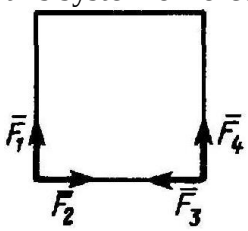
Engineering and Technologies: Second-round Sample Tasks for the Open Doors Master's and Doctoral Track

This sample test comprises 36 tasks, including 20 entry-level tasks with a single correct answer (each correct answer is assigned 1 points), 8 intermediate-level tasks with multiple correct answers (the correct answer is assigned 3-4 points), 4 advanced-level tasks requiring a detailed answer (the answer is assigned 9-11 points depending on its correctness and completeness).
For advanced-level tasks requiring a detailed answer, assessment criteria and a standard answer are provided.

Field of Science 1. Mechanical Engineering

Task 1
Entry level (1 point)

Four forces $F_1 = F_4 = 10$ H, $F_2 = F_3 = 33$ N are applied to the vertices of the rectangle. Determine the modulus of the resultant of this system of forces.

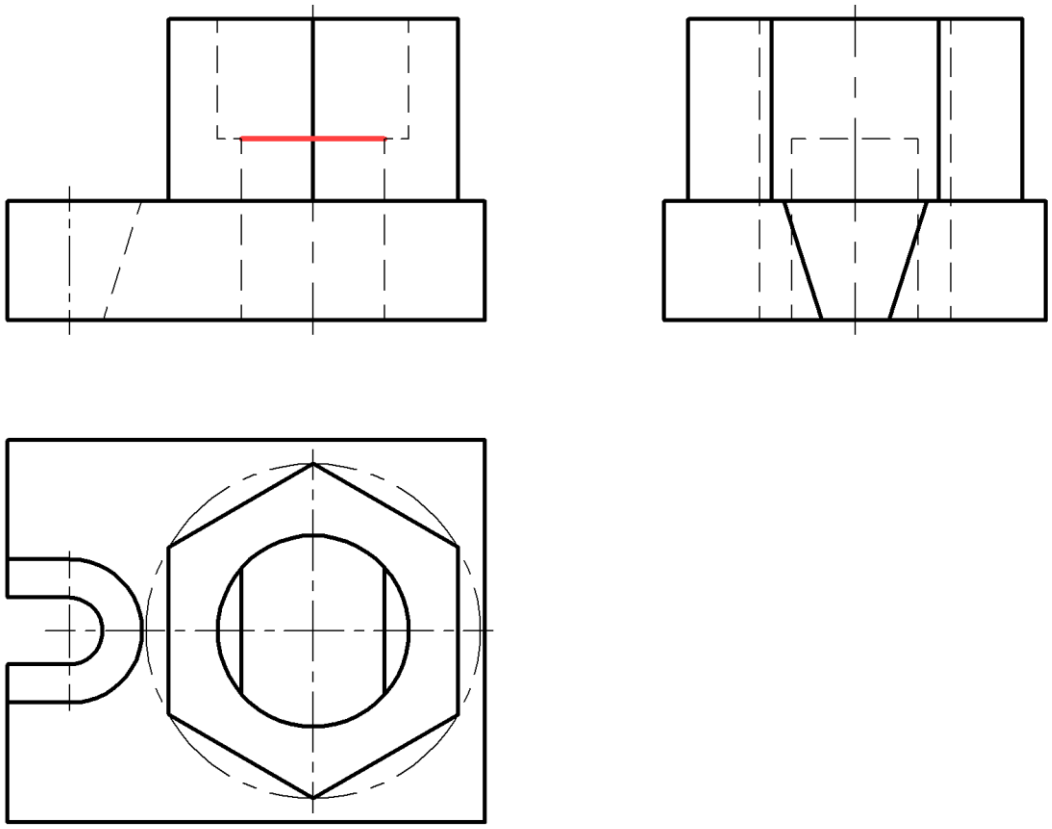


a) 10 N
b) 20 N
c) 40 N
d) 0 N

Answer: a

Task 2
Entry level (1 point)

The drawing of the part shows 3 views: the front view, the left view and the top view.
What type of lines should be used in place of the red line shown in the front view.



a)	
b)	
c)	
d)	No line needed

a) Answer a
b) Answer b
c) Answer c
d) Answer d

Answer: d

Task 3
Entry level (1 point)

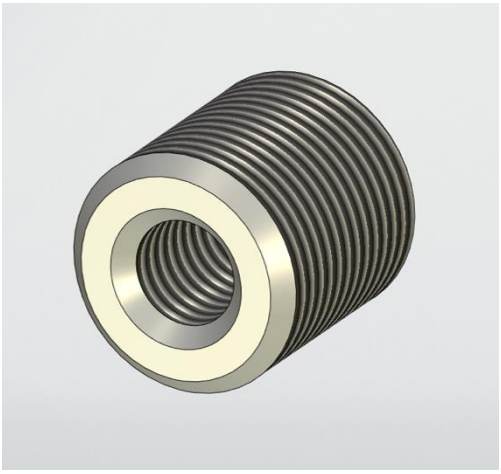
Indicate which design document will be used to manufacture the product shown in the figure.

