Engineering and Technology: second-round sample tasks

Section 1. Theoretical mechanics

Task 1 (1 point)

When is the moment of force about a point equal to zero?
• if the action line of the force intersects the given point
• if the force is located on the coordinate axis
• if the force is at a certain distance from the given point
• if the force intersects the plane in which the point is located
• if the action line of the force passes through the given plane

Answer: if the action line of the force intersects the given point

Task 2 (1 point)

To find the absolute velocity of the points of the rim of the wheel rotating around its fixed axis at an angular speed of 20 rad/s if the radius of the wheel R = 10 cm?

- 0 m/s
- 2 m/s
- 40 m/s
- 15 m/s
- 0.2 m/s

Answer: 2 m/s

Task 3 (6 points)

A point mass M with current position P moves according to the equations:

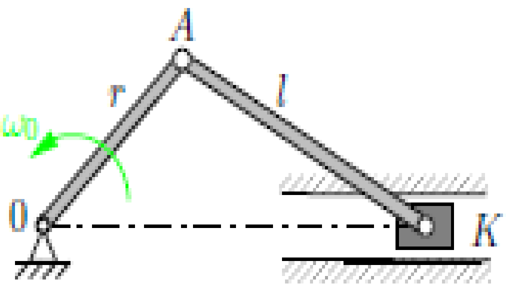
$x(t) = 2t^2 + 3, \quad y(t) = -3t$ (cm)

To find its velocity at the moment t = 1.0 (s). In the answer field, write the integer value of the speed in cm/s.

Answer: 5 cm/s

Task 4 (6 points)

A slider crank mechanism consists of a crankshaft 0A and a connecting rod AK (See Fig.). The crankshaft rotates with a constant angular velocity ω_0=10 rad/s. Determine the angular velocity of the connecting rod if ∠AOK=60°, 0A=1.0 m, AK=2.0 m. In the answer field, write the value of the angular velocity in rad/s, rounded to tenths.

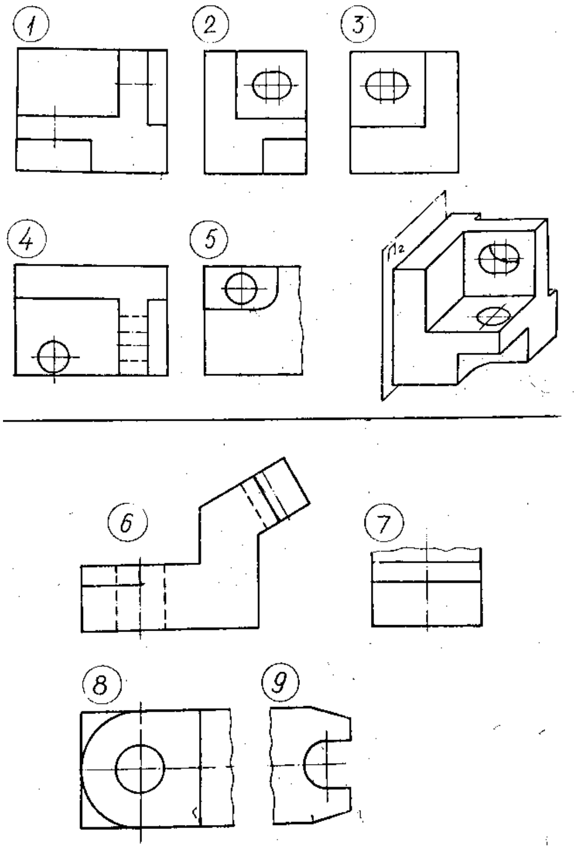


Answer: 2.8 m/s

Section 2. Engineering graphics

Task 1 (1 point)

