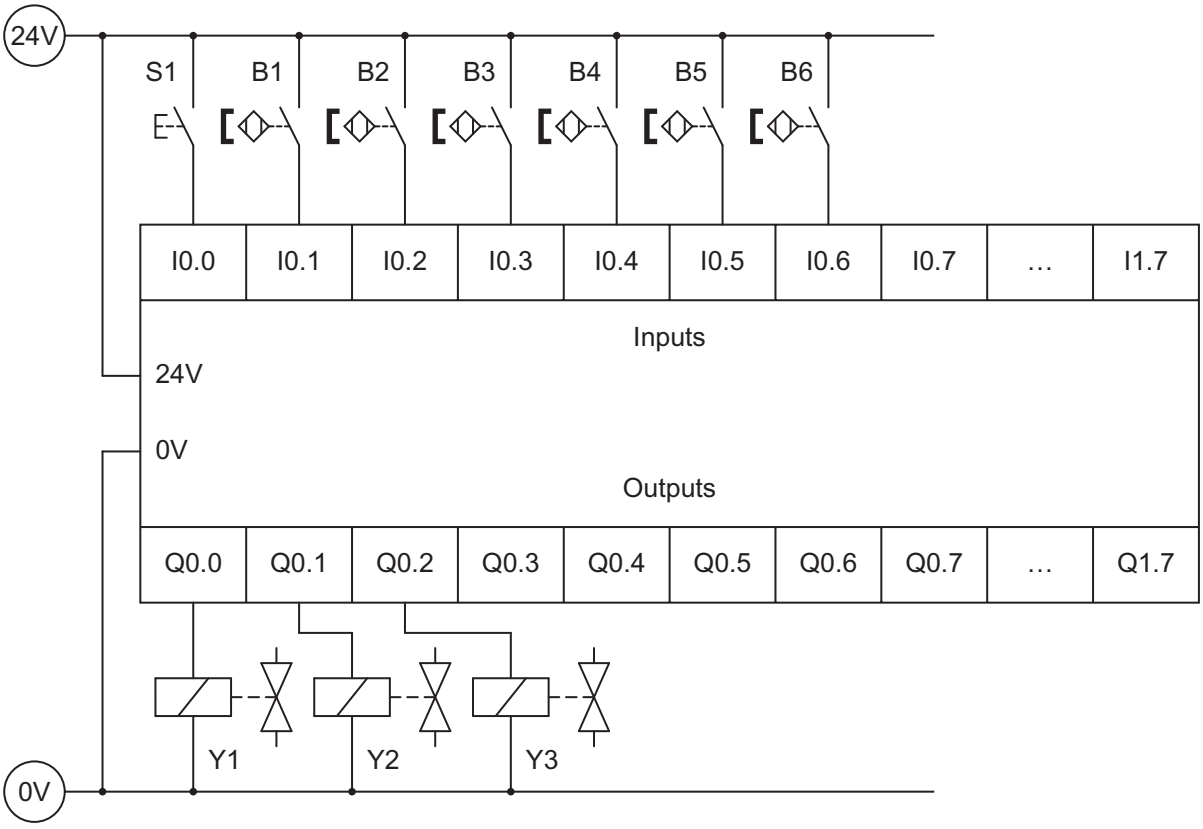
Create a step sequence using the function block diagram. Use a flag for each step. Use separate memory modules for the setting and resetting of the flags.

Use flags in the separate networks assigned for the control of the magnet coils of valves.

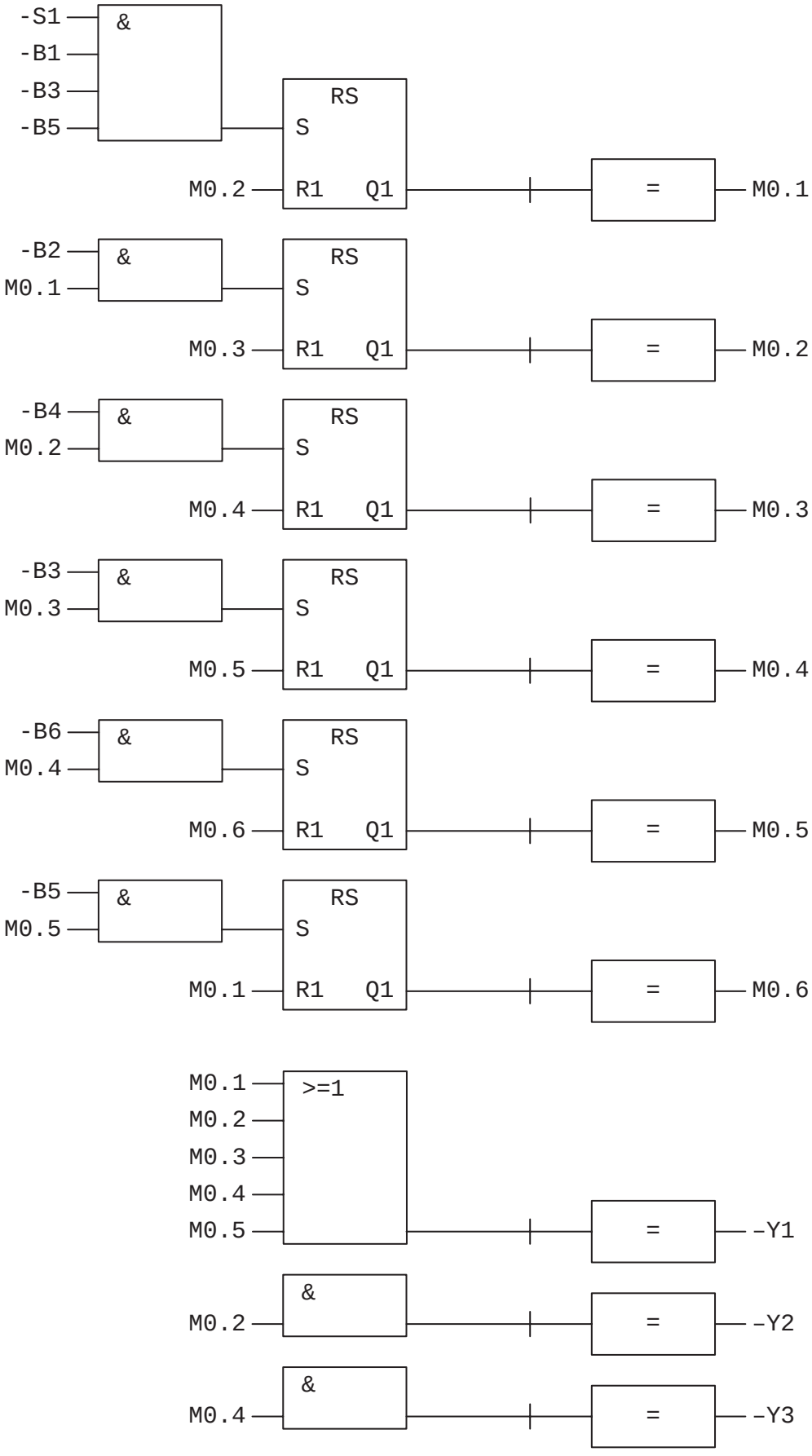
Create a second program in the sequential function chart. Here, six steps should be also created. The end position switches of the cylinders are used as further switching conditions.

The program may differ from the version represented here, according to the used PLC type and the related programming software.

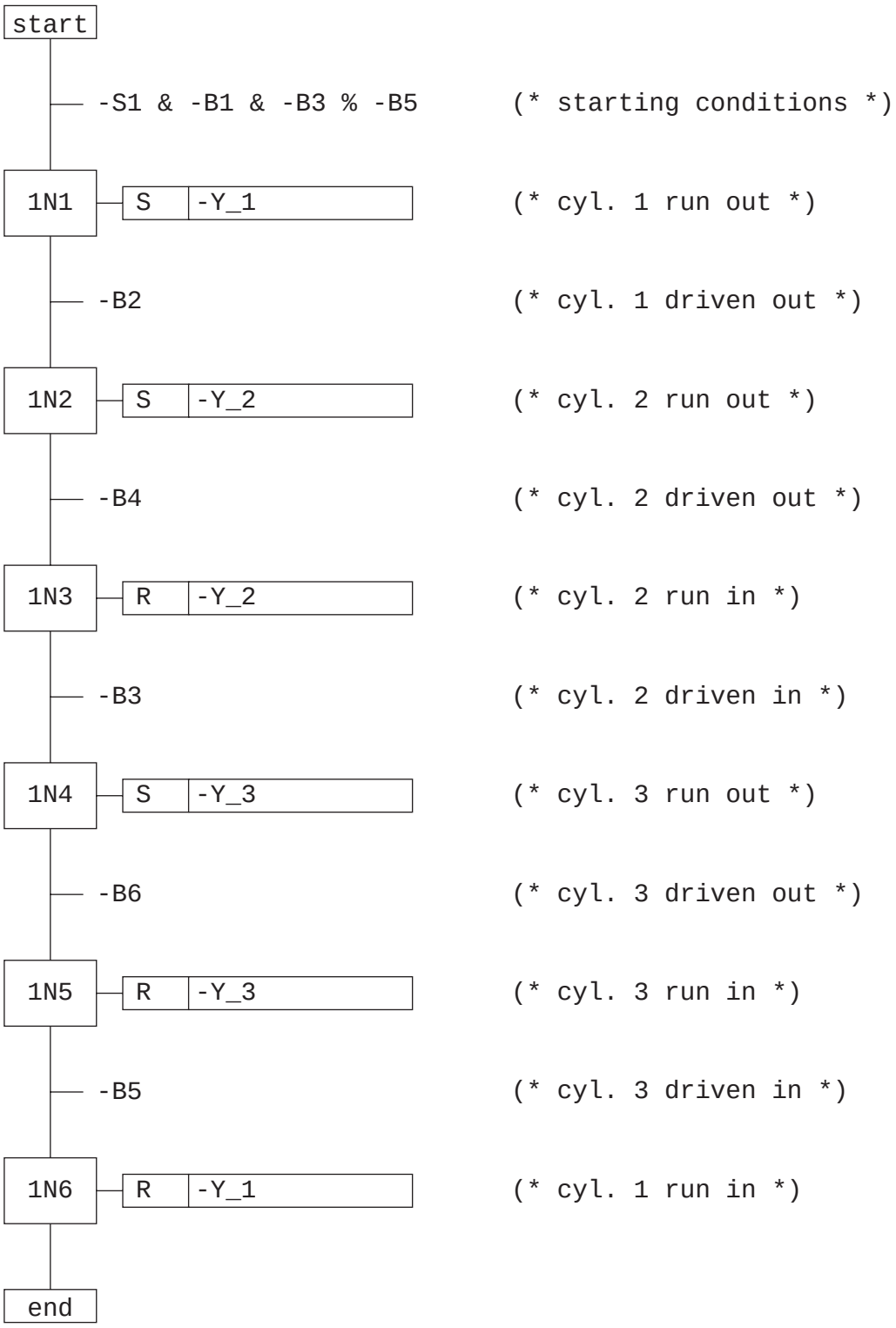
The sixth step can be omitted in the function block diagram. No action is performed by the flag of this step. Because of the starting condition, a new start is possible only after the third cylinder is driven in. In this case, the reset of the fifth step is performed by the first step.



Function block diagram:



Sequential function chart:



3 Electrical drives

3.2 Electrical and magnetic fields

Exercise 13 *What is the measurement unit of electric fields?*

The measurement unit of electric fields is V/m.

What is the direction of the electric flux lines?

The flux lines are directed from positive to negative charge, or from plus to minus. The flux lines leave positive charges and enter negative charges.

Describe the changes of voltage and current curves when applying a sine-shaped alternating voltage to a capacitor.

The sine-shaped alternating voltage makes the applied voltage change continuously. The fastest changes take place at zero-crossings of the sine curve. At this moment the current flow takes its highest values. The voltage value does not change at the sine curve peaks. Therefore, no current flows at these moments. Consequently, the voltage of a capacitor anticipates the current by 90°.

When do we use a free wheeling diode with coils and how does it work?

When applying direct voltage to a coil, a magnetic field builds up at the switching on. Turning off the direct voltage generates a self induction voltage acting in the same direction. The resulting current may damage the contacts of the switch.

To prevent this from happening a free wheeling diode is connected in parallel to the coil. It blocks the current during the normal operation and passes the current generated by self induction at switching off. The current flow through the coil drops down slowly causing no damage to the switch's contacts.

How can we increase the induced voltage?

The induced voltage can be increased by increasing the number of used windings. The larger the number of coil's windings the higher the induced voltage. On the other hand, the more intensive the magnetic flux changes the higher the induced voltage. This can be achieved by increasing the rotational frequency of the coil inside the magnetic field.

3.4 Transformers

Exercise 14 *What is an ideal transformer, and how can be a real transformer considered as ideal one?*

The ideal transformer has an efficiency factor of 100 %. It has no losses. The real transformer in idle running can be considered as ideal transformer. The idle running is the state, when no load is connected to the transformer's output coil.

How can we measure the iron losses of a transformer?

The iron losses can be measured in unloaded transformer. This is designated as idle running test. In this case the losses of the coils are negligible. The iron loss power is equal to the effective power consumed during the idle running test.

How can we measure the losses of coils of a transformer?

The losses of coils can be measured with a short circuited output coil. This is designated as short circuit test. In this case, the resulting iron losses are negligible. The loss power of coils is equal to the effective power consumed during the short circuit test.

What is the difference between transformers with low and high short circuit voltage?

Transformers with low short circuit voltage have small internal resistance. The output voltage decreases only a little under load. The short circuit currents, however, are high due to low internal resistance. These may destroy the coil and the whole transformer. On the other hand, transformers with high short circuit voltage have a contrary behavior.

A transformer should be always connected to voltage supply, but it works under load only for short periods. What should be the ratio between the losses of coils and the iron losses in order to achieve a high value of the annual efficiency factor?

The iron core losses are independent from the load. For transformers that work under load for short periods of time and must always remain switched on, the iron losses must be lower than the losses of coils. This improves the annual efficiency factor.

Exercise 15 The output coil of a transformer has 120 windings. The output voltage should be 24 V. The input voltage amounts 230 V. What is the number of windings at the input side? The transformer is considered as ideal.

The maximal input current amounts 1 A. What is the current value at the output?

A resistance of 250 Ω is connected to the transformer's output. What is the corresponding resistance at the input?

Voltages:

$U_1 / U_2 = N_1 / N_2$

230 V / 24 V = N_1 / 120

N_1 = 230 V / 24 V · 120

N_1 = 1150

The number of windings of the input coil should be 1150.

Current values:

$I_1 / I_2 = N_2 / N_1$

1 A / I_2 = 120 / 1150

I_2 = 1150 / 120 · 1 A

I_1 = 9,6 A

The maximal current at the output amounts 9.6 A.

Resistances:

$Z_1 / Z_2 = N_1^2 / N_2^2$

Z_1 / 250 Ω = 150^2 / 1150^2

Z_1 = 150^2 / 1150^2 · 250 Ω

Z_1 = 4,25 Ω

The output resistance affects the input side with a resistance of 4.25 Ω.

3.5 Rotary electrical machines

Exercise 16 *What is the rotational frequency of a three-pole rotary field at 50 Hz? And what is the frequency of a four-pole rotary field at 50 Hz?*

The three-pole rotary field rotates with 1000 rpm.

The four-pole rotary field rotates with 750 rpm.

How many coils are required for a three-pole and a four-pole rotary field when working with three-phase alternating current?

The three-pole rotary field requires 9 coils.

The four-pole rotary field requires 12 coils.

What is the other designation of the rotor of an asynchronous motor?

The rotor of an asynchronous motor is also designated as short circuit rotor.

Why do asynchronous motors have a slippage?

The rotary field of the motor's stator generates a rotary field. This generates a voltage in the rotor's cage and current flows through the cage's conductors, which are connected together by the short circuit rings.

The rotor's current generates a magnetic field, which makes the rotor turn in the rotation direction of the stator's rotary field. If the rotor reaches a rotational frequency equal to the stator's rotary field frequency no voltage will be induced any more.

What is the need of the capacitor in capacitor motors?

The rotary field in one-phase short circuit rotor motors is generated by phase displacement. In capacitor motors on the other hand, the phase displacement is performed by means of capacitors.

3.7 Current commutator motors

Exercise 17 *What different types of direct current motors are there according to the connection type between the excitation and the armature coils?*

Series excitation motor: the whole current that flows through the armature passes through the excitation coil.
Shunt-wound motor: the excitation coil is connected in parallel to the armature.
Separate excitation motor: the current for the excitation coil is supplied from an external source.
Compound motor: in addition to the parallel excitation coil there is another coil connected in series with the armature, which increases the magnetic field of the excitation coil.

Which motor has the largest startup torque?

The series excitation motor has the largest startup torque.

What should be taken into consideration concerning rotational frequencies when using series excitation motors? How can this problem be solved for small motors?

When operating a series excitation motor without load its rotational frequency will rise up continuously. This leads to overspeed and motor destruction. For small motors it is possible to use large ventilation blades. These blades form an increasing load at high frequencies.

What are the universal motors and where are they used?

The universal motors are one-phase series excitation motors. They can be operated with direct or alternating current. When working with alternating current the performance is a little lower due to the higher resistance value. Universal motors are used in household appliances and small electrical tools first of all.

Mechatronics

Module 5: Mechatronic Components

Trainerguideline
(concept)

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Andrzej Błażejewski

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Institute for Industrial Engineering and
Automation Technologies, Poland

EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

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Bildung und Kultur

Leonardo da Vinci

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1 Inductive sensors

1.1 Theoretical fundamental

Task 1 Identify the source of a variable magnetic field in inductive sensors

The source of a variable magnetic field in inductive sensors is an induction coil. If the current flowing through the coil changes in time, then the magnetic flux in the coil is also variable.

How does energy accumulated in electrical LC resonance circuits change?