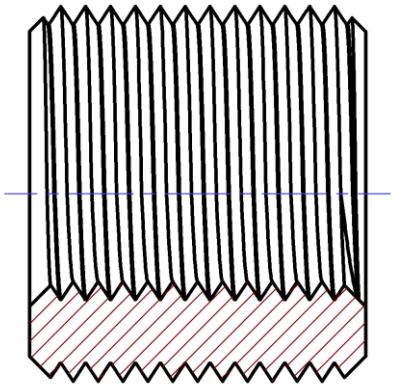
a) installation drawing
b) service manual
c) working drawing of the part
d) assembly drawing

Answer: c.

Task 4
Entry level (1 point)

The figures show an image of a threaded bushing. Indicate what threads are cut on it.



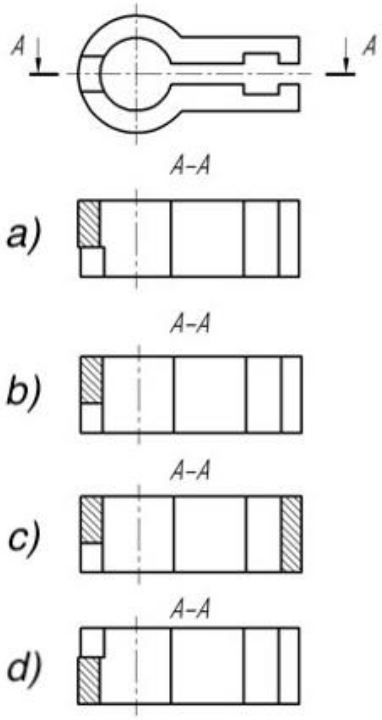


a) right-hand thread on the outside, left-hand thread on the inside
b) right-hand threads on the outside and inside
c) left-hand thread on the outside, right-hand thread on the inside
d) left-hand threads on the outside and inside

Answer: a

Task 5
Entry level (1 point)

The drawing shows a front view of a part and 4 horizontal section options A-A. Determine which one is correct.



Answer: a

Task 6
Entry level (1 point)

What is the value of the upper deviation in the dimension $50_{-0,39}$**?**

a) 50
b) +0,39
c) 0
d) -0,39

Answer: c

Task 7
Entry level (1 point)

What material is used to make cores for casting moulds?

a) Sand and clay mixture
b) Wood
c) Foam
d) Cast iron
e) Steel

Answer: a

Task 8

Intermediate level (3 points)

The motion of point M is given by the equation:

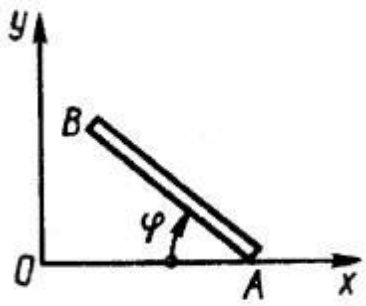
$$x(t) = 5t^2 + 5t/3 - 3, \quad y(t) = 3t^2 + t + 3 \text{ (см)}$$

Determine its acceleration (cm/s^2) at the moment t = 2.0 (s). Write the answer in cm/s^2 rounded to the nearest tenth.

Answer: 11.7

Task 9
Intermediate level (3 points)

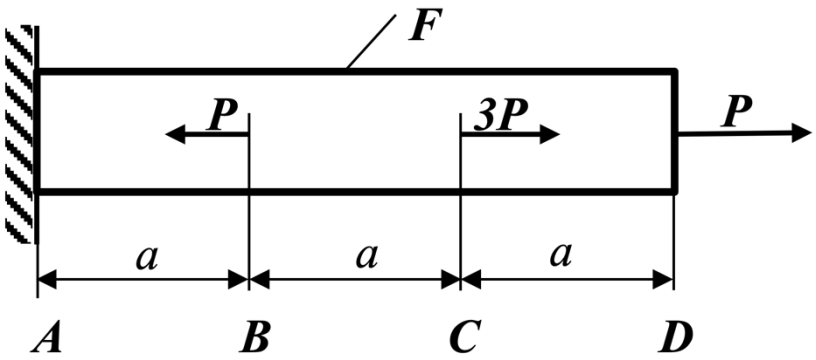
Point B of a rod AB, which has a length of 2 m, moves according to the equation $x_B = 4 \cdot \cos\left(\frac{1}{2}\pi t\right)$ (cm), $y_B = 0$. The rod rotates in the Oxy plane according to the angular law $\varphi = 0.5\pi t$. Determine the projection of the velocity vector of point A onto the Oh axis at time $t_1 = 0.5$ s. Write your answer in cm/s, rounded to three significant digits.