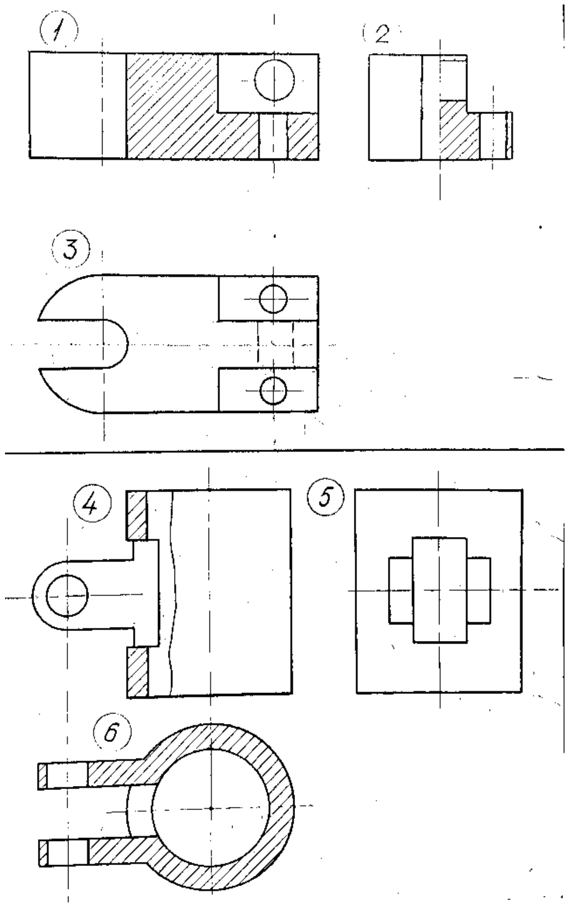
Specify the images on which you see the Main view (front view);



Answer: 2.

Task 2 (1 point)

Specify the image on which Horizontal section was made:



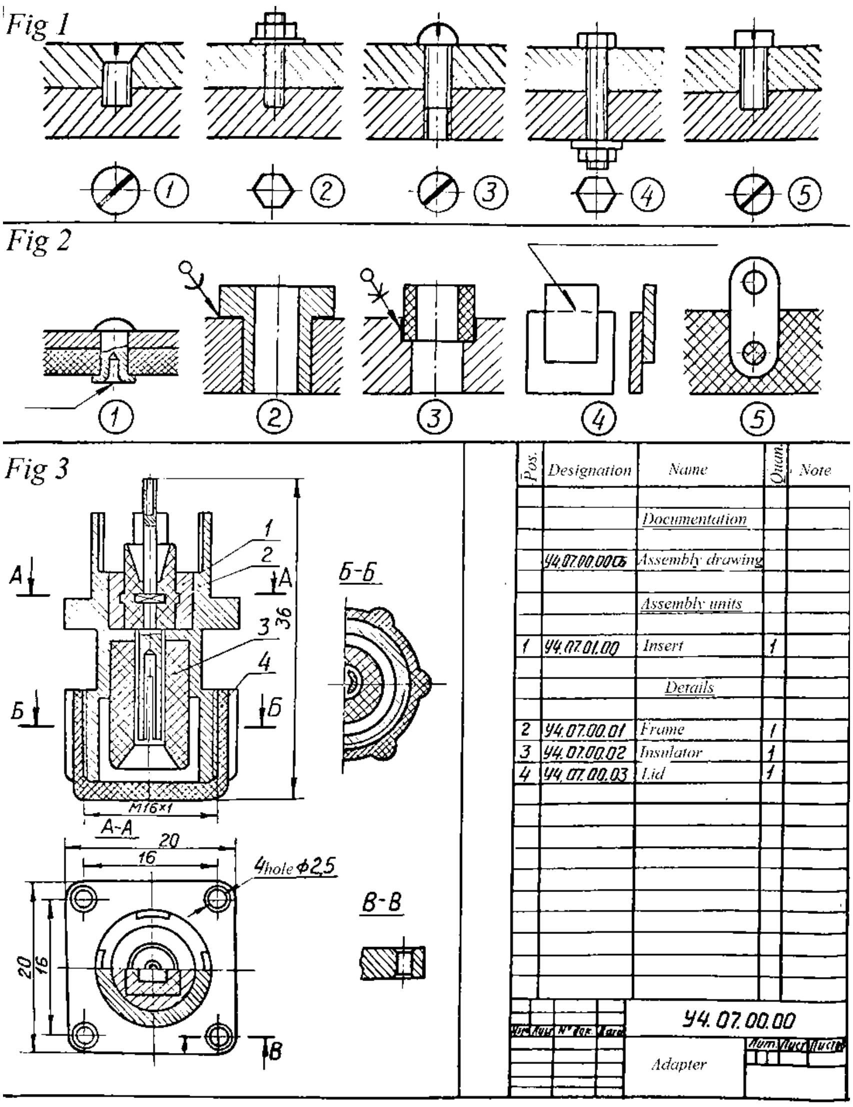
Answer: 4.