In electrical LC resonance circuits, the entire energy is accumulated in a form of the magnetic field energy of an induction coil and electrical field energy of a loaded condenser. At each moment, the summation of these two forms of energy is constant. At the beginning stage, the whole energy is stored on the plates of the loaded condenser. After closing the circuit, the condenser starts discharging and the current starts flowing in the circuit. The whole energy of the condenser will be stored in the coil.

How are oscillations in an LC circuit generated?

The source of oscillations in an LC circuit is the phenomenon of the coil self-inductance that sustains the weakening current flowing in the circuit. This current loads the condenser; the energy is therefore transferred again from the coil to the condenser. The condenser is now loaded in the opposite way and the current in the circuit will flow in the opposite direction. These changes in the direction and value of the current generate oscillations of the electrical field in the condenser and oscillations of the magnetic field in the coil.

How to sustain oscillations in an LC circuit?

Oscillations in an LC circuit may be sustained by an external source of sinusoidal voltage

Specify a condition necessary for the resonance of voltage or current in an LC circuit to occur.

A condition necessary for the resonance of voltage or current in an LC circuit is that the frequency of the sustaining source is equal to the eigen frequency of the non-damped circuit. The amplitude of oscillations is then maximum.

What conditions shall be fulfilled to generate oscillations in a resonance circuit?

To start oscillations, two conditions shall be met independently: that of the phase and that of the amplitude. The phase condition requires that the output voltage is in phase with the input voltage. The amplitude condition requires that the amplifier compensates in full the damping losses introduced by the resonance circuit.

1.2 Basic construction

Task 2 *What constitutes the active part of an inductive sensor?*

The active part of an inductive sensor is a coil wound on the ferrite cup core and generating a variable magnetic field. The purpose of the cup core with an open magnetic circuit is to magnify the magnetic field of the coil and direct it towards the measuring zone of the sensor.

How does an inductive sensor evaluate distance from the detected object to the coil?

The electronic circuit of a sensor determines the distance from an object to the sensor based upon the amplitude damping rate and generates an output signal. It is mostly a two state signal: the object within the sensor's reach or out of the sensor's reach. The signal may be an analogue one. In that case it is in inverse proportion to the distance from the object to the sensor.

What is hysteresis?

Hysteresis is a difference in the distance to which a sensor responds when a metallic object approaches and recesses its face. The state of the sensor changes then from OFF to ON or vice versa. The value of hysteresis depends upon the type and size of a sensor and is usually not greater than 20% of the measuring range.

Why is it recommended that an inductive sensor should have a certain amount of hysteresis?

Apart of a detection section, the electronic system of a sensor comprises a comparator with hysteresis and an output system. As a result of hysteresis, interference events that might appear at the sensor's output are avoided. Interference is most likely to occur at the moment of switching, in the cases of unstable position or vibration of the detected object, fluctuations of the supply voltage and/or ambient temperature.

What are operating frequencies of inductive sensors?

LC generators generating a variable magnetic field in inductive sensors are HF (high frequency) generators with a typical range from 100 KHz to 1 MHz. With the increase in the coil diameter, the maximum frequency of a sensor decreases.

How big is the operating range of inductive sensors and what are their housings?

The range of typical inductive sensors does nor exceed 60 mm. These sensors are provided with different types of housings, both cylindrical (metallic) and prismatic (plastics). This makes it possible to optimally install a sensor in its operating location.

How to define the rated operating range of a sensor?

The rated operating zone $\mathbf{S_n}$ of a sensor is defined as a distance from its face to an object at which the output circuit is subject to switching. This very value is given in the catalogue data.

For what object is the rated operating range of a sensor given in catalogues?

The rated operating range of a sensor is determined in agreement with the EN 60947-5-2 standard for a square steel plate (St37) one mm in thickness and with the side equal to the diameter of the sensor.

What is the actual operating range of a sensor?

The actual operating zone S_r is determined in the course of manufacturing of a sensor may slightly differ from $\mathbf{S_n}$. Usually it lies in the range $0.9\mathbf{S_n} \leq \mathbf{S_r} \leq 1.1\mathbf{S_n}$ **.**

What is the working range of a sensor?

The working operating range defines a safe distance range from a metallic object to the sensor ensuring faultless operation irrespective of the actual operating range guaranteed by the manufacturer. The recommended working range is $\mathbf{S_a} \leq 0.8\mathbf{S_n}$**.**

Which factors influence the operational range of an inductive sensor?

The operating range of an inductive sensor depends upon the housing diameter and, more specifically, upon the coil diameter and ferromagnetic core properties. Sensors in small housings have a smaller operating range than those with bigger overall sizes. There are also special executions of sensors with an enhanced operating range.

What is the role of correctional factors when measuring with inductive sensors?

Materials like gold, copper or aluminium, which feature higher electrical conductivity than steel St37, damp oscillations of a resonance circuit to a lesser degree. By decreasing distance from the object to the sensor these differences may be compensated. This will cause a certain reduction of the zone, in which it is possible to detect an object. Accordingly, if the metal being detected is brass, then the operating range S_n determined for an object made of steel St37 shall be modified by multiplying it using a correctional coefficient for brass equal to 0.5 x $\mathbf{S_n}$.

What influence has the design of a sensor had on its sensitivity?

There are two basic forms of sensors with a cylindrical housing:
– Shielded: the coil is inserted into a sleeve and,
– Non-shielded: the coil protrudes from the sleeve and is located in a plastic cap. The non-shielded sensors feature higher sensitivity for other metallic objects in their vicinity than the shielded ones.

What requirements shall be met when installing shielded sensors close to each other?

A shielded cylindrical sensor is not sensitive to the surrounding metallic objects save those from the frontal sensor's zone. Consequently, these sensors may be installed fully in metallic elements. The free zone from the sensor's face is set by a distance of **3Sn**. To avoid a mutual interference of two sensors situated close to each other, the minimum distance between them shall be greater than two diameters of one sensor.

What requirements shall be met when non-shielded sensors are installed close to each other?

Ą non-shielded cylindrical sensor is sensitive to metallic elements surrounding it from three sides. The sensor must therefore in part protrude so that the free zone includes also its side surfaces. To avoid interference in this case, the distance between sensors shall be greater than 3xD.

What is the meaning of the maximum switching frequency of the sensor's output?

The maximum switching frequency given in the technical specifications of each sensor provides information on the maximum switching frequency of a sensor per second. It is determined when an object made of steel St37 cyclically enters and leaves the sensor's sensitivity zone. When determining this frequency, valid are requirements given in the EN 50 010/IEC 60947-5-2 standard.

What maximum values of the switching frequency shall be expected when using objects different than the standard plate?

He result of a measurement will always depend upon the size of the object that damps the coil, distance from the sensor's face and object speed. By using an object smaller than the standard plate for a given sensor or by using a smaller gap between protrusions, a reduction in the maximum switching frequency of the output may be expected.

1.3 Special inductive sensors

Task 3 *What is the operating rule of an inductive ring sensor?*

The underlying operating rule of an inductive ring sensor is based on a high frequency oscillator that generates a magnetic field inside the hole of the sensor. Toroidal powder cores with a value of the quality factor higher than that for ferrite cores are used in these sensors. The presence of a metallic object activates the sensor causing a reduction in the amplitude of oscillations. This is recognised by a comparator and after a threshold value has been exceeded, the output state is toggled.

Are there limitations concerning the size of objects detected by an inductive ring sensor?

To trigger a sensor, needed is a determined level of damping of the magnetic field. If elements are too small, the level of damping may be insufficient. Consequently, for each size of the sensor there is a minimum length or diameter of the detected objects that guarantees the proper operation of the sensor.

Are there limitations concerning the form of a trajectory that a detected object travels within an inductive ring sensor?

An advantage of ring sensors is that a detected object needs not to move exactly along the same trajectory. The ring shaped active surface of the sensor makes it possible to detect objects irrespective of their spatial orientation, e.g. those subject to the force of gravitation in a plastic tube.

What may be negative impacts of strong magnetic fields on inductive sensors?

Installation of an inductive sensor in a zone of strong magnetic fields (e.g. in the vicinity of welding equipment) is associated with a risk of uncontrolled switching of the output state. This may happen due to the core saturation or due to the induction of an additional voltage in the coil. This additional voltage interferes with the operation of the oscillator and may cause accidental switching of the sensor's output.

How is it possible to protect inductive sensors against negative impacts of strong magnetic fields?

Sensors resistant to strong magnetic fields shell be provided with a special design of the electronic circuit and a core with a small magnetic permeability that gets saturated in a magnetic flux a few times denser than is the case for typical ferrite cores. The highest resistance to the action of external magnetic fields have sensors altogether without the core. In these design solutions, the coils are wound around non-magnetic bobbins made of plastics.

How are sensors operating in the vicinity of electric arc welding protected?

Welding processes are inherently associated with a large number of sparks that may impair the sensor's housing, and especially its active surface. Sensors designed for operation in the proximity of welding equipment are therefore usually made of brass coated with Teflon® and their frontal surface is protected with a high temperature resistant Duraplast®.

Specify exemplary types of sensors designed for operation in difficult conditions

These might be sensors resistant to high pressure, temperature, chemically aggressive environment, oil, humidity and miniature sensors for operation in difficult access locations.

What features shall inductive sensors have for operation under high pressure conditions?

Sensors operating under high pressure conditions shall be provided with a robust and tight housing to prevent any damages to internal electronic components. The coil and core of a sensor shall be protected with a thick disk, e.g. a wear resistant ceramic disk. Needed are also some modifications of the oscillator system lest the operating range of the sensor is too small, thick disk notwithstanding.

How is the determination of object trajectories in a bi-stable ring sensor carried out?

An inductive bi-stable sensor has two coils set next to each other and fed from two independent generators. At a given moment of time only one generator is enabled. If an object approaches from the left side rightwards then damped is the circuit of the first coil and next the circuit of the second coil. In the opposite motion the situation is reversed. By analysing values of currents flowing through the coils, the measuring system recognises the direction (sense) of movement.

What is the operating principle of NAMUR inductive sensors?

NAMUR inductive sensors are two lead sensors, the internal resistance of which changes as a result of detection of a metallic object. Small resistance of the sensor corresponds to a „no metallic object" situation, and a high resistance – to „a metallic object detected". These sensors co-operate with external amplifiers. NAMUR inductive sensors consist of an oscillator with a partially damped coil and a demodulator. A change in the distance between the detected object and the sensor is transformed into a change in the supplied current. This change is converted by the external amplifier into a two-state signal.

What are the main features of NAMUR inductive sensors?

NAMUR inductive sensors feature a strictly defined range of values of the allowable output current. According to the EN 60947-5-6 standard this range is from 1.2 mA to 2.1 mA. All NAMUR sensors fed from a DC amplifier have the same current characteristic and feature a strictly defined switching hysteresis equal to 0.2 mA.

For what conditions the Namur inductive sensors are best suited?

NAMUR inductive sensors in conjunction with a spark-proof switching amplifier may operate in explosion proof installations or in explosion hazard zones (zone I or II). These sensors my also operate with relay amplifiers (not complying with the safety regulations) but in that case the amplifier must be located outside the explosion hazard zone.

What are differences between analogue output and two state output sensors?

Two state sensors identify only the state of detection or non-detection of an object. Inductive sensors with an analogue output register, on the other hand, the position of an object in the whole measuring range. To a changing position of the object from a distance of S_n to zero corresponds a change in the output signal from 0 to 20 mA.

How are inductive analogue sensors designed?

Inductive analogue sensors consist of a head with a coil, generator, linearization system and the output system in a range of 0 to 20 mA.

1.4 Supply and connections of sensors

Task 4 *What are permissible fluctuations of DC supply voltage for inductive sensors?*

DC supplied sensors co-operate mostly with adapters, the output voltage of which is fluctuating. To large fluctuations of the amplitude of momentary values of this voltage may cause unpredictable behaviour of an inductive sensor. To ensure faultless operation, fluctuations of the supply voltage must be kept within a 10% range from the average value of the supply voltage.

How to protect a sensor against short-time surges of the supply voltage?

To avoid to large surges of the supply voltage, it is recommended to use a stabilised adapter or to use a large voltage smoothing condenser.

What are possible manufacturing configurations of DC supplied sensors?

Outputs of sensors supplied with DC current are made in the NPN or PNP layout. That means that for an NPN configuration the load $\mathbf{R_L}$ is connected between the output of the sensor and the plus of the voltage supply**,** and for a PNP configuration – between the output and the minus of the voltage supply.

What is a difference between an NO and NC execution of sensors?

DC supplied sensors in the PNP and NPN configurations manufactured with the NO (normally open) output function switch on the current in the load attached to the sensor's output. NC (normally closed) sensors switch off the current.

Is it allowed for AC supplied sensors to be directly fed from the mains?

AC supplied inductive sensors must not be connected directly to an AC power supply adapter. Such connection may result with a total damage to internal circuits of a sensor. The supply of these sensors is only possible after a series connected load has been attached to the sensor.

Is it possible that there is a flow of current in the electric circuitry of an AC supplied sensor even if it is OFF?

Yes. These sensors, apart of the oscillator, have a power amplifying transistor that is connected in series with a load. The result is a residual leakage current in the circuit, even if the sensor is in the off state. This causes a certain supply voltage loss.

What is the purpose of sensors' grouping?

A series or parallel connection of a few sensors opens a possibility to realise different operational strategies of the equipment that may be connected in the external circuit as load. By a skilful connection of sensors, such logical functions as AND, OR and/or NOR may be obtained.

What logical functions may be performed by series connected sensors?

Series connected sensors can realise the AND or OR functions. The logical function AND guarantees that the output signal from a series of sensors will appear only if each of the sensors has changed the state of its output from OFF to ON. The NOR function causes an interruption of the circuit supplying the load, which is effective only when all sensors in a group have changed their state from ON to OFF.

Which factor determines the maximum number of series connected sensors?

The maximum number of series connected sensors depends upon the supply voltage, voltage drops at the output of the sensors and parameters of the attached load. The supply voltage of the system, reduced by a total amount of voltage drops, at the output of the sensors must always be greater than the minimum operating voltage with the load connected.

What logical functions can be performed by parallel connected sensors?

Groups of sensors connected in parallel can realise the OR function. This function generates the output signal when at least one sensor in a group has changed its output state.

Which factor determines the maximum number of parallel connected sensors?

For parallel connected three lead DC sensors set in parallel there are no substantial quantitative limitations. Irrespective of the output function, a dozen or so sensors may be connected in parallel.

Is it allowed to connect two lead sensors in parallel?

Yes, it is allowed to connect two lead sensors in parallel. For parallel connection of two lead sensors, the leakage currents of all sensors in a group may add, which is disadvantageous for a trouble free operation of the system. The maximum number of sensors in a group depends in that case upon the type of load and upon the sum of the leakage currents flowing through the output circuit of the sensors.

1.5 Safety and protections

Task 5 *Against what unwanted effects are the outputs of DC fed sensors protected?*

In most of the DC supplied sensors the outputs are protected against the following disadvantageous phenomena or actions:

- Reverse connection of the supply voltage

- Over voltage at the output as a result of switching off

- Short and non-cyclic impulses from the supply line

- Excessive output current or short-circuits.

Are short-circuits at the output of a DC supplied sensor dangerous to its operation?

Short-circuits in an electrical circuit with constant-current sensors do not cause damage to a sensor, even if recurrent and prolonged. During a short-circuit, the diodes in the sensor are disabled. After removal of the short-circuit, the sensor operates properly.

When is a grounding of the sensor's shield required?

Sensors in metallic housings, if supplied with a voltage dangerous to a human life, need an additional grounding lead.

What precautions shall be taken against the presence of leakage current in the electric circuitry of a sensor?

When an approach sensor is in the OFF state, a leakage current appears in the circuit. This may contribute to an erroneous operation of the sensor, e.g. a permanent dwell in the OFF position. To safeguard against such situations, an additional resistor connected in parallel with the load is used. The resistor takes the leakage current such that the current flowing through the load is less than a minimum value required by the load.

2 Capacitive sensors

2.1 Basic information

Task 1 *From what type of materials can objects be detected by capacitive sensors?*

Capacitive sensors, besides metal objects, can detect nonconducting objects, e.g. plastics. A capacitive sensor is also able to react to objects located behind a nonconducting layer, which makes it a classic sensor for detecting liquids or pellets through the container's walls. Capacitive sensors are usually used as proximity detectors, but they can also generate a signal proportional to the distance of an object from the sensor's face.

Which of the below listed materials can be detected by capacitive sensors?

1. Steel
2. Copper
3. Rubber
4. Ebony
5. Water
6. Cereal
7. Hydrogen

A capacitive sensor will detect steel, copper, rubber, ebony, water, and cereal. In the case of hydrogen (hydrogen is a gas), its detection is impossible.

What are the main components of a capacitive sensor?

The main components of a capacitive sensor are: a head with electrodes, potentiometer P, an oscillator, a detection circuit and an output circuit.

Which elements constitute the active component of a capacitive sensor?

The capacitive sensor's active components are two metal electrodes forming an open capacitor. As an object gets closer to the sensor, the latter's capacitance changes. The capacitor's total capacitance, which determines the output signal level, is the sum of the sensor's basic capacitance and the change in capacitance caused by the action of the object being detected.

What is the operating range of capacitive sensors?

The operating distance of capacitive sensors is rather short – up to 30 mm, but there are special versions whose operating distance is as long as 60 mm.

2.2 Theoretical basis

Task 2 *Does the capacitance of a condenser increase proportionally to the interelectrode distance?*

No, the capacitance of a capacitor is in inverse proportion to the interelectrode distance. It is proportional to the surface area of the capacitor electrodes and to the dielectric constant of the filling material.

ow is it possible to get an open capacitor?

The capacitor has two electrodes: A and B, situated opposite each other in its basic version. An open capacitor is obtained by putting the electrodes in one plane.

What is the role of an indirect electrode?