Answer: -2,22

Task 10
Intermediate level (3 points)

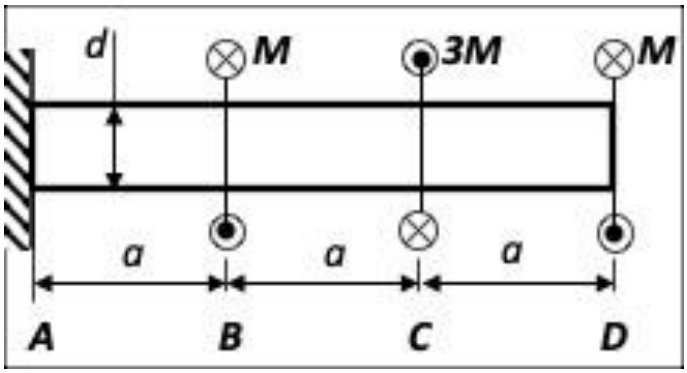
A bar of uniform section **F** with its left edge rigidly fixed in section **A** is loaded by local forces **P**, **3P** and **P** in sections **B**, **C** and **D** correspondingly (**P** = 5 kN). Find the maximum value (in modulus) of axial force $\mathbf{N_x}$. Answer in kN in the answer field, rounded to the nearest integer value.



Answer: 20 kN

Task 11
Intermediate level (3 points)

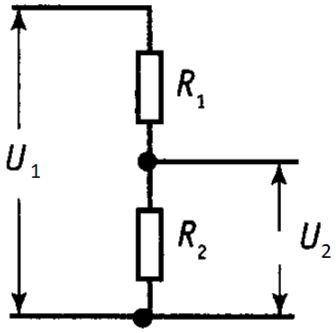
A shaft of constant stiffness and round section with diameter d, with its left edge rigidly fixed in section **A,** is loaded by local torques **M**, **3M** and **M** in sections **B**, **C** and **D,** correspondingly (**M** = 20 kN·m). Determine the maximum value (in modulus) of the torque M_x. Provide the answer in kN·m, rounded to the nearest integer.



Answer: 40 kN·m

Task 12
Intermediate level (3 points)

R_1=10 Ω, R_2=15 Ω, U_1=30 V. What is U_2 equal to? Write the answer in V, rounding to the nearest integer.

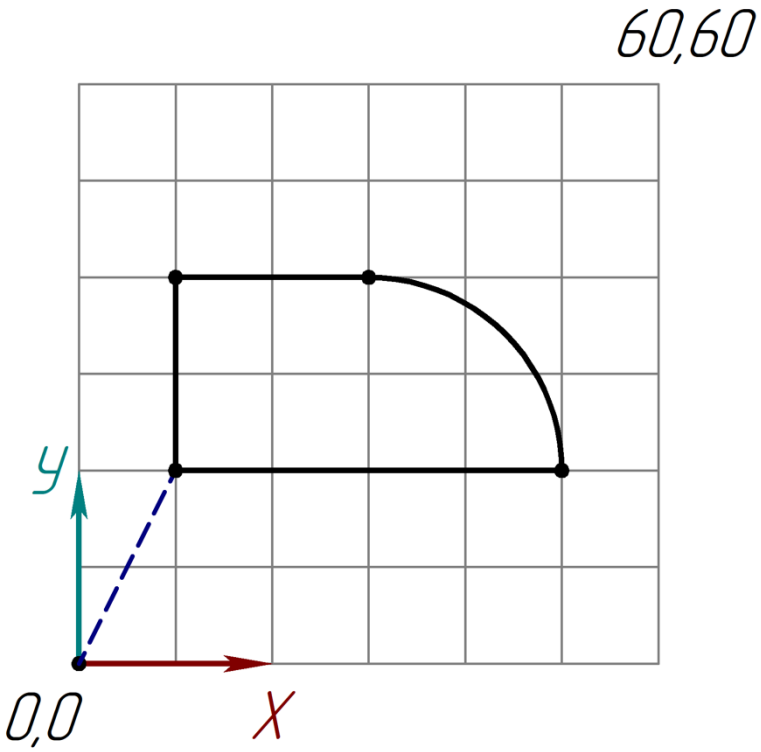


Answer: 18

Field of Science 2. Robotics

Task 13
Intermediate level (3 points)

The figure shows the tool path during CNC milling.