Task 3 (6 points)

In the table you will find 5 questions with possible answers. Enter space-separated answers for each question. Example: "1 2 3 4 5".

Question №	Question content	Possible answer	Code
1	Specify the image containing the button head screw (Fig.1).	Image No. corresponds to Code No.	1 2 3 4 5
2	Specify the image containing the weld connection (Fig.2).	Image No. corresponds to Code No.	1 2 3 4 5
3	Specify the position number of the part included in the product and having 8 chamfers (Fig. 3).	item no. corresponds to code no.	1 2 3 4

			5
4	Specify the position number of the part included in the product and having 4 protrusions (Fig. 3).	item no. corresponds to code no.	1
			2
			3
			4
			5
5	In what sequence are the names of the following standard products recorded in the specification (Fig. 3).	Nut…Washer…Bolt	1
		Bolt…Washer…Nut	2
		Washer… Nut… Bolt	3
		Bolt… Nut… Washer	4
		Nut…Bolt…Washer	5



Answers:

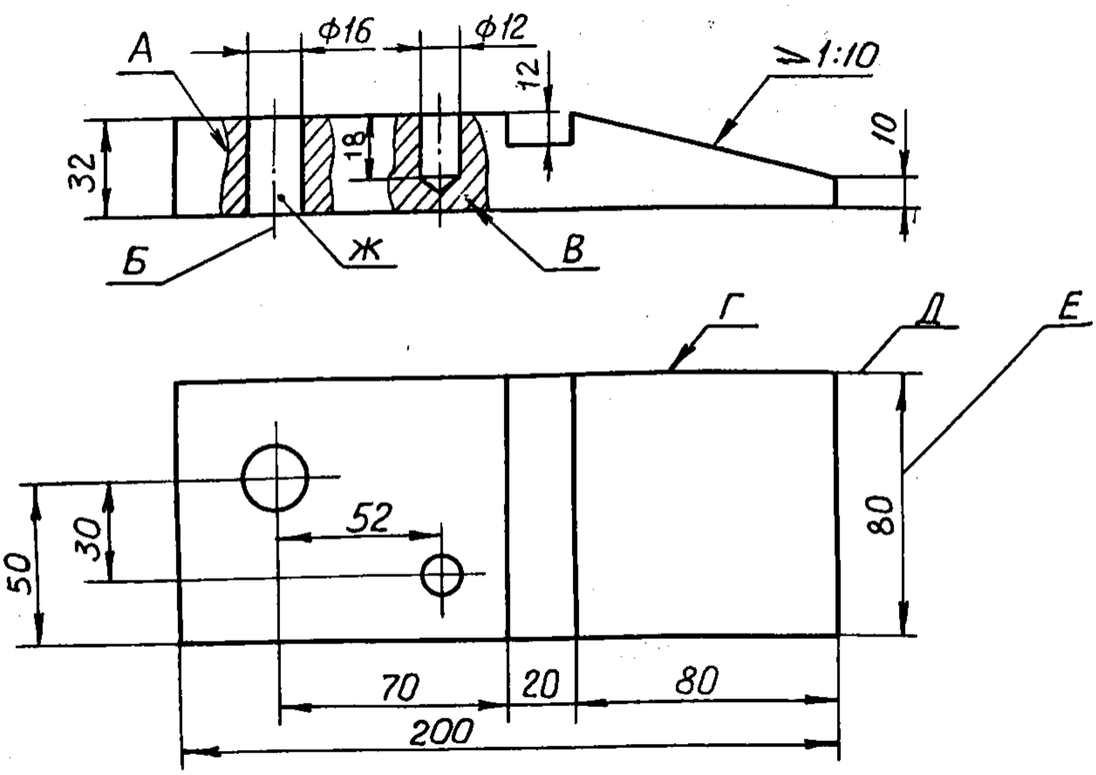
Question №	1	2	3	4	5
Answer	3	4	2	2	4

Score criteria:

Number of correct answers	0	1	2	3	4	5
Points	0	1	2	4	5	6

Task 4 (6 points)

In the table you will find 5 questions with possible answers. Enter space-separated answers for each question. Example: "1 2 3 4 5".



Question №	Question content	Possible answer	Code
1	Specify the purpose of line A.	Dimensional line	1
		Axial line	2
		cliff line	3
		section line	4
		Extended line	5