By introducing an indirect electrode (having a thickness →0), between the main electrodes one can obtain two capacitors connected in series. A similar effect is obtained in the open capacitor in which an indirect electrode divides the electric field into two fields with opposite directions.

What is the difference between placing a conducting object in the field of an open condenser vs. a non-conducting one?

A conducting object placed in the open capacitor's electrostatic field itself becomes the indirect electrode and the capacitance of such a system is always higher than that of the capacitor without the indirect electrode. A nonconducting object (insulator) put in the open capacitor's field increases its capacitance proportionally to the insulator's dielectric constant. This is due to the fact that the open capacitor's initial capacitance depends on the air permittivity and the dielectric constants of liquids or solids are always higher than the dielectric constant of air (ε_{air} =1)

What factors influence the capacitance of a capacitor?

The capacitance of a capacitor depends upon the surface area of electrodes, interelectrode distance, and a dielectric constant of the filling material.

2.3 Operating principle of a capacitive sensor

Task 3 *Which of the objects is more easily detected by a capacitive sensor and why: a conducting or non-conducting one?*

Conducting objects are more easily detected than the non-conducting ones. Nonconducting objects, such as paper or glass, increase only the sensor's self-capacitance by influencing its dielectric constant. But the increase, dependent on the object's dielectric constant, is slight whereby the operating distance is also small. In the case of ungrounded conducting objects additional two capacitors arranged in series, one between the object and the sensor's electrode and the other between the object and the external electrode, are formed.. The sensor's operating distance is longer in this case.

Does grounding of the object being detected has any significance to the operation of a sensor?

Yes, the grounding of the object being detected increases the operating distance of a sensor. The longest operating distance is obtained when the object being detected is a grounded conductor. Then the additional capacitance between the object and the electrode forms a parallel connection with the sensor's self-capacitance.

What is the role of a potentiometer in a capacitive sensor?

In the feedback circuit between the oscillator and the electrode there is a potentiometer through which one can set the oscillator circuit's activation point.

Give the definition of the standardised object for a capacitive sensor.

The standardised object for a capacitive sensor applies to a grounded 1 mm thick metal object made of steel FE360, square in cross section, whose side is equal to the diameter of the sensor's face or to three values of S_n, depending on which value is larger.

How is the reliable operating range of a capacitive sensor defined?

The reliable operating range of a capacitive sensor is defined as $0 <= S_a <= 0.71*S_n$.

From what does the capacitive structure of a sensor depend on?

The sensor's capacitive structure always depends on the kind of object being detected and its grounding.

2.4 Types of capacitive sensors

Task 4 *What are typical varieties of capacitive sensors?*

Capacitive sensors are usually available in the form of cylindrical or cuboidal proximity detectors with the active part at one of the ends. There also special elastic versions which can be stuck on horizontal and curved surfaces.

What are types of cylindrical capacitive sensors?

Cylindrical sensors are available in two varieties. One is screened so that the operating zone extends only from the sensor's face. Such sensors are flush mounted in metal or plastics. Sensors of the other type have an additional operating zone at a small distance from the sensor's cylindrical surface. They are designed to be used in cases when the sensor is in contact with the medium being detected, e.g. liquids or pellets. The operating zone of such a sensor is by 50% larger since the sensor's larger electric field closes at its sides.

How to evaluate the real operating distance of a sensor?

To evaluate the actual operating distance of a sensor, the catalogue nominal operating distance S_n Should be multiplied by the correction coefficient proper for the kind of material of the object being detected. The nominal operating distance S_n given in the catalogue is valid for a standardised metallic object.

From what does the detecting distance for organic materials depend on?

The distance at which a capacitive sensor detects organic materials such as wood or grain to a high degree depends on the water content in the materials. This is connected with a very high dielectric constant of water (ε_{water}=80).

At what distance from each other shall two capacitive sensors be installed?

Capacitive sensors shall be installed at a distance greater than $3 * S_n$. If the sensors are installed face to face, this distance shell be twice as big.

2.5 Compensation of interference events

Task 5 *Is there a difference in the switching distance when detecting an object made of copper or steel?*

No, there is no difference in the switching distance. In the case of objects made of conducting materials, the type of material has no influence on the operating range.

Which material is more easily detected: water or oil?

Water is more easily detected. The dielectric constant for water is equal to 80 and is the highest among non-conducting materials. For the transformer oil this constant is equal to 2.2.

What is the influence of pollution on the operation of a sensor?

The pollution of a sensor, a change in air humidity or the deposition of dew particles on the sensor's active surfaces may result in its improper responses. Pollution increases the capacitance between the sensor electrode and the screen.

Is it possible to limit the influence of pollution by the design of capacitive sensors?

Yes. To maintain the constant detection distance in the case of a uniform field of interference, an additional compensation electrode is being employed. Pollution increases the capacitance between the sensor's electrode and the screen. At the same time the capacitance between the sensor's electrode and the compensation electrode generates a compensation coupling. But in the case of a direct contact between a thin object (e.g. a sheet of paper) and the sensor there is a danger that the interference signal will neutralise the main electrode reading and no sensor switching will occur.

How to eliminate the influence of external magnetic fields?

The detection circuit incorporates interference filters which eliminate the influence of external electric fields if the latter are not too large. The filters, however, can significantly lower the maximum switching frequency and thus deteriorate the sensor's dynamic characteristic.

3 Ultrasonic sensors

3.1 Physical fundamentals

Task 1 *Explain the mechanism of propagation of a sound wave in air.*

The propagation of a sound wave is related to vibrations of air particles. The vibrating particles incite to vibrations adjacent particles. As a result, a sound wave propagates in the space without translation of the vibrating air particles. Sound waves may propagate in different media (gases, liquids, solids). In the air, these are longitudinal waves.

How is the length of a sound wave defined?

The length of a sound wave is a distance that a wave travels during one period. The frequency of vibrations is a number of periods occurring per one second. It is expressed in Hertz's.

How is it possible to calculated the distance from an obstacle to the source of sound?

Based upon the measurement of time **t** necessary for the reflected wave (echo) to return to the sensor and knowing the speed of sound in the air **V**, it is possible to calculate the distance **S** from an obstacle to the sensor using the following formula:

$S = V \cdot t / 2$

where:

V − speed of sound propagation in air (343m/s at 20^{o}C),

t − time span between the emission and reception of ultrasounds, in [s],

S − distance between the sensor and the obstacle, in [m].

Explain the idea of the piezoelectric effect.

The piezoelectric effect consists in the creation of electrical charges in a crystal of quartz as a result of stressing. This phenomenon is reversible so under a voltage applied to a crystal it is subject to deformations. Piezoelectric properties display also other materials like lithium sulphate or ceramic materials.

How do piezoelectric materials behave in elevated temperatures?

Piezoelectric properties of piezoelectric materials vanish at high temperatures. The maximum temperature of operation of a quartz material shall not exceed 200 ºC, and that of a ceramic transducer – 100 ºC.

How is a sound wave generated?

A piezoelectric element is incited to vibrations by changes in the applied voltage. Vibrations of this element are transferred to particles of air or other medium and a wave is thus generated in this medium. And conversely, if vibrations of the medium particles are transferred to a transducer, then as a result of deformations experienced on the surface of this transducer, electrical charges are generated. The same transducer, if there is a need, may thus be employed for the generation and reception of waves.

What range of frequencies is employed in ultrasonic sensors?

In ultrasonic detecting sensors used for the detection of objects, sound frequencies from a range of 23 to 400 kHz are mostly used.

What shape the area of enhanced energy of a sound wale has?

The area of propagation of an ultrasonic wave is to a high degree dispersed. The greatest energy of sound is present close to the sensor's axis. The shape of a beam that is sufficiently strong for measurements is close to a cone.

Which factors determine the size and cone angle of a sound wave?

Depending upon needs, sensors emitting a wave with different cone angles are manufactured. These angles vary from a few to a few dozen of degrees. Both the angle and the beam shape are determined by the size, shape, and frequency of the vibrating surface of the sensor.

How is it possible to determine the diameter of the cone of an ultrasonic beam?

The diameter of the ultrasonic beam cone at a distance X from the sensor's face may be calculated from the following formula.

$$D = 2 \cdot X \cdot \tan(\alpha/2)$$

Where:
X – distance from the object to the sensor
α – cone angle of the ultrasonic beam cone

3.2 Ultrasonic sensor measurements

Task 2 *What is the operating rule of an ultrasonic sensor?*

Typical ultrasonic sensors operate in one of the two modes: a diffusion one (diffuse sensors) and through one (through beam sensors). The diffusion reflection is the most popular method for ultrasonic sensors. A sound wave reflected from an object returns to the sensor as an echo. Depending upon the output type, a distance determined based upon the time measurement is transformed into a voltage or current analogue signal or a relevant state of the two-position output (ON/OFF). When the object has left the measurement zone of the sensor, its output system returns to the previous state.

What phases may be isolated in the operation of an ultrasonic sensor?

Ultrasonic measurements feature two phases:
- Emission of an ultrasonic beam from a transducer towards an object.
- Emission of an ultrasonic beam by the detected object in the direction of the transducer whereas in this case the beam is an echo of the signal emitted from the transducer.

Is it possible that the same transducer operate as the emitter and the receiver?

In diffusion sensors these two functions can be performed by the same piezoelectric transducer. There are also models of diffusion sensors in which each of the two functions is performed by a separate transducer. In through sensors the emitter and the receiver are located in separate housings. In each of these housings there is a separate sensor.

What are the main components of an ultrasonic sensor?

The main components of an ultrasonic sensor are a high voltage generator, a piezoelectric converter located in the head of the sensor, a system of signal processing and an output system.

Are ultrasonic sensors resistant to external sound interference?

Ultrasonic sensors generate acoustic waves with frequencies clearly out of the range of audible ones, i.e. over 20 kHz. The high frequency of operation of ultrasonic sensors makes them practically immune to interference with surrounding sounds.

What is the main application area of ultrasonic sensors?

Ultrasonic sensors are employed for the detection of objects, for the detection of levels of transparent and non-transparent fluids, and for the measurement of distances. They find application in areas of high dust content and in locations where, due to a high degree of soiling, application of optical sensors is not possible.

How do material properties of detected objects influence the sensitivity of ultrasonic sensors?

The sensitivity of a sensor is the higher the higher is the density of the detected object. A greater part of the sound wave is then reflected. By virtue of this fact, ultrasonic sensors are especially useful for the detection of objects with a high value of the acoustic reflection coefficient. A high value of the reflection coefficient feature solid or liquid materials or granulate-type media.

What is the working cycle of an ultrasonic sensor with one piezoelectric sensor?

A transducer emits periodic sound impulses. The time gap between the moment of impulse generation and the registration of the reflected echo is proportional to the actual distance between the object and the sensor. The duration of the impulse $_i$ must be clearly shorter than the time necessary for the return of the echo. The waiting time for the returning echo starts as soon as the impulse has been sent and is continued till the next signal has been sent. The time of the echo return to the sensor is measured. Based upon this time it is possible to calculate the distance to the object. In detection sensors the presence of an echo signifies a detection of an object in the operating range of the sensor and causes the switching of the output state of the sensor.

What is a possible method of eliminating the influence of the background?

The maximum operating range of a sensor may be limited by an appropriate potentiometer. By its virtue, objects located outside of this limit are not detected. The blanking out of the background function is thus realised.

What is the reason of the dead zone presence?

The dead zone is a result of the dual function of a transducer, namely that of the sound generator and receiver. A transducer is ready for the reception of the echo no sooner than a sound impulse has been emitted. The size of the dead zone depends upon the range and size of the sensor. Short sensors with a limited range have shorter dead zones than sensors with a bigger range.

Is there a possibility to set the lower range limit in ultrasonic sensors?

A possibility to set the lower limit of the range is available in some types of the sensors only. A locked zone is then additionally obtained, which makes it possible to define more precisely the active zone, i.e. a zone where objects will be detected. The defining of the locked zone prevents detection of objects that are within its limits.

What cone angles of the ultrasonic beam are offered in sensors?

Depending upon application, sensors with a cone angle of the ultrasonic beam varying from 3 to a few dozens of degrees are offered. This angle shall be selected such that the target section of the detected area is included in the cone and the remaining objects are ignored.

What is considered as a standard object when determining the range of an ultrasonic sensor?

A standard object is a metal plate 1 mm in thickness reflecting the ultrasonic beam. The plate shall be positioned vertically to the axis of the sound wave. Its size depends upon the range of the sensor; consequently, for short reach sensors (till 300 mm) it may be a 10 mm square plate, and for sensors with the reach above 800 mm, it should be a 100 mm square plate. Objects of different dimensions, shapes, and properties may not guarantee catalogue values of the detection range.

What is the operating principle of a through mode sensor?

In through mode sensors, an ultrasonic transducer generates a sound wave in the direction of a receiver located in an independent housing. An object interfering with the sound wave interrupts it and toggles the sensor's output .

How is a sound wave generated in through sensors?

In through ultrasonic sensors, contrary to diffusion and reflective sensors, the transducer generates a continuous sound wave and the dead zone is here absent.

What is the main application area of ultrasonic sensors?

Ultrasonic through sensors find application for the detection of not only sound reflecting objects but especially for the detection of porous objects dissipating or absorbing sound; also for objects with shapes difficult for detection by diffusion sensors.

Which sensors feature higher switching frequency: through ones or diffusive ones?

The maximum switching frequency of the output state in through sensors is higher that in diffusion sensors and may be as high as 200 Hz.

3.3 Interference events in the operation of ultrasound sensors

Task 3 *Which physical factors may interfere with the operation of ultrasonic sensors?*

The operation of ultrasonic sensors may be interfered by changes in the temperature of the air in the vicinity of objects being detected, intensive air currents (wind gusts), and by absorption of sound by some materials that are in the vicinity of the object being detected.

What influence on the operation of ultrasonic sensors has temperature?

Temperature increases in the operational range of a sensor due to thermal impacts from an object emitting large amounts of heat may result in the creation of a variable temperature zone, which changes the propagation time of a wave and reduces the sensor's accuracy. An increase of temperature may result in the fact that a detected distance is shorter than the actual one. An increase of temperature by 20 °C results with a few percent increase of the sensor's range and the readout distance is then underestimated.

Which installation factors may interfere with the operation of ultrasonic sensors?

Ultrasonic sensors are especially fit for the detection of hard objects with a flat surface perpendicular do the axis of detection. Any deviations from this recommendation may result with a faulty operation of a sensor. These are: Angular position of the frontal surface of an object with respect to the reference axis of the sensor, shape of the object oriented such that the direction of the reflected wave diverges form the axis of the emitted wave, wavy surface of fluids, and mutual interference of sensors.

May ultrasonic sensors interfere mutually?

If sensors are installed to close to each other, then the reflected sound wave emitted by one sensor may return to the other sensor and produce an unwanted toggle of the output. To avoid such situation, it is necessary to follow the recommended minimum spacing between the sensors.

How is it possible to avoid mutual interference of ultrasonic sensors installed in a close proximity to each other?

The synchronisation of two or more sensors by a skilful connection of their outputs makes it possible to locate them in a very close proximity without a threat of mutual interference. Synchronised sensors emit signals at the same time and operate as one sensor with enhanced acoustic cone detecting the same object

3.4 Special types of ultrasonic sensors

Task 4 *What is the operating principle of ultrasound reflexive sensors?*

Ultrasound reflexive sensors operate with a reflector. The role of the reflector may be performed by any flat and hard surface. The measurement is based upon a difference between the time of return of a sound wave reflected from the object being detected and the return time of a sound wave reflected from the reflector. The sound wave reflected from the object must return to the sensor earlier than that reflected from the reflector. The sensor output state is then toggled.

Which sensors may detect the full interruption of an ultrasound beam?

The full interruption of an ultrasound beam can be detected by through and reflexive sensors. The reflexive sensors detect also absorbing objects or objects deflecting sound in other direction. An interruption of the beam, i.e. detection of an object, causes also the switching the output state to OFF. Reflexive sensors are especially suitable for the detection of materials absorbing to a high degree sound like cotton, foam, textile materials.

How do ultrasound sensors with two transducers in one housing operate?

Double transducer sensors in one housing may function in the diffusion mode and in the reflexive mode with a reflector. One of the transducer functions as the emitter, and the other – as the receiver of the ultrasonic wave. This arrangement makes it possible to detect small object from a very short distance as the receiver need not wait till the impulse has been generated from the emitter. The two transducers shell, however, be synchronised.

Is a custom design of ultrasound sensors necessary for the measurement of distance?

The majority of ultrasonic sensors is equipped with both two-state outputs and analogue outputs. When measurements of distance are at stake, the voltage or current output is used. The magnitude of the voltage or current output is proportional to the measured distance.

4 Photoelectric sensors

4.1 Photoelectric components

4.1.1 Physical fundamentals

Task 1 *What ranges of electromagnetic radiation are used in photoelectric sensors?*

In photoelectric sensors, visible red light or infrared light is mostly used. Visible light is this part of electromagnetic radiation range that is perceived by the human eye. Approximate wavelength is from 380 to 770 nm. Light waves with a length greater than 770 nm are considered as infrared radiation.

How does light reflect from surfaces?

The way in which light is reflected from different surfaces depends on their reflective properties such as roughness, structure, colour and lustre. For lustrous metal surfaces and mirrors there is a directional reflection: the reflection angle is equal to the incidence angle. From rough surfaces light reflects in all directions (a dispersed reflection). Surfaces with high finish (but not lustrous) may reflect light in part directionally and in part dispersedly xxx. Such directional and disperse reflection is only possible at certain angles of incidence.

Explain the refraction of light

Refraction is the alteration of the course of light as it passes from one medium to another medium of different density. In special cases, instead of being refracted, the whole light may be internally reflected from the surface separating the two media.

4.1.2 Emitters and receivers

Task 2 *What photoemitters are used in photoelectrical sensors?*

There are three types of photoemitters employed in photoelectrical sensors. These are light emitting diodes (LED), which emit visible radiation, IR light emitting diodes, which emit infrared radiation with a wavelength above 780 nm, and semiconductor laser diodes (LD) operating in a visible light or infrared range.