Indicate which of the G-CODE programs corresponds to it. Assume that the tool is initially located at point (0,0).

a)
G91
G00 X10 Y20
G01 X0 Y20 F200
G01 X20 Y0
G02 Y-20 I0 J-20
G01 X-40

b)
G90
G00 X10 Y20
G01 X0 Y20 F200
G01 X20
G02 X20 Y-20 R20
G01 X-40

c)

G91
G00 X10 Y20
G01 X0 Y20 F200
G01 X20 Y0
G02 X-20 Y-20 R20
G01 X-40

d)
G90
G00 X10 Y20
G01 X10 Y40 F200
G01 X30 Y40
G02 X50 Y20 R20
G01 X10

Answer: a, d

Task 14
Entry level (1 point)

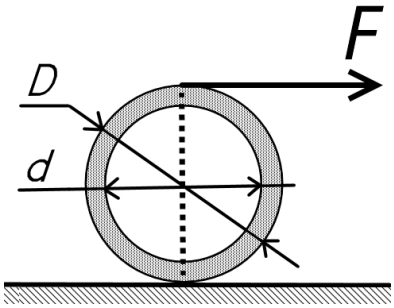
What distance will a point of mass m travel along the Ox axis in time t = 1s if it moves under the action of a force $F_x = 12mt^2$ (N)? At time t_0 = 0, the coordinate x_0 = 3 m, and velocity v_{x0} = 6 m/s.

a) 3 m
b) 6 m
c) 10 m
d) 25 m

Answer: c.

Task 15
Intermediate level (3 points)

A force F = 100 N was applied to the upper part of a pipe located on a horizontal plane. The pipe has an inner diameter d = 0.15 m, outer diameter D = 0.25 m and mass m = 40 kg. Determine the angular acceleration of the pipe. There is no slip between the pipe and the surface. Write the answer in rad/s² in the answer box, rounded to an integer value.



Answer: 59

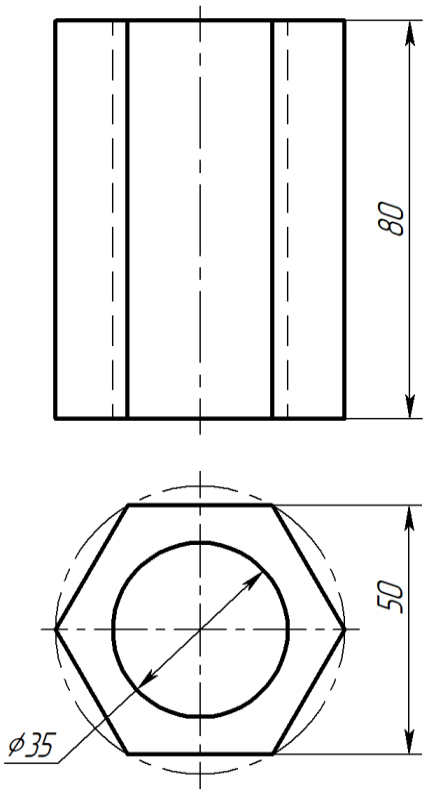
Task 16

Advanced level (11 points)

Bushings made of PETG plastic must be printed on a 3D printer according to the provided drawing and the printing parameters specified in the table.

1. Calculate how many spools of plastic (each weighing 1 kg) are required to print 1,000 parts.
2. Take into account a 3% print failure rate (on average, 3 out of every 100 parts fail due to detachment from the print bed or nozzle blockage).

Line width: 0.4 mm;
Layer thickness: 0.2 mm;
Number of bottom/roof layers: 10;
Number of perimeters: 5;
Filling: 20%.



Express the answer in grams, with an approximation to the nearest whole number.
When calculating, take π=3.14. The density of PETG material is taken as 1.27 g/cm³. The dimensions in the drawing are given in millimetres.

Note that the assessment will take into account both the solution process and the reasoning behind it; simply providing the final answer will not be sufficient.

Solution
The volume of a hexagonal prism with a cylindrical hole is calculated using the formula:

$V = \frac{\sqrt{3}}{2} S^2 h - \frac{1}{4}\pi D^2 h$, where S is the distance between the opposite faces of the hexagonal prism (width across flats), D is the diameter of the cylindrical hole, and H is the height of the part.
It is necessary to calculate the volume of the part printed with 100% filling (walls, bottom, lid) – 3 points
and the internal volume of the part printed with 20% filling – 3 points.
The thickness of the side walls will be
$L = s \cdot n_{st} = 0{,}4 \cdot 5 = 2\ mm$, where s is the line width, nst is the number of wall lines (perimeters).
The thickness of the bottom and lid can be calculated using the formula
$H = h_l \cdot n_l = 0{,}2 \cdot 10 = 2\ mm$, where hl is the layer height, nl is the number of layers of the bottom and cover.
The volume of the part will be:
$V = \frac{\sqrt{3}}{2} \cdot 50^2 \cdot 80 - \frac{1}{4} \cdot 3.14 \cdot 35^2 \cdot 80 = 96275\ mm^3$.
The internal volume printed by the filling is obtained by subtracting the thickness of the walls, bottom and roof:
$V_{int} = \frac{\sqrt{3}}{2} \cdot (50 - 2 \cdot 2)^2 \cdot (80 - 2 \cdot 2) - \frac{1}{4} \cdot 3.14 \cdot (35 + 2 \cdot 2)^2 \cdot (80 - 2 \cdot 2) = 48528\ mm^3$.
The external volume occupied by the walls, bottom and roof will be:
$V_{ext} = V - V_{int} = 47747\ mm^3$.
Thus, we can calculate the mass of the bushing as:
$m = \rho V_{ext} + 0.2\rho V_{int} = 73\ g$.
To produce 1,000 parts, 73 spools of plastic are required. However, considering a 3% defect rate (due to detachment from the print bed or nozzle blockage), it is necessary to print at least 1,031 parts, which will require 76 spools of plastic.

Answer: 76

Assessment criteria

The answer includes the total volume of the part printed with 100% infill (including walls, bottom, and top layers) – 3 points.
The answer includes the internal volume of the part printed with 20% infill – 3 points.
The number of spools is calculated without accounting for defects, with an acceptable deviation of ±1 spool – 3 points.
The correct number of spools, including a 3% defect allowance, is given – 11 points.

Field of Science 3. Telecommunications

Task 17
Entry level (1 point)

What is the resistance at the terminals of the 10N sensor if the measured temperature of this sensor is 0 degrees Celsius?

a) 0 Ω
b) 10 Ω

c) 50 Ω
d) 100 Ω

Answer: b

Task 18
Entry level (1 point)

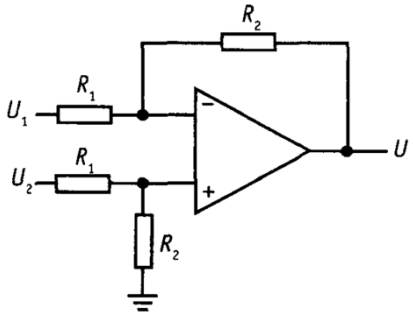
How many seven-segment digital indicators will be required to indicate an integer range of values from -10 to 10?

a) 1
b) 2
c) 3
d) 4

Answer: c

Task 19
Intermediate level (3 points)

What is the K gain of a differential amplifier if R_1 =10Ω, R_2 =20Ω, U_1=5V, U_2=-5 V? Write the answer, rounding it to an integer value.



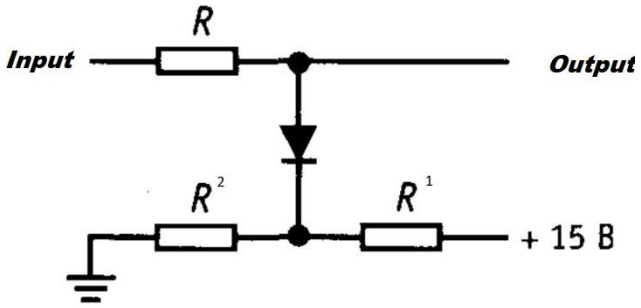
Answer: 2

Task 20
Advanced level (9 points)

There is a rectifier diode, the opening voltage of which can be neglected, and a set of resistors R=1kΩ, R_1=1kΩ, R_2=1.5kΩ, R_3=2kΩ, R_4=10kΩ, R_5=20kΩ. Using a reference voltage source U = 15V, a resistor opening a rectifier diode R, and the proposed values of resistors R_1 to R_5, design a circuit of a diode limiter that does not exceed the output voltage of 14.3 V. In the answer, give the circuit of the diode limiter and specify the values of the resistors selected.

Note that the assessment will take into account both the solution process and the reasoning behind it; simply providing the final answer will not be sufficient.

Solution
The designed diode limiter circuit is as follows: 4 points for a correctly designed circuit.



The selection of resistors for the reference voltage divider to calculate the voltage rating of the limiter is done using the formula:

$$U = \frac{U R^2}{R^1 + R^2} = \frac{15 * 20000}{1000 + 20000} = 14{,}3\text{В}$$

resistor ratings must be selected to achieve the required voltage rating R^1=1kΩ, R^2=20kΩ

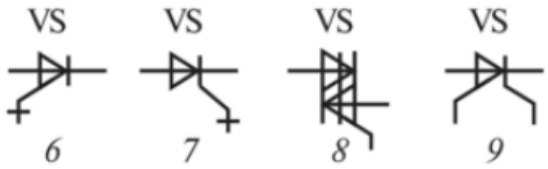
Answer**:** R^1=1kΩ, R^2=20kΩ

Assessment criteria
Correctly designed diode limiter circuit - 4 points.
Selection of resistors for the reference voltage divider to calculate the voltage rating of the limiter - 5 points.

Field of Science 4. Electrical and Electronic Engineering

Task 21
Entry level (1 point)

Which diagram shows a reverse-blocking tetrode thyristor?