Explain the phenomenon of electroluminescence.

The phenomenon of electroluminescence consists in the emission of electromagnetic radiation in a semiconductor under the influence of an exciting agent in the form of an electric current coming from the outside.

What determines the intensity of luminescence of an LED?

The intensity of luminescence of an LED diode depends on the applied current value. This relationship is linear in a wide range of conduction current variations.

What influences the colour of light emitted by an LED diode?

The colour of light emitted by an LED diode is determined by the dominant wavelength luminescence and depends on the kind of semiconductor material. The latter may have a different composition and contain different dopes, resulting in different colours of emitted light. Red light in most often used, sometimes blue and white.

When is it advantageous to use sensors with the emitter of visible light and when with the emitter of infrared light?

Visible light makes it easier to properly position the sensor while infrared pulses are preferred for their low power consumption, precision and detection ability at longer distances.

What is the function of lenses closing the housing of an LED diode?

A beam of light emitted from a diode is considerably divergent and needs focusing. For this reason LED housings include lens forming (focusing) the luminous flux. This makes it possible to obtain an optimum shape of the angular characteristic of radiation.

What are advantages of laser emitters when compared to LED diodes?

The laser light, as opposed to the light of an LED diode, is an almost parallel light beam. With big measurement ranges this makes it easier to properly position the emitter relative to a target. Sensors with laser emitters are particularly useful for detecting small objects or for their accurate positioning.

What are differences between the characteristics of a laser diode and an LED diode?

The intensity of the laser light is a few times greater than that of an LED diode. Additionally, the laser light is very uniform in terms of wavelength, whereas an LED diode generates a highly dispersed light.

What are types and what role do photodetectors play in photoelectric sensors?

Semiconductor photodetectors convert the light energy radiated by an emitter into electric energy. These are mostly semiconductor photodiodes, linear PSD and CCD photodetectors or phototransistors.

How to define the response speed of a photodetector for a light pulse?

The speed of response of photodetectors to a light pulse is defined as a time of photocurrent gain from 0.1 to 0.9 of the maximum photocurrent value. Similarly, the fall time is a time of photocurrent drop from 0.9 to 0.1 of its maximum value.

What are differences in properties between a typical photodiode and a PIN photodiode?

In a typical photodiode the thickness of the absorber is much smaller than the depth to which photons penetrate into the semiconductor. Consequently, the photodiode's efficiency is not high whereby the generated photocurrent is reduced. The latter is higher in a PIN photodiode by virtue of an additional layer increasing the thickness of the area in which an electric field exists. For such a diode a typical time of the rise of a pulse (being a current response to a short light pulse) is shorter than for ordinary photodiodes and also its efficiency is higher.

On what base does a PSD photodetector determines the position of a light spot?

The position sensitive detector (PSD) is essentially a PIN photodiode in the shape of an elongated ruler exposed to light. It has two symmetrical current circuits. Any shift of the light spot from the middle of the light sensitive ruler will cause a decrease of the current in one circuit and a simultaneous increase of the current in the second circuit. By measuring the ratio of the currents flowing through the two electrical circuits one can determine the linear position of the maximum of the light intensity.

Is a CCD photodetectors more resistant to interference events than a PSD photodetector?

A charge couple device (CCD) is more resistant to interference from accidental or secondary light reflections reaching the receiver than a PSD detector owing to the fact that the CCD reacts only to light intensity and not to light quantity as it is the case in the PSD. A typical digital CCD matrix is a regular linear structure made up of light-sensitive cells (pixels) with an output consisting of discrete voltages representing the quantity of light falling on each pixel of the detector.

What is a difference in the design of a transistor and a phototransistor?

The design of a phototransistor is similar to that of an ordinary amplifying transistor but the housing additionally permits illumination of a proper area of the semiconductor (the base area). Additionally, the output signal from the phototransistor depends from both the radiation and electrical signals. The phototransistor is a detector whose sensitivity is several times higher than that of the photodiode, owing to the fact that the current produced under the influence of a light ray is additionally amplified in the phototransistor. Its limiting frequency, however, is considerably lower than that of the photodiode.

4.2 Basic kinds of sensors

Task 3 *What is the operating rule of a through beam sensor?*

In through beam sensors, a light beam is sent directly from the emitter to the receiver coaxially placed in separate housings. Such sensors detect objects which appear between the emitter and the receiver, interrupting the light beam and switching the output signal in the receiver.

What properties through beam sensors feature?

Through beam sensors feature the longest operating distance (over 50m) when compared to other types of sensors. They are highly insensitive to difficult external conditions such as dust in the air, dirt on the lenses, steam or mist.

What objects may be detected by through beam sensors?

The material of a detected object is of no importance. The surfaces may be painted, translucent, transparent, rough, smooth, metal, plastic, etc. To make a detection possible, an object must eclipse at least 50% of the light beam that is emitted by the emitter

What is the operating rule of a retro-reflexive sensor?

In retro-reflective sensors the emitter and the receiver are built into one housing. In a solution like that the light that is emitted from the emitter must be reflected from an additional surface to direct the beam back to the receiver. Reflectors or special reflecting bands are used for this purpose. A dissipating surface object moving towards the light beam dissipates it and the object is not being detected by the sensor. (The sensor's output state is not triggered).

Explain the design of reflectors and that reflecting bands

A reflector is a set of spatial systems, each of them being built with three mirrors oriented at right angles to each other. In agreement with the laws of light reflection, a light beam entering this system is totally reflected by all the three surfaces and exits parallel to the incident beam. Such reflector guarantees that the light emitted from the sensor will return, if not interrupted by an obstacle, to the receiver.

What influences the effective stream of light for a reflexive sensor?

The effective light beam depends on the diameter of lenses in the emitter and the receiver as well as on the size of the frontal area of the reflector.

What is the operating rule of a diffusive sensor?

Diffuse sensors are used for direct detection of objects. Their main advantage, besides the fact that the emitter and the receiver are located in one housing, is that no reflector is needed. The emitter emits light which is reflected from an object and returns to the receiver, generating a target detection signal.

What are properties of diffusive sensors?

Diffuse sensors have a short operating distance (up to 100 mm, rarely to 200 mm). Foreign objects (or the background) beyond this distance are not being detected, i.e. their interference is inevitably dampened. The colour and type of surface affect to some degree the operating distance. Depending on the object's properties, the coefficient of reflection of light from the target may vary widely. Shiny surfaces located even far from the sensor may reflect most of the light whereby detection of the proper target may become very difficult. Additionally, the face of the sensor must be exactly parallel to the surface of the reflecting target. Dark or mat objects may absorb most of the light and the remaining amount of light may prove insufficient for the detection of the object.

How is the maximum detecting distance for diffusive sensors determined?

To determine the sensing distance of a diffuse sensor, a calibrated diffusing target surface, e.g. a sheet of white paper or Kodak paper (reflecting about 90% of the light beam) is used. For more light absorbing surfaces this distance shell be reduced accordingly.

4.3 Signal processing

Task 4 *What might be sources of interference in the undisturbed operation of photoelectric sensors?*

Phoelectric sensors are sensitive to optical interference from both natural and artificial external light sources. Light rays coming from such sources may significantly affect the intensity of the current generated by the emitter and thus result in erroneous sensor output signals. In order to reduce erroneous responses, sensors have built-in circuits eliminating, to a certain degree, such interference and noise and have circuits for the fine tuning of their sensitivity. Environmental pollution, e.g. oil, dust and dirt deposited on the surfaces of detected objects or on the emitter and receiver lenses can aggravate the problem.

Which types of sensor are most susceptible to optical interference?

Diffuse sensors belong to sensors most susceptible to optical interference originating from natural constant intensity light or artificial light close to the natural light spectrum as well as variable intensity light (blinker light).

What advantages result from the operation of sensors with modulated light?

The operation of photoelectric sensors with modulated light means that the emitter's light is switched on only for a short time. Such sensors are less sensitive to ambient light, their operating distance increases, and the amount of generated heat decreases, which extends the lifetime of LEDs.

Explain the polarisation of light

Polarisation consists in total or partial ordering of light wave vibrations. If light is not polarised, electric and magnetic field vibrations occur in different directions, whereas if it is polarised, the vibrations occur only in one direction.

For what purposes is the polarised light used in photooptic sensors?

The polarised light makes it possible to differentiate between the light reflected from the element being detected and the other received light signals.

How is the polarisation of light carried out?

Vertical and horizontal filters are used for the polarisation of light. Natural non-polarised light, after having passed through such a filter, becomes the polarised light, either in the vertical or horizontal plane. Such polarised light may be easily stopped or let go by posting in its path a polarisation filter.

How does the polarised light reflect from surfaces of objects?

The reflection of polarised light from diffusing surfaces destroys polarisation. The reflection of polarised light from lustrous surfaces does not destroy polarisation, it may change its direction only. Specifically, a system of three mirrors (a reflector) does not destroy polarisation changing it from a horizontal one to a vertical one.

How to understand a notion of the „performance margin" of a photoelectric sensor?

The operating margin of a sensor determines how many times the amount of light falling on the photoelectric element of a sensor is greater than the amount necessary to toggle its output state. Sensors are equipped with diodes signalling if the amount of light at a given moment is sufficient to ensure is undisturbed operation. A reduction in the amount of light may be a result of soiled sensor, other than expected dispersion of light by the detected object or a result of the emitter ageing.

What shall be an excess of light to ensure an undisturbed operation of a photoelectric sensor?

In order to ensure a certain reserve, the margin should be larger than 1, i.e. the actual amount of incident light shall exceed the minimum level needed to switch the output device. The higher the excess, the more reliable the sensor's operation. For clean air and a low probability that the lenses or the reflector will get dirty, the minimum operating margin should not be less than 1.5. In a very dirty environment and when lens cleaning is limited, the minimum operating margin should be larger than 50.

What does a „dead zone" of a photooptic sensor mean?

The presence of a dead zone in photooptic sensors means that there is a certain area close to the sensor's face where it may happen that objects are not detected. This is related to the design of reflexive and diffusive sensors which have the emitter and the receiver in one housing. The smaller is this zone, the more universal in the sensor. In through beam sensors, where the emitter and the receiver are positioned opposite to each other, the dead zone is absent.

Define the response time of a photooptic sensor.

Response time is the time counted from the instant a light beam appears between the emitter and the receiver to a change of the switch output state. Knowing the response time one can determine how long the moving object must remain in the sensor's field of vision in order to be detected by it, i.e. at what maximum velocity the object can move or how long the spacing between successive objects must be.

4.4 Special types of photoelectric sensors

Task 5 *What are differences between a reflexive sensor with polarisation and a typical reflexive sensor?*

In retro-reflective sensors which exploit polarisation, the emitter light is focused by a lens and directed through a horizontal polarisation filter onto a reflector with triple mirrors. An important feature of the triple mirrors used in reflectors is that they change light ray polarisation by 90°. Some of the light rays reflected from the reflector reach the receiver via another vertical polarisation filter. The filters are so matched and positioned that only the light reflected from the reflector, and not any light reflected from the other objects within the sensor's range, reaches the receiver. A typical sensor has no filters. It is therefore susceptible to interference from other light beams.

What are possibilities of suppression of the background and the foreground?

The simples method of suppression of the fore- and background is a limitation of the active area through intersection of the optical axes of the emitter and receiver. It is effected by a mechanical change in the setting of lenses or by a change in the setting angle of the receiver. Even more effective is the electronic method of background suppression, where the sensor 'sees' the background but can ignore it. An example here can be a diffuse sensor with two light receivers or a triangulation sensor equipped with a CCD camera or a PSD transducer.

In what modes may sensors with electronic elimination of interference operate?

Sensors with electronic background suppression can operate in one of the three modes:

- protection against detection of object located outside the detection area (background suppression),
- protection against detection of object located before the detection area (foreground suppression),
- detection of only object located within the defined area (the window function).

What receivers of light are employed in triangulating sensors?

In triangulation sensors, linear PSD photodetectors or linear CCD cameras may be used as light receivers. By virtue of such receivers, these sensors, apart of the detection function, can measure the distance from the object to the sensor.

Explain the process of autocolimation.

Autocollimation consists in automatic conversion of a divergent light beam into a parallel beam whereby even at a smaller beam diameter there is enough light directed towards the receiver.

What additional features reflexive sensors with autocolimation have?

Autocollimation makes it possible to detect transparent objects (targets) and ones located very close to the sensor (in standard sensors' dead zone).

Explain the design of fibre-optic cables

A fibre-optic cable consists of a core made of glass or plastic rod surrounded by cladding made of another glass or plastic with a lower refractive index and a protective jacket.

Explain the effect of the full reflection in a fibre-optic cable

The total internal reflection occurs when light falls on the boundary between two media characterised by different refractive indexes. The total internal reflection means that 100% of the light beam's energy reflected from the boundary returns to the fibre-optic cable. A light ray is reflected from the boundary layer only when it passes from a medium with a higher refractive index.

Why is it practically impossible to use fibre-optic cables of infinite length?

Theoretically, light intensity is not reduced by internal reflections in the fibre-optic cable. But impurities and slight imperfections, both in the core's material and in the boundary layer, cause some losses effectively reducing the fibre-optic cable length at which light is transmitted.

What are differences between fibre-optic cables made of glass and plastic?

Glass fibre-optic cables are more durable than plastic ones – in the standard version they withstand temperatures up to 250°C (plastic fibre-optic cables – only up to 70°C). But plastic fibre-optic cables are stronger, cheaper and can be more easily shortened by cutting off the ends. Glass optical fibres effectively transmit both visible and infrared light whereas plastic optical fibres' infrared light transmission efficiency is low. Therefore glass optical fibres can be used for visible and infrared light whereas plastic optical fibres are suitable only for visible light.

What is the principle of operation of fiber-glass sensors?

The principle of operation of photoelectric sensors with optical fibres is the same as that of other photoelectric sensors, except for the fact that both emitted and received light is transported by an optical fibre. The fibre's metal end is very small (in the order of a few millimetres) whereby it can be located in inaccessible places far away from the sensor's optoelectronic circuits housed in a separate amplifier.

4.5 Connection technology

Task 6 *What modes of operation are characteristic for photoelectric sensors?*

Photoelectric sensors can operate in a dark operate mode (DO) or in the light operate mode (LO). In the dark operate mode the sensor's output switch is ON when the emitter light does not reach the receiver. This corresponds to the normally open (NO) output state in inductive and capacitive sensors. In the light operate mode the output is active when the light from the emitter does reach the receiver. This corresponds to the normally closed (NC) output state in inductive and capacitive sensors.

What factors influence the shape and size of the switching zone of the sensor's output?

In order for the output to be switched the object being detected or the emitter must be within the switching zone. Each photoelectric sensor has its characteristic output state switching zone whose size and shape depends on the diameter of the light beam sent by the emitter and the distance of the object being detected from the sensor. In the case of through-beam sensors, the receiver-emitter distance is critical.

5 Magnetic sensors

5.1 Basic information

5.1.1 Magnetic field

Task 1 *What may be a source of the magnetic field and what is the trajectory of this field lines?*

A source of the magnetic field may be a permanent magnet, a coil and any live conductor. Force lines of the magnetic field are closed lines, the trajectory of which is always from the north pole **N** to the south pole **S.**

What physical properties characterise the magnetic field?

Characteristic properties of the magnetic field are :
– intensity H of the magnetic field (expressed in A/m),
– magnetic induction B of the magnetic field (expressed in Tesla, T),
– relative magnetic permeability μ_r .

How to divide materials with respect to their magnetic properties?

In agreement with magnetic properties of all substances expressed by the magnetic permeability μ_r, materials may be divided into diamagnetics, paramagnetics, and ferromagnetics. Diamagnetics (μ_r <1), which are not attracted by magnets, include e.g. glass and bismuth. Paramagnetics (μ_r slightly above 1) include e.g. aluminium, platinum, and tin. The most important group are ferromagnetics ($\mu_r >> 1$), for which the magnetic permeability is very high. For pure iron it may be as high as a few thousand, depending upon the intensity of the magnetic field.

Explain the phenomenon of magnetisation in ferromagnetics

Ferromagnetics become magnetised as a result of action of an external magnetic field. This field changes a chaotic structure of magnetic domains into an arranged one. Magnetic domains are very small areas in the structure of materials. After arrangement of these areas, due to the action of the external magnetic field, a material becomes a magnet. Alloys of iron are ferromagnetics.

What are soft and hard magnetic materials?

Hard ferromagnetics feature a broad hysteresis loop. These include : Fe-Co, Ni-Co alloys and hard ferrites xxx. That means that a ferromagnetic is difficult for magnetisation and demagnetisation. It is used for permanent magnets. Soft ferromagnetics feature a narrow hysteresis and can be quickly magnetised and demagnetised. They may, therefore, be used for magnetic cores. Soft magnetic materials include iron, Fe-Si and Fe-Al alloys, soft ferrites and amorfic alloys.

5.1.2 A reed sensor

Task 2 *How is a reed contact sensor built?*

A reed contact sensor consists of a hermetic glass bulb filled with neutral gas, or vacuum filled, with two embedded thin plates made of a ferromagnetic material. To improve the functioning of the contacts and to obtain a stable performance characteristic, the tips of the contacts are coated, depending upon operational conditions, with a layer of a noble metal like ruthenium, rhodium, gold etc.

What is the purpose of additional protections to a reed contact sensor?

Each time when the contacts of a reed contact sensor open or close a circuit with the current flowing, an electrical discharge may occur between the contacts. This may result with an impaired operation of this sensor and even its damage.

What is the maximum switching frequency of a reed contact sensor?

The maximum switching frequency of a reed contact sensors depends upon its design and material properties. Usually, it does not exceed 200 to 250 Hz.

What determines the number of contact closings of a reed contact sensor when changing position of the magnet?