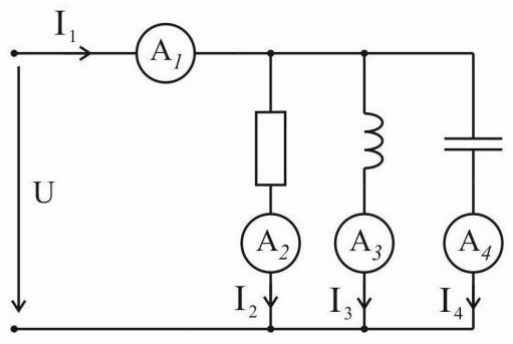


a) 6
b) 7
c) 8
d) 9

Answer: d

Task 22
Entry level (1 point)

Find the reading of the device A_1 if A_2 = 3A, A_3 = 6A, A_4= 2A.



a) 5A
b) 11A
c) 1A
d) 7A

Answer: a

Task 23
Intermediate level (3 points)

A three-phase asynchronous motor is connected to a three-phase network with a voltage of 380V, and frequency f = 50 Hz, using a delta (Δ) connection. Active power consumption is P = 2.5 kW, and the power factor is cosφ = 0.9.
Determine the total power consumption of the electric motor.
Enter the result in VA in the answer box, rounded to an integer value.

Answer: 2782

Task 24
Advanced level (11 points)

A linear electrical circuit is described by a transfer function of the form: $W(s) = \frac{100}{10S+10}$.
Find the transition time for this circuit, provided that a single-step action is applied to its input. Introduce an inertia-free correction link into the chain so that the transient process time is reduced by 2 times. What is the correction factor?

Note that the assessment will take into account both the solution process and the reasoning behind it; simply providing the final answer will not be sufficient.

Solution

Let us reduce the original transfer function (TF) $W(s) = \frac{100}{10S+10}$ to the canonical form: $W(s) = \frac{K}{TS+1}$
$W(s) = \frac{10}{1S+1}$, Dividing the numerator and denominator of the TF by 10, from the obtained TF in the canonical form, we can see that the time constant of the circuit is equal to T=1, respectively the time of the transient process t=3T = 3*1=3 s. (3 points)

To find the correction factor to reduce the transient time, we will use the introduction of negative feedback into the original linear electric circuit. For convenience, let's pass from the initial RC to the transfer function of the circuit: $W(s) = \frac{10}{S+1}$. Using the formula for expressing

the closed TF through the open loop TF, we obtain: $W(s)_з = \frac{W(s)_з}{1+K_{oc}W(s)}$. For the initial TF we obtain:

$$W(s)_з = \frac{\frac{10}{1S+1}}{1+K_{oc}\frac{10}{1S+1}} = \frac{10}{1*S+1+10*K_{oc}} = \frac{\frac{10}{1+10*K_{oc}}}{\frac{1}{1+10*K_{oc}}S+1},$$

the result is: $\frac{1}{1+10*K_{oc}} = \frac{1}{2}$, $1 + 10 * K_{oc} = 2$, K_{oc}=0,1.

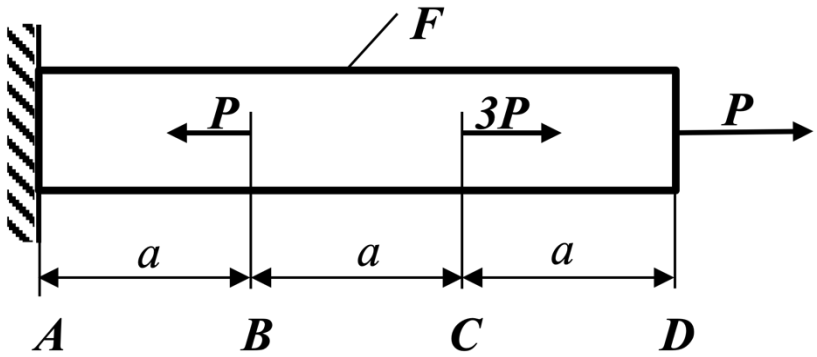
Answer K_{oc}=0,1

Assessment criteria
Correct determination of the transient (settling) time – 4 points.
Derivation of the expression for the closed-loop transfer function – 4 points.
Accurate calculation of the correction coefficient – 3 points.

Field of Science 5. Materials Science, Characterization and Testing

Task 25
Entry level (1 point)

A bar of uniform section **F** with its left edge rigidly fixed in section **A** is loaded by local forces **P**, **3P** and **P** in sections **B**, **C** and **D,** correspondingly (**P** = 10 kN). The allowable stress of bar material is [σ] = 200MPa. Find the minimum value of **the F** section area, derived from the strength state condition.