The number of contact closings of a reed sensor depends upon the orientation of the magnet axis with respect to the axis of the sensor and the direction of translation of the magnet. Three, two or one switching events are possible. A translation of the magnet in the direction perpendicular to the axis of the sensor may cause only one closing or opening of the contacts. Moving the magnet parallel to the axis of the reed contact sensor will cause either three closings of the contacts (in the middle and in the proximity of the sensor's ends) or two times (close to the two ends of the sensor). The first case will happen when the magnet axis is set parallel to the axis of the reed sensor; the second – when the axis of the magnet is set perpendicular to the axis or the reed sensor.

5.1.3 Magnetic phenomena employed in sensors

Task 3 *What is the underlying principle of the Hall's Effect?*

The Hall Effect consists in the creation of an additional magnetic field in a DC current carrying plate made of a conductor or semiconductor and exposed to an external magnetic field. The influence of this external magnetic field on these charges results in their accumulation at one edge of the plate. A difference of potential at the two edges of the plate is a so-called Hall's voltage $\mathbf{V_H}$.

How is it possible to increase the Hall's voltage?

The higher Hall's voltage may be obtained by using a plate made of a material featuring a high mobility of electrons. This material may be a semiconductor of InSb, InGaAs, Si, GaAs type. The thinner is the plate, the higher is the Hall's voltage. A possibility to increase the voltage $\mathbf{V_H}$ by increasing the current flowing through the plate is considerably limited by the allowable power dissipated in the plate. The value of this power depends, to a considerable degree, on the design and shape of the semiconductor plate.

Why does the magnetic field change the magnetoresistance of semiconductors?

The magnetic field increases magnetoresistance of semiconductors because it causes deviation in the direction of the flowing current. This is due to an increased path of electrical charges. A value of the deviation angle increases with an increase in the intensity of the magnetic field making the path from one edge to the other edge longer.

What is the function of electrodes coated onto the magnetoresisitive tape?

Gold and aluminium electrodes set at the path of the current flow modify its direction and, as a result, the path of electrical charges becomes still longer causing an additional increase in the resistance of the semiconductor.

What are the main features of „impulse conductors"?

An "impulse conductor" has two magnetically different areas: the core and the shell. The core has the properties of a soft magnetic material (narrow hysteresis) and the shell has the properties of a hard magnetic material (wide hysteresis). These conductors are manufactured from a ferromagnetic material (an alloy of iron and vanadium), approximately 0.3mm in diameter, that is cold multi-twisted to produce an appropriate state of strain.

Explain the idea of the Wiegand's Effect

The Wiegand Effect consists in the generation of an electrical impulse in turns of a coil wound on an "impulse conductor" as a result of changes in the direction of the external magnetic field.

How do layers of the „impulse conductor" respond to changes in the magnetic field?

The two magnetically differing layers of an "impulse conductor" respond differently to changes in the direction of the external magnetic field. The magnetically soft core changes the direction of its magnetisation faster than the magnetically hard shell.

In what situations does an electric impulse appear in a coil with the impulse conductor?

An electrical impulse in the coil will appear when, as a result of activation of the external magnetic field, the direction of magnetisation in the soft core has changed and the direction of magnetisation of the shell remains the same. The amplitude of this short voltage impulse (10 - 20μs) is nearly independent of the speed of changes in the direction of the magnetic field.

5.2 Fundamental types of magnetic sensors

Task 4 *Which elements may respond to changes in the magnetic field?*

Elements responding to the magnetic field may be a hermetic electrical coupler (a reed sensor), a semi-conducting element (a Hall Effect), a magnetoresistor or a coil with an “impulse conductor”.

What advantages magnetic sensors have?

Magnetic sensors feature a hermetic design, variety of housing shapes and high operational ranges that go together with small dimensions. Base modifications of these sensor do not require electrical supply and may be directly coupled to drivers inputs as well as may control the operation of machinery independently. An additional advantage of these sensors is a broad range of switching voltage and current levels, even above 1000 V and a few A.

Can magnetic sensors detect objects that are behind a plastic wall?

Yes, they can as the magnetic field penetrates most non-magnetic materials, hence the detection of items can be carried out even if there are diamagnetic obstacles, e.g. a tube or container walls made of plastics between an item and the sensor.

To what type of objects magnetic sensors respond?

Magnetic sensors respond to the magnetic field generated usually by permanent magnets attached to detected items. The element being detected may the very magnet or magnets that are attached the detected item. In the latter case the item can be made of any material but its magnetic properties may increase or decrease the operating range of the sensor. It is advantageous to attach magnets to non-ferromagnetic objects as this increases the operating range of the sensor.

What are the main components of a magnetic sensor?

The main components of a magnetic sensor are: one element responding to changes in the magnetic field, a system of detection of the output controlling signal and an output system. Sensors may be provided additionally with a diode signalling the state of the output.

What is the operating principle of a magnetic sensor with a reed sensor?"

A magnetic sensor with a reed contact sensor responds to an approaching magnet. In the magnetic field generated by this magnet, the contacts of a reed contact sensor become magnetised. If the force of the contact attraction overcomes the force of elasticity, then the sensor will change is state from the open one to the closed one. By virtue of this fact, the whole electrical circuit will also be closed together with the connected load.

What is the state of the output of a reed sensor when it is not subject to the magnetic field?

It depends upon the type of a reed sensor employed in the sensor. The contacts of a reed sensor, when not in the magnetic field, may, depending upon type, be normally open (NO) or in one of the two possible states NO or NC (normally closed).

Have magnetic sensors with a reed sensor only one active surface?

There may be a few active surfaces in a reed contact sensor. This is governed by the shape of the housing as it defines areas of possible translations for the magnet. There are sensors where the only possible translation of the magnet is along the face of the sensor and there are sensors where translations of the magnet are possible also with respect to the side surfaces of the sensor. Magnetic reed contact sensors have diversified housing shapes, starting from simple ones (cylindrical, prismatic) to more complex geometrical forms.

Which factors influence the maximum operating range of a magnetic reed contact sensor?

The maximum operating range S_{max} of a reed sensor is governed by the force of the magnetic field attraction. This force depends upon the size and properties of the magnet, from one side, and from the distance between the active surface of the sensor and the magnet, from the other side. Additionally, in agreement with the operational characteristic of the reed sensor, the operating range depends upon location of the magnet with respect to the active elements of the sensor.

How many leads are there in the output of magnetic reed contact sensors?

Reed contact sensors have three leads; those without a diode signalling the state of the sensor have two leads only.

What is the operating principle of a Hall's effect magnetic sensor

Hall's effect magnetic sensors are supplied with a DC current that flows through a semi-conducting plate (a hallotron). As long as the magnet is outside of the operating range of the sensor, the current may flow unimpeded through the hallotron. The difference of potentials at the edges of the hallotron is then equal to zero (V = 0). When the magnet appears in the operating range of the sensor, its magnetic field generates the Hall voltage (V=$\mathbf{V_H}$) at the edges of the hallotron. This voltage is a signal that controls the output transistor of the sensor.

Do reed contact sensors respond to any change in the direction (polarisation) of the magnetic field?

Not always. Hall's effect magnetic sensors may be manufactured in an omnipolar version (respond to any given polarisation of the magnetic field), unipolar (respond to only one specified polarisation of the magnetic field) or bipolar (the switching off is triggered by the magnetic pole opposite to the pole causing the switching on).

5.3 Special types of magnetic sensors

Task 5 *What is the operating rule of Wiegand's sensors?*

The operating rule of a magnetic Wiegand sensor consists in the registration of changes in the magnetic field direction (polarisation) of the "impulse conductor" core. Polarisation of the core magnetisation may be reversed if the external magnetic field changes its direction.

How is it possible to do changes in the magnetic field direction in Wiegand's sensors?

There are three possible methods of changing the magnetic field direction acting on the impulse conductor:

- Magnets with a variable polarisation move one by one in front of a stationary sensor that houses an impulse conductor with a wound coil.

- Impulse conductors move one by one in front of a stationary sensor that houses two magnets with a coil.

- Ferromagnetic objects move one by one in front of a sensor that houses two magnets and a coil together with an impulse conductor.

How is the detection of mobile magnets by Wiegand's sensors done?

In the first phase, the "impulse conductor" is exposed to the magnetic field of an N/S polarised magnet and then, to the field of the next magnet with the reversed (S/N) polarisation. This change of the external magnetic field polarisation generates a voltage impulse in a coil wound around the impulse conductor. The impulse, after transformation, is the output signal from the sensor.

How is the detection of a translating „impulse conductor" carried out?

As a result of a translating motion of an impulse conductor in front of a stationary magnet with the N/S polarisation, and then in front of the second magnet with the reversed (S/N) polarisation, the direction of magnetisation in the core of the impulse conductor changes. This produces a voltage impulse which, after transformation, is the output signal.

Do Wiegand's sensors require voltage supply?

Wiegand sensors do not require electrical supply and may be manufactured as simple two-lead sensors, which are perfectly fit for operation in difficult environmental conditions.

Which element in sensors with a magnet responds to the magnetic field?

The elements responding to the magnetic field in these sensors is a coil wound directly on a permanent magnet.

What situations can sensors with a magnet detect?

These type of magnetic sensors detect motion of a ferromagnetic object. They cannot, however, be employed for the detection of stationary objects as the output voltage depends upon a speed with which the detected object approaches the sensor

Do magnetic sensors with a magnet require voltage supply?

Magnetic sensors with a magnet do not require electrical supply because a ferromagnetic object nearing a sensor changes the magnetic flux penetrating the coil generating at the same time a voltage at the coil terminals. This voltage, after transformation, constitutes the output signal.

Which factors influence the value of the output voltage in magnetic sensors with a magnet?

The output voltage in magnetic sensors with a magnet depends upon the speed with which an object being detected approaches the sensor. Values of these voltages are low and need additional amplification to toggle the state of the output system. When the speed of an object decreases, then the output voltage also decreases. For a stationary object the voltage drops to zero.

5.4 Installation conditions and applications

Task 6 *Does the type of material into which a magnetic sensor is installed influence its operation?*

Only if the material is a ferromagnetic one. It is advantageous in such situations to raise it possibly high above the surface of the ferromagnetic material. It is recommended also to introduce an additional isolation layer made of nonmagnetic (dielectric) material separating the sensor and the ferromagnetic material.

Will the introduction of a thin element between a sensor and the magnet compromise the operation of the sensor?

The introduction of a non ferromagnetic material between the sensor and the magnet does not influence the behaviour of the magnetic sensor. On the other hand, its behaviour will change if a ferromagnetic element appears between the sensor and the magnet. This may end with a changed state of the output of the sensor, i.e. with an interference in its operation.

What are the main applications of magnetic sensors?

Magnetic sensors find application, among others, in:

- The detection of objects located outside plastic wall, e.g. inside pipes or containers.
- The detection of objects in aggressive environments, through protective partitions.
- The detection of object in areas of elevated temperature thanks to a possibility of withdrawal of the magnetic field by the use of ferromagnetic elements.
- The detection of objects in translation and rotation.

Mechatronics

Module 6: Mechatronic Systems and Functions

Trainerguideline
(concept)

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EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

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1 Inductive sensors

1.1 Basic construction

Task 1 *What constitutes the active part of an inductive sensor?*

The active part of an inductive sensor is a coil wound on the ferrite cup core and generating a variable magnetic field. The purpose of the cup core with an open magnetic circuit is to magnify the magnetic field of the coil and direct it towards the measuring zone of the sensor.

How does an inductive sensor evaluate distance from the detected object to the coil?

The electronic circuit of a sensor determines the distance from an object to the sensor based upon the amplitude damping rate and generates an output signal. It is mostly a two state signal: the object within the sensor's reach or out of the sensor's reach. The signal may be an analogue one. In that case it is in inverse proportion to the distance from the object to the sensor.

What is hysteresis?

Hysteresis is a difference in the distance to which a sensor responds when a metallic object approaches and recesses its face. The state of the sensor changes then from OFF to ON or vice versa. The value of hysteresis depends upon the type and size of a sensor and is usually not greater than 20% of the measuring range.

Why is it recommended that an inductive sensor should have a certain amount of hysteresis?

Apart of a detection section, the electronic system of a sensor comprises a comparator with hysteresis and an output system. As a result of hysteresis, interference events that might appear at the sensor's output are avoided. Interference is most likely to occur at the moment of switching, in the cases of unstable position or vibration of the detected object, fluctuations of the supply voltage and/or ambient temperature.

What are operating frequencies of inductive sensors?

LC generators generating a variable magnetic field in inductive sensors are HF (high frequency) generators with a typical range from 100 KHz to 1 MHz. With the increase in the coil diameter, the maximum frequency of a sensor decreases.

How big is the operating range of inductive sensors and what are their housings?

The range of typical inductive sensors does nor exceed 60 mm. These sensors are provided with different types of housings, both cylindrical (metallic) and prismatic (plastics). This makes it possible to optimally install a sensor in its operating location.

How to define the rated operating range of a sensor?

The rated operating zone $\mathbf{S_n}$ of a sensor is defined as a distance from its face to an object at which the output circuit is subject to switching. This very value is given in the catalogue data.

For what object is the rated operating range of a sensor given in catalogues?

The rated operating range of a sensor is determined in agreement with the EN 60947-5-2 standard for a square steel plate (St37) one mm in thickness and with the side equal to the diameter of the sensor.

What is the actual operating range of a sensor?

The actual operating zone S_r is determined in the course of manufacturing of a sensor may slightly differ from $\mathbf{S_n}$. Usually it lies in the range $0.9\mathbf{S_n} \leq \mathbf{S_r} \leq 1.1\mathbf{S_n}$ **.**

What is the working range of a sensor?

The working operating range defines a safe distance range from a metallic object to the sensor ensuring faultless operation irrespective of the actual operating range guaranteed by the manufacturer. The recommended working range is $\mathbf{S_a} \leq 0.8\mathbf{S_n}$**.**

Which factors influence the operational range of an inductive sensor?

The operating range of an inductive sensor depends upon the housing diameter and, more specifically, upon the coil diameter and ferromagnetic core properties. Sensors in small housings have a smaller operating range than those with bigger overall sizes. There are also special executions of sensors with an enhanced operating range.

What is the role of correctional factors when measuring with inductive sensors?

Materials like gold, copper or aluminium, which feature higher electrical conductivity than steel St37, damp oscillations of a resonance circuit to a lesser degree. By decreasing distance from the object to the sensor these differences may be compensated. This will cause a certain reduction of the zone, in which it is possible to detect an object. Accordingly, if the metal being detected is brass, then the operating range S_n determined for an object made of steel St37 shall be modified by multiplying it using a correctional coefficient for brass equal to 0.5 x $\mathbf{S_n}$.

What influence has the design of a sensor had on its sensitivity?

There are two basic forms of sensors with a cylindrical housing:
– Shielded: the coil is inserted into a sleeve and,
– Non-shielded: the coil protrudes from the sleeve and is located in a plastic cap. The non-shielded sensors feature higher sensitivity for other metallic objects in their vicinity than the shielded ones.

What requirements shall be met when installing shielded sensors close to each other?

A shielded cylindrical sensor is not sensitive to the surrounding metallic objects save those from the frontal sensor's zone. Consequently, these sensors may be installed fully in metallic elements. The free zone from the sensor's face is set by a distance of **3Sn**. To avoid a mutual interference of two sensors situated close to each other, the minimum distance between them shall be greater than two diameters of one sensor.

What requirements shall be met when non-shielded sensors are installed close to each other?

Ą non-shielded cylindrical sensor is sensitive to metallic elements surrounding it from three sides. The sensor must therefore in part protrude so that the free zone includes also its side surfaces. To avoid interference in this case, the distance between sensors shall be greater than 3xD.

What is the meaning of the maximum switching frequency of the sensor's output?

The maximum switching frequency given in the technical specifications of each sensor provides information on the maximum switching frequency of a sensor per second. It is determined when an object made of steel St37 cyclically enters and leaves the sensor's sensitivity zone. When determining this frequency, valid are requirements given in the EN 50 010/IEC 60947-5-2 standard.

What maximum values of the switching frequency shall be expected when using objects different than the standard plate?

He result of a measurement will always depend upon the size of the object that damps the coil, distance from the sensor's face and object speed. By using an object smaller than the standard plate for a given sensor or by using a smaller gap between protrusions, a reduction in the maximum switching frequency of the output may be expected.

1.2 Special types of inductive sensors

Task 2 *What is the operating rule of an inductive ring sensor?*

The underlying operating rule of an inductive ring sensor is based on a high frequency oscillator that generates a magnetic field inside the hole of the sensor. Toroidal powder cores with a value of the quality factor higher than that for ferrite cores are used in these sensors. The presence of a metallic object activates the sensor causing a reduction in the amplitude of oscillations. This is recognised by a comparator and after a threshold value has been exceeded, the output state is toggled.

Are there limitations concerning the size of objects detected by an inductive ring sensor?

To trigger a sensor, needed is a determined level of damping of the magnetic field. If elements are too small, the level of damping may be insufficient. Consequently, for each size of the sensor there is a minimum length or diameter of the detected objects that guarantees the proper operation of the sensor.

Are there limitations concerning the form of a trajectory that a detected object travels within an inductive ring sensor?

An advantage of ring sensors is that a detected object needs not to move exactly along the same trajectory. The ring shaped active surface of the sensor makes it possible to detect objects irrespective of their spatial orientation, e.g. those subject to the force of gravitation in a plastic tube.

What may be negative impacts of strong magnetic fields on inductive sensors?

Installation of an inductive sensor in a zone of strong magnetic fields (e.g. in the vicinity of welding equipment) is associated with a risk of uncontrolled switching of the output state. This may happen due to the core saturation or due to the induction of an additional voltage in the coil. This additional voltage interferes with the operation of the oscillator and may cause accidental switching of the sensor's output.

How is it possible to protect inductive sensors against negative impacts of strong magnetic fields?

Sensors resistant to strong magnetic fields shell be provided with a special design of the electronic circuit and a core with a small magnetic permeability that gets saturated in a magnetic flux a few times denser than is the case for typical ferrite cores. The highest resistance to the action of external magnetic fields have sensors altogether without the core. In these design solutions, the coils are wound around non-magnetic bobbins made of plastics.

Specify exemplary types of sensors designed for operation in difficult conditions.

These might be sensors resistant to high pressure, temperature, chemically aggressive environment, oil, humidity and miniature sensors for operation in difficult access locations.

What features shall inductive sensors have for operation under high pressure conditions?

Sensors operating under high pressure conditions shall be provided with a robust and tight housing to prevent any damages to internal electronic components. The coil and core of a sensor shall be protected with a thick disk, e.g. a wear resistant ceramic disk. Needed are also some modifications of the oscillator system lest the operating range of the sensor is too small, thick disk notwithstanding.

What is the operating principle of NAMUR inductive sensors?

NAMUR inductive sensors are two lead sensors, the internal resistance of which changes as a result of detection of a metallic object. Small resistance of the sensor corresponds to a „no metallic object" situation, and a high resistance – to „a metallic object detected".

What are the main features of NAMUR inductive sensors?

NAMUR inductive sensors feature a strictly defined range of values of the allowable output current. According to the EN 60947-5-6 standard this range is from 1.2 mA to 2.1 mA. All NAMUR sensors fed from a DC amplifier have the same current characteristic and feature a strictly defined switching hysteresis equal to 0.2 mA.

For what conditions the NAMUR inductive sensors are best suited?

NAMUR inductive sensors in conjunction with a spark-proof switching amplifier may operate in explosion proof installations or in explosion hazard zones (zone I or II). These sensors my also operate with relay amplifiers (not complying with the safety regulations) but in that case the amplifier must be located outside the explosion hazard zone.

What are differences between analogue output and two state output sensors?

Two state sensors identify only the state of detection or non-detection of an object. Inductive sensors with an analogue output register, on the other hand, the position of an object in the whole measuring range. To a changing position of the object from a distance of S_n to zero corresponds a change in the output signal from 0 to 20 mA.

How are inductive analogue sensors designed?

Inductive analogue sensors consist of a head with a coil, generator, linearization system and the output system in a range of 0 to 20 mA.

1.3 Supply and connections of sensors

Task 3 *What are permissible fluctuations of DC supply voltage for inductive sensors?*

DC supplied sensors co-operate mostly with adapters, the output voltage of which is fluctuating. To large fluctuations of the amplitude of momentary values of this voltage may cause unpredictable behaviour of an inductive sensor. To ensure faultless operation, fluctuations of the supply voltage must be kept within a 10% range from the average value of the supply voltage.

What are possible manufacturing configurations of DC supplied sensors?

Outputs of sensors supplied with DC current are made in the NPN or PNP layout. That means that for an NPN configuration the load $\mathbf{R_L}$ is connected between the output of the sensor and the plus of the voltage supply**,** and for a PNP configuration – between the output and the minus of the voltage supply.

What is a difference between an NO and NC execution of sensors?

DC supplied sensors in the PNP and NPN configurations manufactured with the NO (normally open) output function switch on the current in the load attached to the sensor's output. NC (normally closed) sensors switch off the current.

Which factor determines the maximum number of series connected sensors?

The maximum number of series connected sensors depends upon the supply voltage, voltage drops at the output of the sensors and parameters of the attached load. The supply voltage of the system, reduced by a total amount of voltage drops, at the output of the sensors must always be greater than the minimum operating voltage with the load connected.

Is it allowed for AC supplied sensors to be directly fed from the mains?

AC supplied inductive sensors must not be connected directly to an AC power supply adapter. Such connection may result with a total damage to internal circuits of a sensor. The supply of these sensors is only possible after a series connected load has been attached to the sensor.

What is the purpose of sensors' grouping?

A series or parallel connection of a few sensors opens a possibility to realise different operational strategies of the equipment that may be connected in the external circuit as load. By a skilful connection of sensors, such logical functions as AND, OR and/or NOR may be obtained.

1.4 Safety and protections

Task 4 *Against what unwanted effects are the outputs of DC fed sensors protected?*

In most of the DC supplied sensors the outputs are protected against the following disadvantageous phenomena or actions:

- Reverse connection of the supply voltage

- Over voltage at the output as a result of switching off

- Short and non-cyclic impulses from the supply line

- Excessive output current or short-circuits.

Are short-circuits at the output of a DC supplied sensor dangerous to its operation?

Short-circuits in an electrical circuit with constant-current sensors do not cause damage to a sensor, even if recurrent and prolonged. During a short-circuit, the diodes in the sensor are disabled. After removal of the short-circuit, the sensor operates properly.

When is a grounding of the sensor's shield required?

Sensors in metallic housings, if supplied with a voltage dangerous to a human life, need an additional grounding lead.

What precautions shall be taken against the presence of leakage current in the electric circuitry of a sensor?

When an approach sensor is in the OFF state, a leakage current appears in the circuit. This may contribute to an erroneous operation of the sensor, e.g. a permanent dwell in the OFF position. To safeguard against such situations, an additional resistor connected in parallel with the load is used. The resistor takes the leakage current such that the current flowing through the load is less than a minimum value required by the load.

2 Capacitive sensors

2.1 Operating principle of a capacitive sensor

Task 1 *From what type of materials can objects be detected by capacitive sensors?*

Capacitive sensors, besides metal objects, can detect nonconducting objects, e.g. plastics. A capacitive sensor is also able to react to objects located behind a nonconducting layer, which makes it a classic sensor for detecting liquids or pellets through the container's walls. Capacitive sensors are usually used as proximity detectors, but they can also generate a signal proportional to the distance of an object from the sensor's face.

What are the main components of a capacitive sensor?

The main components of a capacitive sensor are: a head with electrodes, potentiometer P, an oscillator, a detection circuit and an output circuit.

Which elements constitute the active component of a capacitive sensor?

The capacitive sensor's active components are two metal electrodes forming an open capacitor. As an object gets closer to the sensor, the latter's capacitance changes. The capacitor's total capacitance, which determines the output signal level, is the sum of the sensor's basic capacitance and the change in capacitance caused by the action of the object being detected.

Which of the objects is more easily detected by a capacitive sensor and why: a conducting or non-conducting one?

Conducting objects are more easily detected than the non-conducting ones. Nonconducting objects, such as paper or glass, increase only the sensor's self-capacitance by influencing its dielectric constant. But the increase, dependent on the object's dielectric constant, is slight whereby the operating distance is also small. In the case of ungrounded conducting objects additional two capacitors arranged in series, one between the object and the sensor's electrode and the other between the object and the external electrode, are formed.. The sensor's operating distance is longer in this case.

Does grounding of the object being detected has any significance to the operation of a sensor?

Yes, the grounding of the object being detected increases the operating distance of a sensor. The longest operating distance is obtained when the object being detected is a grounded conductor. Then the additional capacitance between the object and the electrode forms a parallel connection with the sensor's self-capacitance.

2.2 Types of capacitive sensors

Task 2 *What are typical varieties of capacitive sensors?*

Capacitive sensors are usually available in the form of cylindrical or cuboidal proximity detectors with the active part at one of the ends. There also special elastic versions which can be stuck on horizontal and curved surfaces.

What are types of cylindrical capacitive sensors?

Cylindrical sensors are available in two varieties. One is screened so that the operating zone extends only from the sensor's face. Such sensors are flush mounted in metal or plastics. Sensors of the other type have an additional operating zone at a small distance from the sensor's cylindrical surface. They are designed to be used in cases when the sensor is in contact with the medium being detected, e.g. liquids or pellets. The operating zone of such a sensor is by 50% larger since the sensor's larger electric field closes at its sides.

How to evaluate the real operating distance of a sensor?

To evaluate the actual operating distance of a sensor, the catalogue nominal operating distance S_n Should be multiplied by the correction coefficient proper for the kind of material of the object being detected. The nominal operating distance S_n given in the catalogue is valid for a standardised metallic object.

From what does the detecting distance for organic materials depend on?

The distance at which a capacitive sensor detects organic materials such as wood or grain to a high degree depends on the water content in the materials. This is connected with a very high dielectric constant of water (ε_{water}=80).

At what distance from each other shall two capacitive sensors be installed?

Capacitive sensors shall be installed at a distance greater than $3 * S_n$. If the sensors are installed face to face, this distance shell be twice as big.

2.3 Compensation of interference events

Task 3 *Is there a difference in the switching distance when detecting an object made of copper or steel?*

No, there is no difference in the switching distance. In the case of objects made of conducting materials, the type of material has no influence on the operating range.

Which material is more easily detected: water or oil?

Water is more easily detected. The dielectric constant for water is equal to 80 and is the highest among non-conducting materials. For the transformer oil this constant is equal to 2.2.

What is the influence of pollution on the operation of a sensor?

The pollution of a sensor, a change in air humidity or the deposition of dew particles on the sensor's active surfaces may result in its improper responses. Pollution increases the capacitance between the sensor electrode and the screen.

Is it possible to limit the influence of pollution by the design of capacitive sensors?

Yes. To maintain the constant detection distance in the case of a uniform field of interference, an additional compensation electrode is being employed. Pollution increases the capacitance between the sensor's electrode and the screen. At the same time the capacitance between the sensor's electrode and the compensation electrode generates a compensation coupling. But in the case of a direct contact between a thin object (e.g. a sheet of paper) and the sensor there is a danger that the interference signal will neutralise the main electrode reading and no sensor switching will occur.

How to eliminate the influence of external magnetic fields?

The detection circuit incorporates interference filters which eliminate the influence of external electric fields if the latter are not too large. The filters, however, can significantly lower the maximum switching frequency and thus deteriorate the sensor's dynamic characteristic.

3 Ultrasonic sensors

3.1 Operating principle of a ultrasonic sensor

Task 1 *What is the operating rule of an ultrasonic sensor?*

Typical ultrasonic sensors operate in one of the two modes: a diffusion one (diffuse sensors) and through one (through beam sensors). The diffusion reflection is the most popular method for ultrasonic sensors. A sound wave reflected from an object returns to the sensor as an echo. Depending upon the output type, a distance determined based upon the time measurement is transformed into a voltage or current analogue signal or a relevant state of the two-position output (ON/OFF). When the object has left the measurement zone of the sensor, its output system returns to the previous state.

What phases may be isolated in the operation of an ultrasonic sensor?

Ultrasonic measurements feature two phases:
- Emission of an ultrasonic beam from a transducer towards an object.
- Emission of an ultrasonic beam by the detected object in the direction of the transducer whereas in this case the beam is an echo of the signal emitted from the transducer.

Is it possible that the same transducer operate as the emitter and the receiver?

In diffusion sensors these two functions can be performed by the same piezoelectric transducer. There are also models of diffusion sensors in which each of the two functions is performed by a separate transducer. In through sensors the emitter and the receiver are located in separate housings. In each of these housings there is a separate sensor.

What are the main components of an ultrasonic sensor?

The main components of an ultrasonic sensor are a high voltage generator, a piezoelectric converter located in the head of the sensor, a system of signal processing and an output system.

Are ultrasonic sensors resistant to external sound interference?

Ultrasonic sensors generate acoustic waves with frequencies clearly out of the range of audible ones, i.e. over 20 kHz. The high frequency of operation of ultrasonic sensors makes them practically immune to interference with surrounding sounds.

3.2 Ultrasonic sensor measurements

Task 2 *What is the main application area of ultrasonic sensors?*

Ultrasonic sensors are employed for the detection of objects, for the detection of levels of transparent and non-transparent fluids, and for the measurement of distances. They find application in areas of high dust content and in locations where, due to a high degree of soiling, application of optical sensors is not possible.

How do material properties of detected objects influence the sensitivity of ultrasonic sensors?

The sensitivity of a sensor is the higher the higher is the density of the detected object. A greater part of the sound wave is then reflected. By virtue of this fact, ultrasonic sensors are especially useful for the detection of objects with a high value of the acoustic reflection coefficient. A high value of the reflection coefficient feature solid or liquid materials or granulate-type media.

What is the working cycle of an ultrasonic sensor with one piezoelectric sensor?

A transducer emits periodic sound impulses. The time gap between the moment of impulse generation and the registration of the reflected echo is proportional to the actual distance between the object and the sensor. The duration of the impulse $_{i}$ must be clearly shorter than the time necessary for the return of the echo. The waiting time for the returning echo starts as soon as the impulse has been sent and is continued till the next signal has been sent. The time of the echo return to the sensor is measured. Based upon this time it is possible to calculate the distance to the object. In detection sensors the presence of an echo signifies a detection of an object in the operating range of the sensor and causes the switching of the output state of the sensor.

What is a possible method of eliminating the influence of the background?

The maximum operating range of a sensor may be limited by an appropriate potentiometer. By its virtue, objects located outside of this limit are not detected. The blanking out of the background function is thus realised.

What is the reason of the dead zone presence?

The dead zone is a result of the dual function of a transducer, namely that of the sound generator and receiver. A transducer is ready for the reception of the echo no sooner than a sound impulse has been emitted. The size of the dead zone depends upon the range and size of the sensor. Short sensors with a limited range have shorter dead zones than sensors with a bigger range.

Is there a possibility to set the lower range limit in ultrasonic sensors?

A possibility to set the lower limit of the range is available in some types of the sensors only. A locked zone is then additionally obtained, which makes it possible to define more precisely the active zone, i.e. a zone where objects will be detected. The defining of the locked zone prevents detection of objects that are within its limits.

What cone angles of the ultrasonic beam are offered in sensors?

Depending upon application, sensors with a cone angle of the ultrasonic beam varying from 3 to a few dozens of degrees are offered. This angle shall be selected such that the target section of the detected area is included in the cone and the remaining objects are ignored.

What is considered as a standard object when determining the range of an ultrasonic sensor?

A standard object is a metal plate 1 mm in thickness reflecting the ultrasonic beam. The plate shall be positioned vertically to the axis of the sound wave. Its size depends upon the range of the sensor; consequently, for short reach sensors (till 300 mm) it may be a 10 mm square plate, and for sensors with the reach above 800 mm, it should be a 100 mm square plate. Objects of different dimensions, shapes, and properties may not guarantee catalogue values of the detection range.

What is the operating principle of a through mode sensor?

In through mode sensors, an ultrasonic transducer generates a sound wave in the direction of a receiver located in an independent housing. An object interfering with the sound wave interrupts it and toggles the sensor's output.

How is a sound wave generated in through sensors?

In through ultrasonic sensors, contrary to diffusion and reflective sensors, the transducer generates a continuous sound wave and the dead zone is here absent.

What is the main application area of ultrasonic sensors?

Ultrasonic through sensors find application for the detection of not only sound reflecting objects but especially for the detection of porous objects dissipating or absorbing sound; also for objects with shapes difficult for detection by diffusion sensors.

Which sensors feature higher switching frequency: through ones or diffusive ones?

The maximum switching frequency of the output state in through sensors is higher that in diffusion sensors and may be as high as 200 Hz.

3.3 Interference events in the operation of ultrasound sensors

Task 3 *Which physical factors may interfere with the operation of ultrasonic sensors?*

The operation of ultrasonic sensors may be interfered by changes in the temperature of the air in the vicinity of objects being detected, intensive air currents (wind gusts), and by absorption of sound by some materials that are in the vicinity of the object being detected.

What influence on the operation of ultrasonic sensors has temperature?

Temperature increases in the operational range of a sensor due to thermal impacts from an object emitting large amounts of heat may result in the creation of a variable temperature zone, which changes the propagation time of a wave and reduces the sensor's accuracy. An increase of temperature may result in the fact that a detected distance is shorter than the actual one. An increase of temperature by 20 °C results with a few percent increase of the sensor's range and the readout distance is then underestimated.

Which installation factors may interfere with the operation of ultrasonic sensors?

Ultrasonic sensors are especially fit for the detection of hard objects with a flat surface perpendicular do the axis of detection. Any deviations from this recommendation may result with a faulty operation of a sensor. These are: Angular position of the frontal surface of an object with respect to the reference axis of the sensor, shape of the object oriented such that the direction of the reflected wave diverges form the axis of the emitted wave, wavy surface of fluids, and mutual interference of sensors.

May ultrasonic sensors interfere mutually?

If sensors are installed to close to each other, then the reflected sound wave emitted by one sensor may return to the other sensor and produce an unwanted toggle of the output. To avoid such situation, it is necessary to follow the recommended minimum spacing between the sensors.

How is it possible to avoid mutual interference of ultrasonic sensors installed in a close proximity to each other?

The synchronisation of two or more sensors by a skilful connection of their outputs makes it possible to locate them in a very close proximity without a threat of mutual interference. Synchronised sensors emit signals at the same time and operate as one sensor with enhanced acoustic cone detecting the same object

3.4 Special types of ultrasonic sensors

Task 4 *What is the operating principle of ultrasound reflexive sensors?*

Ultrasound reflexive sensors operate with a reflector. The role of the reflector may be performed by any flat and hard surface. The measurement is based upon a difference between the time of return of a sound wave reflected from the object being detected and the return time of a sound wave reflected from the reflector. The sound wave reflected from the object must return to the sensor earlier than that reflected from the reflector. The sensor output state is then toggled.

Which sensors may detect the full interruption of an ultrasound beam?

The full interruption of an ultrasound beam can be detected by through and reflexive sensors. The reflexive sensors detect also absorbing objects or objects deflecting sound in other direction. An interruption of the beam, i.e. detection of an object, causes also the switching the output state to OFF. Reflexive sensors are especially suitable for the detection of materials absorbing to a high degree sound like cotton, foam, textile materials.

How do ultrasound sensors with two transducers in one housing operate?

Double transducer sensors in one housing may function in the diffusion mode and in the reflexive mode with a reflector. One of the transducer functions as the emitter, and the other – as the receiver of the ultrasonic wave. This arrangement makes it possible to detect small object from a very short distance as the receiver need not wait till the impulse has been generated from the emitter. The two transducers shell, however, be synchronised.