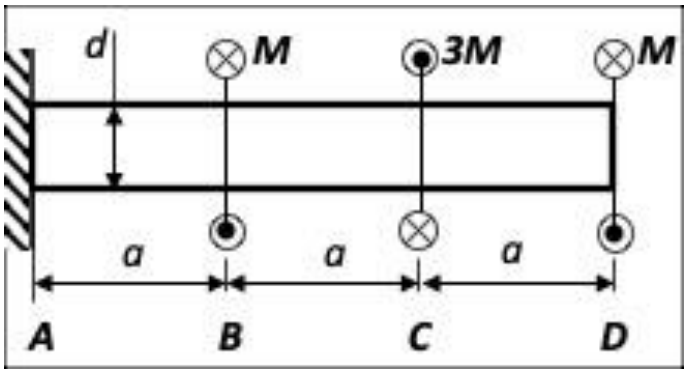


a) 1 cm^2
b) 2 cm^2
c) 3 cm^2
d) 4 cm^2

Answer: d.

Task 26
Entry level (3 points)

A shaft of constant stiffness and round section with diameter d, with its left edge rigidly fixed in section **A** is loaded by local torques **M**, **3M** and **M** in sections **B**, **C** and **D** correspondingly (**M** = 10 kN·m). The allowable stress of bar material is [τ] = 200MPa. The sectional modulus of torsion $W_P=\pi d^3/16$. Determine the minimum value of shaft diameter **d** derived by the strength state condition. Write the answer in cm, rounded to tenths.

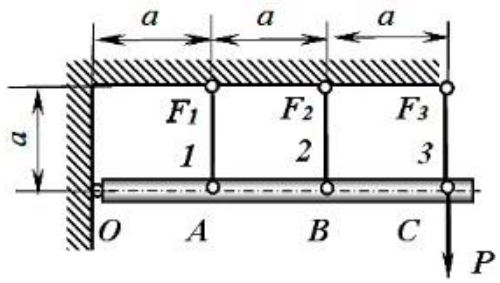


Answer: 12,7 cm

Task 27
Advanced level (11 points)

Beam **OC** is suspended on rods **1, 2, and 3,** which are made of a material with Young's modulus E. The rods have cross-sectional areas - **F_1, F_2, and F_3**, respectively, and the rods' length is **a**. The distance from the joint and between the rods is equal to **a**. The **OC** beam is considered an absolutely solid body compared to the rods. The left end of the beam at point **O** is attached to a rigid wall by a hinge-fixed support, and at point **C,** it is loaded with force **P**. The weight of the beam in comparison with the force **P** is neglected. **P** = 28 kN, **F1=F2=F3=F**.

Determine the value of the longitudinal force **N_1** in rod **1**. Enter the answer in (kN) rounded to an integer value in the answer field.

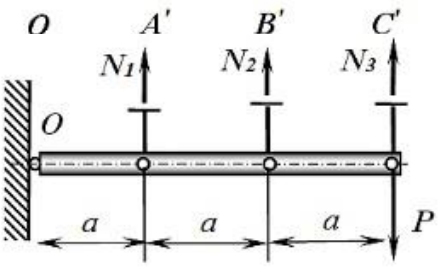


Solution

Given that the beam is in equilibrium under the applied loads, we cut it out along the rods near the beam and write the equilibrium equation, assuming that all the rods experience tension.

$$\Sigma M_o = 0 \Rightarrow N_1 \cdot a + N_2 \cdot 2a + N_3 \cdot 3a = P \cdot 3a \quad (1)$$

Build a deformed system. Under the action of force **P**, beam **OC** will rotate around hinge **O**. The amount of rotation of the beam is determined by the deformations of rods **1, 2** and **3**. Due to the smallness of deformations, we can assume that any point of the beam moves vertically downward.



The position of the beam without load is shown as OC′, and under the action of load P as OC. Accordingly, AA′ represents the elongation of rod 1, BB′ the elongation of rod 2, and CC′ the elongation of rod 3. The geometric similarity of the elongations of the rods can be expressed as

$$\Delta l_2 = 2\Delta l_1 \quad \text{и} \quad \Delta l_3 = 3\Delta l_1 \quad (2)$$

Express the elongation of rods through forces, lengths, and stiffness

$$\Delta l_1 = N_1 \cdot a / EF$$
$$\Delta l_2 = N_2 \cdot a / EF \quad (3)$$
$$\Delta l_3 = N_3 \cdot a / EF$$

Replacing expressions for extensions (3) in (2), we get

$$N_2 = 2\,N_1 \quad \text{и} \quad N_3 = 3\,N_1 \quad (4)$$

Next, we substitute expression (4) in (1)

$$N_1 = \frac{3}{14} \cdot P \qquad N_2 = \frac{6}{14} \cdot P \qquad N_3 = \frac{9}{14} \cdot P \quad (5)$$

By substituting the load value **P** = 28 kN, we get the amount of force in rod 1 – N_1 = 6 kN.