Is a custom design of ultrasound sensors necessary for the measurement of distance?

The majority of ultrasonic sensors is equipped with both two-state outputs and analogue outputs. When measurements of distance are at stake, the voltage or current output is used. The magnitude of the voltage or current output is proportional to the measured distance.

4 Photoelectric sensors

4.1 Basic kinds of sensors

Task 1 *What is the operating rule of a through beam sensor?*

In through beam sensors, a light beam is sent directly from the emitter to the receiver coaxially placed in separate housings. Such sensors detect objects which appear between the emitter and the receiver, interrupting the light beam and switching the output signal in the receiver.

What properties through beam sensors feature?

Through beam sensors feature the longest operating distance (over 50m) when compared to other types of sensors. They are highly insensitive to difficult external conditions such as dust in the air, dirt on the lenses, steam or mist.

What objects may be detected by through beam sensors?

The material of a detected object is of no importance. The surfaces may be painted, translucent, transparent, rough, smooth, metal, plastic, etc. To make a detection possible, an object must eclipse at least 50% of the light beam that is emitted by the emitter

What is the operating rule of a retro-reflexive sensor?

In retro-reflective sensors the emitter and the receiver are built into one housing. In a solution like that the light that is emitted from the emitter must be reflected from an additional surface to direct the beam back to the receiver. Reflectors or special reflecting bands are used for this purpose. A dissipating surface object moving towards the light beam dissipates it and the object is not being detected by the sensor. (The sensor's output state is not triggered).

Explain the design of reflectors and that reflecting bands

A reflector is a set of spatial systems, each of them being built with three mirrors oriented at right angles to each other. In agreement with the laws of light reflection, a light beam entering this system is totally reflected by all the three surfaces and exits parallel to the incident beam. Such reflector guarantees that the light emitted from the sensor will return, if not interrupted by an obstacle, to the receiver.

What influences the effective stream of light for a reflexive sensor?

The effective light beam depends on the diameter of lenses in the emitter and the receiver as well as on the size of the frontal area of the reflector.

What is the operating rule of a diffusive sensor?

Diffuse sensors are used for direct detection of objects. Their main advantage, besides the fact that the emitter and the receiver are located in one housing, is that no reflector is needed. The emitter emits light which is reflected from an object and returns to the receiver, generating a target detection signal.

What are properties of diffusive sensors?

Diffuse sensors have a short operating distance (up to 100 mm, rarely to 200 mm). Foreign objects (or the background) beyond this distance are not being detected, i.e. their interference is inevitably dampened. The colour and type of surface affect to some degree the operating distance. Depending on the object's properties, the coefficient of reflection of light from the target may vary widely. Shiny surfaces located even far from the sensor may reflect most of the light whereby detection of the proper target may become very difficult. Additionally, the face of the sensor must be exactly parallel to the surface of the reflecting target. Dark or mat objects may absorb most of the light and the remaining amount of light may prove insufficient for the detection of the object.

How is the maximum detecting distance for diffusive sensors determined?

To determine the sensing distance of a diffuse sensor, a calibrated diffusing target surface, e.g. a sheet of white paper or Kodak paper (reflecting about 90% of the light beam) is used. For more light absorbing surfaces this distance shell be reduced accordingly.

4.2 Signal processing

Task 2 *What might be sources of interference in the undisturbed operation of photoelectric sensors?*

Phoelectric sensors are sensitive to optical interference from both natural and artificial external light sources. Light rays coming from such sources may significantly affect the intensity of the current generated by the emitter and thus result in erroneous sensor output signals. In order to reduce erroneous responses, sensors have built-in circuits eliminating, to a certain degree, such interference and noise and have circuits for the fine tuning of their sensitivity. Environmental pollution, e.g. oil, dust and dirt deposited on the surfaces of detected objects or on the emitter and receiver lenses can aggravate the problem.

Which types of sensor are most susceptible to optical interference?

Diffuse sensors belong to sensors most susceptible to optical interference originating from natural constant intensity light or artificial light close to the natural light spectrum as well as variable intensity light (blinker light).

What advantages result from the operation of sensors with modulated light?

The operation of photoelectric sensors with modulated light means that the emitter's light is switched on only for a short time. Such sensors are less sensitive to ambient light, their operating distance increases, and the amount of generated heat decreases, which extends the lifetime of LEDs.

Explain the polarisation of light.

Polarisation consists in total or partial ordering of light wave vibrations. If light is not polarised, electric and magnetic field vibrations occur in different directions, whereas if it is polarised, the vibrations occur only in one direction.

For what purposes is the polarised light used in photooptic sensors?

The polarised light makes it possible to differentiate between the light reflected from the element being detected and the other received light signals.

How is the polarisation of light carried out?

Vertical and horizontal filters are used for the polarisation of light. Natural non-polarised light, after having passed through such a filter, becomes the polarised light, either in the vertical or horizontal plane. Such polarised light may be easily stopped or let go by posting in its path a polarisation filter.

How does the polarised light reflect from surfaces of objects?

The reflection of polarised light from diffusing surfaces destroys polarisation. The reflection of polarised light from lustrous surfaces does not destroy polarisation, it may change its direction only. Specifically, a system of three mirrors (a reflector) does not destroy polarisation changing it from a horizontal one to a vertical one.

How to understand a notion of the „performance margin" of a photoelectric sensor?

The operating margin of a sensor determines how many times the amount of light falling on the photoelectric element of a sensor is greater than the amount necessary to toggle its output state. Sensors are equipped with diodes signalling if the amount of light at a given moment is sufficient to ensure is undisturbed operation. A reduction in the amount of light may be a result of soiled sensor, other than expected dispersion of light by the detected object or a result of the emitter ageing.

What shall be an excess of light to ensure an undisturbed operation of a photoelectric sensor?

In order to ensure a certain reserve, the margin should be larger than 1, i.e. the actual amount of incident light shall exceed the minimum level needed to switch the output device. The higher the excess, the more reliable the sensor's operation. For clean air and a low probability that the lenses or the reflector will get dirty, the minimum operating margin should not be less than 1.5. In a very dirty environment and when lens cleaning is limited, the minimum operating margin should be larger than 50.

Define the response time of a photoelectric sensor.

Response time is the time counted from the instant a light beam appears between the emitter and the receiver to a change of the switch output state. Knowing the response time one can determine how long the moving object must remain in the sensor's field of vision in order to be detected by it, i.e. at what maximum velocity the object can move or how long the spacing between successive objects must be.

4.3 Special types of photoelectric sensors

Task 3 *What are differences between a reflexive sensor with polarisation and a typical reflexive sensor?*

In retro-reflective sensors which exploit polarisation, the emitter light is focused by a lens and directed through a horizontal polarisation filter onto a reflector with triple mirrors. An important feature of the triple mirrors used in reflectors is that they change light ray polarisation by 90°. Some of the light rays reflected from the reflector reach the receiver via another vertical polarisation filter. The filters are so matched and positioned that only the light reflected from the reflector, and not any light reflected from the other objects within the sensor's range, reaches the receiver. A typical sensor has no filters. It is therefore susceptible to interference from other light beams.

What are possibilities of suppression of the background and the foreground?

The simples method of suppression of the fore- and background is a limitation of the active area through intersection of the optical axes of the emitter and receiver. It is effected by a mechanical change in the setting of lenses or by a change in the setting angle of the receiver. Even more effective is the electronic method of background suppression, where the sensor 'sees' the background but can ignore it. An example here can be a diffuse sensor with two light receivers or a triangulation sensor equipped with a CCD camera or a PSD transducer.

In what modes may sensors with electronic elimination of interference operate?

Sensors with electronic background suppression can operate in one of the three modes:

- protection against detection of object located outside the detection area (background suppression),
- protection against detection of object located before the detection area (foreground suppression),
- detection of only object located within the defined area (the window function).

What receivers of light are employed in triangulating sensors?

In triangulation sensors, linear PSD photodetectors or linear CCD cameras may be used as light receivers. By virtue of such receivers, these sensors, apart of the detection function, can measure the distance from the object to the sensor.

Explain the process of autocollimation.

Autocollimation consists in automatic conversion of a divergent light beam into a parallel beam whereby even at a smaller beam diameter there is enough light directed towards the receiver.

What additional features reflexive sensors with autocolimation have?

Autocollimation makes it possible to detect transparent objects (targets) and ones located very close to the sensor (in standard sensors' dead zone).

Explain the design of fibre-optic cables

A fibre-optic cable consists of a core made of glass or plastic rod surrounded by cladding made of another glass or plastic with a lower refractive index and a protective jacket.

Explain the effect of the full reflection in a fibre-optic cable

The total internal reflection occurs when light falls on the boundary between two media characterised by different refractive indexes. The total internal reflection means that 100% of the light beam's energy reflected from the boundary returns to the fibre-optic cable. A light ray is reflected from the boundary layer only when it passes from a medium with a higher refractive index.

What are differences between fibre-optic cables made of glass and plastic?

Glass fibre-optic cables are more durable than plastic ones – in the standard version they withstand temperatures up to 250°C (plastic fibre-optic cables – only up to 70°C). But plastic fibre-optic cables are stronger, cheaper and can be more easily shortened by cutting off the ends. Glass optical fibres effectively transmit both visible and infrared light whereas plastic optical fibres' infrared light transmission efficiency is low. Therefore glass optical fibres can be used for visible and infrared light whereas plastic optical fibres are suitable only for visible light.

What is the principle of operation of fiber-glass sensors?

The principle of operation of photoelectric sensors with optical fibres is the same as that of other photoelectric sensors, except for the fact that both emitted and received light is transported by an optical fibre. The fibre's metal end is very small (in the order of a few millimetres) whereby it can be located in inaccessible places far away from the sensor's optoelectronic circuits housed in a separate amplifier.

4.4 Connection technology

Task 4 *What modes of operation are characteristic for photoelectric sensors?*

Photoelectric sensors can operate in a dark operate mode (DO) or in the light operate mode (LO). In the dark operate mode the sensor's output switch is ON when the emitter light does not reach the receiver. This corresponds to the normally open (NO) output state in inductive and capacitive sensors. In the light operate mode the output is active when the light from the emitter does reach the receiver.

What factors influence the shape and size of the switching zone of the sensor's output?

In order for the output to be switched the object being detected or the emitter must be within the switching zone. Each photoelectric sensor has its characteristic output state switching zone whose size and shape depends on the diameter of the light beam sent by the emitter and the distance of the object being detected from the sensor. In the case of through-beam sensors, the receiver-emitter distance is critical.

5 Magnetic sensors

5.1 Magnetic phenomena employed in sensors

Task 1 *What are soft and hard magnetic materials?*

Hard ferromagnetics feature a broad hysteresis loop. These include : Fe-Co, Ni-Co alloys and hard ferrites xxx. That means that a ferromagnetic is difficult for magnetisation and demagnetisation. It is used for permanent magnets. Soft ferromagnetics feature a narrow hysteresis and can be quickly magnetised and demagnetised. They may, therefore, be used for magnetic cores. Soft magnetic materials include iron, Fe-Si and Fe-Al alloys, soft ferrites and amorfic alloys.

What is the underlying principle of the Hall's Effect?

The Hall Effect consists in the creation of an additional magnetic field in a DC current carrying plate made of a conductor or semiconductor and exposed to an external magnetic field. The influence of this external magnetic field on these charges results in their accumulation at one edge of the plate. A difference of potential at the two edges of the plate is a so-called Hall's voltage $\mathbf{V_H}$.

Why does the magnetic field change the magnetoresistance of semiconductors?

The magnetic field increases magnetoresistance of semiconductors because it causes deviation in the direction of the flowing current. This is due to an increased path of electrical charges. A value of the deviation angle increases with an increase in the intensity of the magnetic field making the path from one edge to the other edge longer.

What is the function of electrodes coated onto the magnetoresisitive tape?

Gold and aluminium electrodes set at the path of the current flow modify its direction and, as a result, the path of electrical charges becomes still longer causing an additional increase in the resistance of the semiconductor.

What are the main features of „impulse conductors"?

An "impulse conductor" has two magnetically different areas: the core and the shell. The core has the properties of a soft magnetic material (narrow hysteresis) and the shell has the properties of a hard magnetic material (wide hysteresis).

Explain the idea of the Wiegand's Effect

The Wiegand Effect consists in the generation of an electrical impulse in turns of a coil wound on an "impulse conductor" as a result of changes in the direction of the external magnetic field.

5.2 Fundamental types of magnetic sensors

Task 2 *Which elements may respond to changes in the magnetic field?*

Elements responding to the magnetic field may be a hermetic electrical coupler (a reed sensor), a semi-conducting element (a Hall Effect), a magnetoresistor or a coil with an “impulse conductor”.

What advantages magnetic sensors have?

Magnetic sensors feature a hermetic design, variety of housing shapes and high operational ranges that go together with small dimensions. Base modifications of these sensor do not require electrical supply and may be directly coupled to drivers inputs as well as may control the operation of machinery independently. An additional advantage of these sensors is a broad range of switching voltage and current levels, even above 1000 V and a few A.

Can magnetic sensors detect objects that are behind a plastic wall?

Yes, they can as the magnetic field penetrates most non-magnetic materials, hence the detection of items can be carried out even if there are diamagnetic obstacles, e.g. a tube or container walls made of plastics between an item and the sensor.

To what type of objects magnetic sensors respond?

Magnetic sensors respond to the magnetic field generated usually by permanent magnets attached to detected items. The element being detected may the very magnet or magnets that are attached the detected item. In the latter case the item can be made of any material but its magnetic properties may increase or decrease the operating range of the sensor. It is advantageous to attach magnets to non-ferromagnetic objects as this increases the operating range of the sensor.

What are the main components of a magnetic sensor?

The main components of a magnetic sensor are: one element responding to changes in the magnetic field, a system of detection of the output controlling signal and an output system. Sensors may be provided additionally with a diode signalling the state of the output.

What is the operating principle of a magnetic sensor with a reed sensor?”

A magnetic sensor with a reed contact sensor responds to an approaching magnet. In the magnetic field generated by this magnet, the contacts of a reed contact sensor become magnetised. If the force of the contact attraction overcomes the force of elasticity, then the sensor will change is state from the open one to the closed one. By virtue of this fact, the whole electrical circuit will also be closed together with the connected load.

What is the state of the output of a reed sensor when it is not subject to the magnetic field?

It depends upon the type of a reed sensor employed in the sensor. The contacts of a reed sensor, when not in the magnetic field, may, depending upon type, be normally open (**NO**) or in one of the two possible states **NO** or **NC** (normally closed).

Have magnetic sensors with a reed sensor only one active surface?

There may be a few active surfaces in a reed contact sensor. This is governed by the shape of the housing as it defines areas of possible translations for the magnet. There are sensors where the only possible translation of the magnet is along the face of the sensor and there are sensors where translations of the magnet are possible also with respect to the side surfaces of the sensor. Magnetic reed contact sensors have diversified housing shapes, starting from simple ones (cylindrical, prismatic) to more complex geometrical forms.

Which factors influence the maximum operating range of a magnetic reed contact sensor?

The maximum operating range S_{max} of a reed sensor is governed by the force of the magnetic field attraction. This force depends upon the size and properties of the magnet, from one side, and from the distance between the active surface of the sensor and the magnet, from the other side. Additionally, in agreement with the operational characteristic of the reed sensor, the operating range depends upon location of the magnet with respect to the active elements of the sensor.

How many leads are there in the output of magnetic reed contact sensors?

Reed contact sensors have three leads; those without a diode signalling the state of the sensor have two leads only.

What is the operating principle of a Hall's effect magnetic sensor

Hall's effect magnetic sensors are supplied with a DC current that flows through a semi-conducting plate (a hallotron). As long as the magnet is outside of the operating range of the sensor, the current may flow unimpeded through the hallotron. The difference of potentials at the edges of the hallotron is then equal to zero (V = 0). When the magnet appears in the operating range of the sensor, its magnetic field generates the Hall voltage ($V=\mathbf{V_H}$) at the edges of the hallotron. This voltage is a signal that controls the output transistor of the sensor.

5.3 Special types of magnetic sensors

Task 3 *What is the operating rule of Wiegand's sensors?*

The operating rule of a magnetic Wiegand sensor consists in the registration of changes in the magnetic field direction (polarisation) of the "impulse conductor" core. Polarisation of the core magnetisation may be reversed if the external magnetic field changes its direction.

How is it possible to do changes in the magnetic field direction in Wiegand's sensors?

There are three possible methods of changing the magnetic field direction acting on the impulse conductor:

- Magnets with a variable polarisation move one by one in front of a stationary sensor that houses an impulse conductor with a wound coil.

- Impulse conductors move one by one in front of a stationary sensor that houses two magnets with a coil.

- Ferromagnetic objects move one by one in front of a sensor that houses two magnets and a coil together with an impulse conductor.

How is the detection of mobile magnets by Wiegand's sensors done?

In the first phase, the "impulse conductor" is exposed to the magnetic field of an N/S polarised magnet and then, to the field of the next magnet with the reversed (S/N) polarisation. This change of the external magnetic field polarisation generates a voltage impulse in a coil wound around the impulse conductor. The impulse, after transformation, is the output signal from the sensor.

How is the detection of a translating „impulse conductor" carried out?

As a result of a translating motion of an impulse conductor in front of a stationary magnet with the N/S polarisation, and then in front of the second magnet with the reversed (S/N) polarisation, the direction of magnetisation in the core of the impulse conductor changes. This produces a voltage impulse which, after transformation, is the output signal.

Do Wiegand's sensors require voltage supply?

Wiegand sensors do not require electrical supply and may be manufactured as simple two-lead sensors, which are perfectly fit for operation in difficult environmental conditions.

Which element in sensors with a magnet responds to the magnetic field?

The elements responding to the magnetic field in these sensors is a coil wound directly on a permanent magnet.

What situations can sensors with a magnet detect?