Answer: 6

Assessment criteria
Force diagram is correctly drawn – 2 points.
Equilibrium condition (1) is correctly formulated – 3 points.
Deformed system is constructed, and the compatibility condition (2) is written – 3 points.
System of equations (3) and (4) is solved correctly, and the final answer is correct – 3 points.

Task 28
Entry level (1 point)

What is tensile strength?

a) The maximum size of a body at which it fails
b) The minimum stress that occurs in a body before it fractures
c) A physical quantity that indicates at what external force acting on a substance a body fails.
d) The maximum stress that occurs in a body before it fractures

Answer: d

Field of Science 5. Nuclear Science and Technology

Task 29
Entry level (1 point)

An electron e^- has momentum p. Which of the following formulas correctly defines its de Broglie wavelength?

a) p/h
b) h/p
c) $\frac{h}{pc}$

d) $\frac{h}{ep}$

Answer: b

Task 30
Entry level (1 point)

What is the wavelength of the X-ray characteristic line for $K_\alpha$aluminium ($^{27}_{13}Al$):

a) 844 pm
b) 100 pm
c) 11,0 pm
d) 0.88 pm

Answer: b

Task 31
Entry level (1 point)

The fission of a uranium nucleus produces two fragments and free neutrons
$^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{145}_{56}Ba + {}^{M}_{Z}X + 3{}^{1}_{0}n + 200\text{МэВ}$

Identify the second fragment.

a) $^{137}_{55}Cs$
b) $^{140}_{54}Xe$
c) $^{88}_{36}Kr$
d) $^{108}_{44}Ru$

Answer: c

Task 32
Intermediate level (4 points)

Helium is produced by the radioactive alpha decay of radium $^{226}_{88}$Ra. How much helium is formed over the period of 40 years from 1.0 grams of radium, given that the half-life of $^{226}_{88}$Ra is 1600 years? Express the answer in μg rounded to the nearest hundredth.

Answer: 0.44

Field of Science 6. Automation and Control Systems

Task 33
Entry level (1 point)

Which differential equation gives a mathematical description of the aperiodic link?

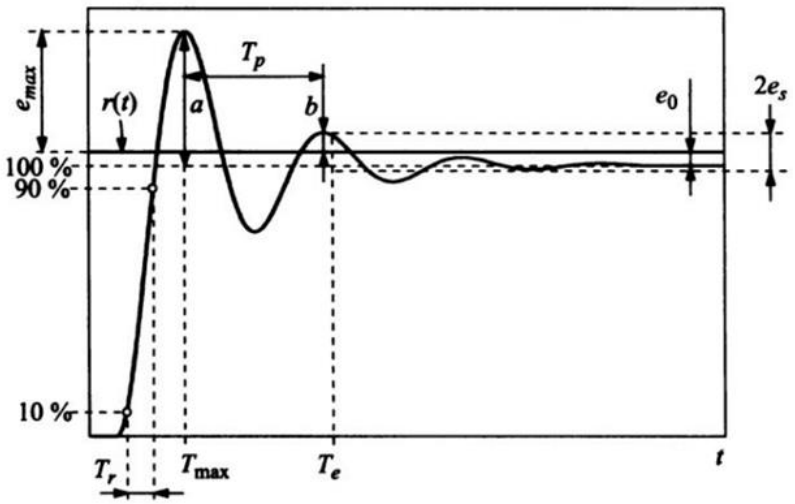
1	$T\dot{y}(t)+y(t)=kx(t)$
2	$T_2^2\ddot{y}(t)+T_1\dot{y}(t)+y(t)=kx(t), T_1 \geqslant 2T_2$
3	$T^2\ddot{y}(t)+2\xi T\dot{y}(t)+y(t)=kx(t), 0<\xi<1$
4	$y(t)=k\left[T\dot{x}(t)+x(t)\right]$
5	$y(t)=k\left[T^2\ddot{x}(t)+2\xi T\dot{x}(t)+x(t)\right]$
6	$y(t)=kx(t)$

a) 1
b) 2
c) 3
d) 4
e) 5
f) 6

Answer: a

Task 34
Entry level (1 point)

Using the graph of the transient process, estimate its degree of attenuation ψ if a=4,b=3.



a) 1
b) 1/3
c) 1/4
d) 12

Answer: c.

Task 35

Entry level (1 point)

The inertia-free link with K = 10 was covered by rigid negative feedback with a coefficient of 0,25. What is the gain factor of the resulting system?

a) 0,476
b) 0,909
c) 1
d) 1,476
e) 2,857
f) 11,110

Answer: e

Task 36
Intermediate level (4 points)

For a dynamic system model presented in the form of state variables, find the eigenvalues of matrix A.

$$\begin{cases} \frac{dx_1}{dt} = 4x_1 + 4x_2 + u \\ \frac{dx_2}{dt} = 3x_1 \end{cases}$$

a) – 2
b) 0
c) 2
d) 4
e) 6
f) 8

Answer: a, e