These type of magnetic sensors detect motion of a ferromagnetic object. They cannot, however, be employed for the detection of stationary objects as the output voltage depends upon a speed with which the detected object approaches the sensor

Do magnetic sensors with a magnet require voltage supply?

Magnetic sensors with a magnet do not require electrical supply because a ferromagnetic object nearing a sensor changes the magnetic flux penetrating the coil generating at the same time a voltage at the coil terminals. This voltage, after transformation, constitutes the output signal.

Which factors influence the value of the output voltage in magnetic sensors with a magnet?

The output voltage in magnetic sensors with a magnet depends upon the speed with which an object being detected approaches the sensor. Values of these voltages are low and need additional amplification to toggle the state of the output system. When the speed of an object decreases, then the output voltage also decreases. For a stationary object the voltage drops to zero.

5.4 Installation conditions and applications

Task 4 *Does the type of material into which a magnetic sensor is installed influence its operation?*

Only if the material is a ferromagnetic one. It is advantageous in such situations to raise it possibly high above the surface of the ferromagnetic material. It is recommended also to introduce an additional isolation layer made of nonmagnetic (dielectric) material separating the sensor and the ferromagnetic material.

Will the introduction of a thin element between a sensor and the magnet compromise the operation of the sensor?

The introduction of a non ferromagnetic material between the sensor and the magnet does not influence the behaviour of the magnetic sensor. On the other hand, its behaviour will change if a ferromagnetic element appears between the sensor and the magnet. This may end with a changed state of the output of the sensor, i.e. with an interference in its operation.

What are the main applications of magnetic sensors?

Magnetic sensors find application, among others, in:

- The detection of objects located outside plastic wall, e.g. inside pipes or containers.
- The detection of objects in aggressive environments, through protective partitions.
- The detection of object in areas of elevated temperature thanks to a possibility of withdrawal of the magnetic field by the use of ferromagnetic elements.
- The detection of objects in translation and rotation.

6 Functions of sensors in systems

Task 1: *What are the main tasks performed by sensors in modern mechatronic systems?*

Sensors are used to identify:
- the performance of systems in their operating conditions,
- the correctness of process parameter control,
- operating disturbances,
- the degradation of the operating properties, and defects.

What mechatronic system operation parameters are checked by means of sensors?

Subject to checking by sensors are module/system structural node parameters such as:
- rated speeds and accelerations of work assembly motions;
- positions, positioning and orientations of assemblies and objects,
- motion paths (distances);
- rated motion speeds of auxiliary elements;
- transmitted and applied (rated) loads (force, pressure, current, electric power, torque);
- permissible system thermal operating conditions;
- integrated motion abilities;
- energy properties (power, torque) of systems and their modules.

What functions of mechatronic systems require the participation of sensors?

The signals from sensors are needed for:
- recognition of the output for function performance,
- evaluation of readiness for function performance activation,
- function performance activation,
- observation of function performance,
- decision on terminating function performance,
- function performance deactivation,
- transmission of information about function performance termination.

What does the role of sensors in diagnosing mechatronic systems boil down to?

The role of sensors in diagnostic processes boils down to the accurate and reliable measurement of parameters having a bearing on mechatronic system operation correctness.

Task 2: What information can sensors supply for machining process diagnostics?

In manufacturing systems sensors can supply information about:
- the correctness of the work cycle being performed;
- the condition of the tools, e.g. cutting tools;
- the condition of the chips;
- the continuity of cooling the tools and the workpiece;
- the condition of the surface layer;
- the dimension, etc.

What is the role of measurement signals received from sensors in the supervision of mechatronic system operation?

In mechatronic systems measurement signals received from sensors are processed and compared with the required values. Any difference between the two sets of values constitutes a control system adjustment signal or an instantaneous error compensated in a proper way.

What is evaluated by means of sensors in mechatronic system maintenance diagnostics?

The state of wear of a mechatronic system is indirectly or directly evaluated by means of sensors in order to do routine repairs or correct the relevant operating parameters. The evaluation is made through the measurement of parameters indicating the wear of system components.

7 Bus systems

7.1 Digital processing and digital interfaces

Task 1: What is a bus and what benefits does it give?

A bus is a system of lines and switching circuits used to transmit signals between connected devices. A bus allows:
- to significantly decrease costs of data transmission,
- to increase distances between the sensor and the controller,
- to transmit data concerning calibration and characteristics of a sensor.

What is digitalization and quantization of a signal?

Digitalization of analog signals is based on sampling of the analog signal once every specific time period, registering these values and converting them to corresponding digital values. So called quantization of analog signal is being performed. This means, that analog signal can only have a value from a specific range.

Describe serial data transmission.

Serial sending means, that every bit of data (0 or 1) is coded in different way – in simplest case:
- turning current on and off,
- switching between different voltage values,
- changing voltage value from positive to negative, and reverse. There is also a possibility of sending signals using alternative current methods, using amplitude, frequency, or phase modulation.

Describe parallel data transmission.

Parallel transmission, in a simplest case, requires at least a few lines, for example, eight lines. Main advantage of parallel transmission is high speed of data transfer; disadvantages are: large number of lines – which increases costs of wiring, and interference between transmission lines, rising with distance, over which this transmission is being carried out. Because of that, parallel transmission is used only over short distances.

What is the RS 232C interface?

RS232C interface is a standard of connection between the transmitter and the receiver. It is a standard describing an interface between Data Terminal Equipment (DTE) and Data Communication Equipment (DCE), which means, it consists of a connection between the terminal and the modem. RS232C standard allows to transmit data over a maximum distance of 15m, with a maximum transfer speed of 20kb/s. It allows a connection of two devices, one transmitter and one receiver.

.7.2 Communication networks: basic information and management

Task 2: *Describe the structure of communication in a company.*

We are able to distinguish five levels, from the lowest to the highest:
- level of sensors and actuators (field),
- level of group control,
- level of process control,
- level of production control,
- level of company control.

Describe the star-topology network.

In this structure, entire information is sent, come through, a central network concentrator (it could be a computer or any other network device playing a role of a network concentrator). This concentrator controls the flow of information in a network. Particular terminals cannot communicate directly with each other. It makes network strongly dependent on the performance of a concentrator; its damage causes the failure of the entire network.

Describe the ring-topology network.

In a structure of this network, information is transmitted between a few terminals connected in a ring. Every terminal transmits and receives information. After one station receives data, it copies it and marks, that it has been read, and then sends it to the next terminal. Thanks to this method, a transmitter, which has sent data, is capable of recognizing, whether the information has been properly received.

Describe the bus-topology network.

The most popular and most frequently used, is a bus-topology structure, also called linear. All devices are connected to a common data line – a bus. Theoretically, all devices in this network can communicate with each other. All devices have the same access rights.

What is a fieldbus?

Fieldbus is a fully digital, two-way serial communication system, which connects measuring and control elements, such as sensors, actuators and control devices. It provides a network, which connects devices exploited in a process of control and management, and also of automation of production process. It contains implemented mechanisms used to transfer data in real time. It allows for a decentralization of controlling the production process, and also the usage of “intelligent” devices, which affects the rise of elasticity of a communication system.

What is centralized control?

In centralized control, all signals from the processes are sent to the central control systems. A typical example are the PLC, to which, all sensors and actuators are connected. Alternative method of centralization, is using multiplexers and industrial networks to gather all, analog and digital, input and output signals. These signals are gathered in a multiplexer, and then sent through the network to the controlling unit.

What is distributed control?

A current tendency is to transfer functions executed by usually overloaded central processing unit, to network devices on lower levels, and providing them with the local intelligence. Through the intelligence it is possible for these devices to carry out elementary control functions. Such control is called distributed controlling with a local intelligence.

What is the OSI model?

The OSI model is a standard, defined by organizations ISO and ITU-T, describing the structure of the network communication. The OSI model is treated as the reference model for the most of families of communication protocols. Most popular model is OSI-RM (OSI Reference Model). A basic assumption of the model is the division of network systems on 7 completely independent layers. For the Internet, the simplified Model DoD has been formulated, which has only 4 layers. OSI reference model divides processes occurring during the session of communication on seven functional layers, which are organized according to the natural sequence of events occurring during the session of communication. Layers from 1 to 3 allow the network access, and layers from 4 to 7 handle logistically the final communication. In this model we can distinguish two basic zones:
- lower, or of transport (oriented on the communication); layers 1 to 4,
- higher, or the zone oriented on the user, formed by layers 5 to 7.

7.3 Bus systems

Task 3: Describe briefly the AS-I bus.

Originally this interface was created as the low-cost method of addressing single sensors in industrial automation applications. The interface gained popularity for large possibilities, the simplicity of the installation and exploitation, as also in consideration of low devices' addressing costs. The transmission is in it limited to the simple information (enabled or disabled).

Every segment may contain up to 31 devices. This provides 124 inputs and 124 outputs, adding up to the capacity of 248 I/O per single segment of the version 2.0. Every secondary(Slave) system is connected with other, and also with a superior(Master) system, by means of two wires which are used to supply the system and to the data transmission.

Give a short characterization of the CAN bus.

Most often the CAN is found with the bus topology, but it is also possible to join nodes into the star arrangement. Initially, the communication used only a shielded cable as the data carrier. Nowadays there are also other data carriers available e.g. the fiber-optic cable, radio waves, infra-red radiation and the energetic network. In the dependence from used carrier, in the CAN it is possible to transmit data with the speed up to 1 Mbit/s

Characterize briefly a field bus type DeviceNet

DeviceNet is a network based on the communication protocol of the CAN. It is an open system, where all stations have the same access rights to the medium of communication. The access to the broadcasting medium has a rivalizing (CSMA/CR) character. It works basing on the model of the producer / consumer. Exchange of the information in the network is realized by a method of broadcast. A typical example of the broadcast method is radio and television transmissions. In the case of DeviceNet it means, that all stations receive all transmitted data, and using their local filtration, they react only to the chosen data. This network works with the data transmission rates:
1.0 Mb/s over the distance to 50m,
500 Kb/s over the distance to 100m,
125 Kb/s over the distance to 500m.

Characterize the Interbus-S bus.

This network uses the topology of the ring, but the two-way data lines, reaching all devices, are contracted in one common cable, therefore the structure of this bus takes on the form of a tree. To the main network, it is possible to add as far as 16 levels of subnetworks. Interbus is a master-slave type network and allows to connect up to 512 devices in 16 levels of subnetworks. Addresses of the nodes are connected with their physical localization, therefore the connection or disconnection of one device does not require readdressing of existing devices. System data is automatically written to a new device, according to its location in the network, which reminds a plug and play mechanism.

Give characteristics of the Profibus.

Nowadays, Profibus offers communication profiles DP and FMS, physical profiles RS-485, IEC 1158-2, fiber-optic cable transmission, but also application profiles to the specific solutions. The most commonly used communication profile is Profibus DP, which is optimized in the direction of transfer speed, effectiveness and lowering of costs in automation systems. A Profibus DP protocol uses two lowest levels of the OSI model. Profibus FMS is a universal communication profile, slower than DP, but possessing a set of functions to the communication of intelligent devices. These communication functions are defined in a seventh (application) layer of the OSI model. Besides this layer, only layers 1 and 2 are used.

Characterize Profibusses DP and PA

Their main task is a decentralization of control, which means, a transfer of control to a lower level, distribution of inputs and outputs of analog signals, placement of processing cards as close to an object, as possible.

The structure of a network is based on the idea of a main station (Master), which manages the network, and connected to it secondary devices (Slave). The Master station is usually a controller or PC-based operator's station, Slave stations consist of a wide range of different products and circuits, which mainly include: I/O cards of two state and analog signals, motors, cylinders, frequency modulators, operator panels, converters, weighing modules, intelligent controllers stations, computers, etc. Similarly as in standards FMS, FDL, the basic tool for setting up an entire network, is Step 7 software, developed by Siemens.

Name advantages of networks based on the structure of Ethernet.

In comparison to the structure of the standard networks, Ethernet has many advantages:
- fast transmission speed (currently up to 100Mb/s),
- almost no limits to the topology of a network (its structure),
- the possibility of practically unlimited expansion,
- the fact that it is a world standard,
- a connection with the worldwide network (TCP/IP standard).
- constant development of the technology used in this network.

What is NOAH project?

One of the actions leading to the unification of software in field networks and assuring a good cooperation between networks, that is, assuring conflict-less data interchange, at the physical level, as well as software level, is project NOAH (Network Oriented Application Harmonization). NOAH is a program using the application layer in reference model ISO/OSI. The project NOAH is meant to be a standard for the description of such additional functions of the system. It will make possible the description of every device (the creation of its virtual picture) by means of the DDL (Device Description Language). In effect, the description of the device (the sensor) is divided into several levels: the level containing universal parameters of devices, the level of parameters of universal functions, the level of converting and the last level of parameters, proper only to the given producer of the device. The control and communication among systems takes place by using arrays with descriptions of properties of each sensor.

Mechatronics

Module 8: Remote Maintenance, Diagnosis

Trainerguideline
(concept)

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EU-Project Nr. 2005-146319 „MINOS“, duration from 2005 to 2007

European Concept for the additional Qualification Mechatronic of skilled Personnel in the globalized industrial Production.

The project was developed by the European Union within the action program of the European Union for vocational education „Leonardo da Vinci“.

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1 Aims and tasks of remote diagnostics and servicing

Problem 1 What are the reasons for taking diagnostic measures?

Malfunctions of and damage to machines during their operation result in high costs of production delays, standstills and repairs for the users. Therefore it has become necessary to continuously monitor machines and processes, forecast disturbances, take measures preventing process quality deterioration and take necessary remedial actions based on the forecasts.

What is the task of remote diagnostics?

The task of remote diagnostics is to wirelessly transmit (for a short or considerable distance) diagnostic signals with the required informational content from the diagnosed object to a near or far receiver, a monitoring station or a monitoring centre. A proper inference system, an intelligent advisory system or an expert will assess the disturbances and will take appropriate service decisions, remotely generating forecasts, evaluating the deviations and identifying the degradation of the operating parameters with a required accuracy and probability.

What is the task of a remote servicing system?

The tasks of a remote servicing system include:
- preventing excessive deterioration of mechatronic system (machine and equipment) operating parameters by reducing disturbances and compensating errors;
- predicting excessive errors and defects before they occur, whereby remedial action can be taken in a planned and prepared way to keep adverse economic consequences to minimum (intelligent action);
- optimum planning of service tasks for operating periods most convenient to the user.

What are the advantages of remote connection of sensors to communication networks?

The remote connection of sensors to communication networks has resulted in almost limitless possibilities of controlling the diagnosis process using not only single sensors but also groups of sensors. As a result, information from sensors can be used by control, diagnostic and forecasting systems.

2 Idea, components and operation of diagnostic system

Problem 2 What are the input data for object diagnostics?

The input data for object diagnostics are:
- diagnostic signal properties and acquisition points (sensor locations, the rate of changes and availability for service),
- the boundary values of controlled quantities,
- dependencies between the generated signal and the disturbances in the performance of an object or a process,
- sensors and measuring instruments (sensitivity, complexity, adaptability, numerousness, cost, the degree of automation),
- the form of acquired information,
- the methods of processing signals,
- verification methods,
- the method of communicating with receivers,
- the strategy of diagnosis,
- inference methods.

What are the criteria for designing diagnostics?

The criteria for designing diagnostics are:
- diagnostic signal sensitivity to changes in machine/process performance and information capacity,
- the degree of machine/process degradation,
- the level of service personnel qualifications,
- reliability,
- operating costs.

What do typical units for diagnosing mechatronic objects consist of?

A typical unit for diagnosing mechanical objects consists of the following assemblies and components:
1. A measuring system (sensors, matching systems – responsible for energy and information matching of signals, diagnostic sockets for retrieving information from the object).
2. Instrumentation amplifiers, a/d converters, channel selectors, I/O ports and other.
3. A digital signal processor (used for calculating diagnostic symptoms).
4. A decision system (incorporating logic converters, voltage level translators, digital comparators and other).
5. An information display system which decodes information and presents it in the form most convenient for the user (monitor, printer, analogue indicators, digital indicators and other).
6. An information storage system (memory: RAM, RAM-DISK, VDISK).
7. Software (operating system, signal processing and analysis, state diagnosis and prediction, functions performed by the diagnostic unit, communication between system layers, system operation management).

3 Idea, components and operation of service diagnosing system

Problem 3 What is the purpose of and what does service diagnostics consists in?

As opposed to the general diagnosing of the operation of an object and the work processes the latter carries out, which informs the user if the disturbances are within permissible limits and if sufficient product accuracy is being achieved, the purpose of service diagnostics is periodic error correction and planned recovery of the correct operating parameters. Service diagnostics consists in tracking the degree of object (machine) degradation in order to apply error correction and compensation or carry out a planned and well prepared repairs during a short standstill at a time convenient for the user. Thus the purpose of service diagnostics is to restore the machine's operating parameters guaranteeing the desired process (product) accuracy.

Describe the course of degradation of an operating parameter of a machine and the classification of the latter's technical condition.

If the symptom exceeds admissible value $\mathbf{U_d}$, this means that the diagnosed device is no longer fully functional but it can be operated for a certain time, i.e. it is still capable of performing its functions. If the symptom exceeds boundary value U_g (which marks the ultimate date for doing repairs), this means that it is no longer fit for use. Serviceability and unserviceability areas can overlap to some extent. In the overlapped area the device is not fully functional but still serviceable.

What are the main trends in the development of service diagnostics?

Remote diagnostics and servicing have strong economic reasons since they contribute to longer product life. Therefore attempts to increase product life span will translate into the development of diagnostics and supervision. In addition, as the globalization of manufacturing increases so does its dispersion whereby it becomes necessary to employ remote diagnostics and servicing in order to significantly increase the reliability of mechatronic systems, technological processes and the manufactured products. This means that diagnostic system modularity will continue to be developed and an ever larger number of diagnostic functions will be carried out by intelligent sensors. The development of remote diagnosing and servicing of machine systems tends towards full coverage of the latter and towards total supervision and servicing based on forecasts.