2	What are the dimensions of the part?	116x40x40	1
		76x40x20	2
		200x80x32	3
		76x40x40	4
		100x40x40	5
3	What is the shape of the hole given by the surface "G"?	Round	1
		oval	2
		Square	3
		conical	4

		Elliptical	5
4	Which symbol of the material corresponds to the graphic designation of the section of this part?	Steel	1
		Concrete	2
		Glass	3
		Wood	4
		Paronite	5
5	Determine the number of cylindrical surfaces of this part	The number corresponds to the code number	1
			2
			3
			4
			5

Answers:

Question №	1	2	3	4	5
Correct answer	3	3	1	1	2

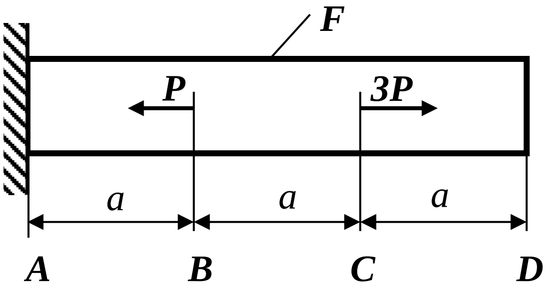
Score criteria:

Number of correct answers	0	1	2	3	4	5
Points	0	1	2	4	5	6

Section 3. Strength of materials

Task 1 (1 point)

Bar of constant cross section with area F = 20 cm^2, left edge of which is rigidly fixed in section A, is loaded with concentrated forces P, 3P in sections B and C respectively (P = 10 kN). Determine the maximum modulo value of the normal stresses σ_x^{max} in the sections.

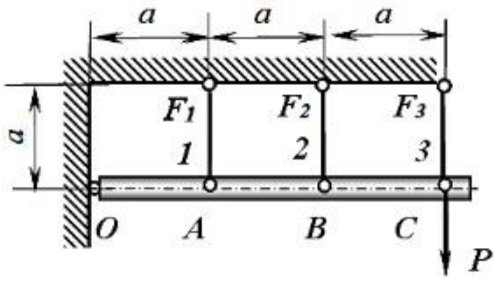


Answer: ***15 MPa.***

Task №2 (6 points)

The beam ***OC*** is suspended on rods ***1, 2, 3*** which are made of a material with a Young's modulus E. Rods have cross-sectional areas - F_1, F_2, F_3, respectively, and 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*** = 14 kN, ***F1=F2=F3=F***.

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

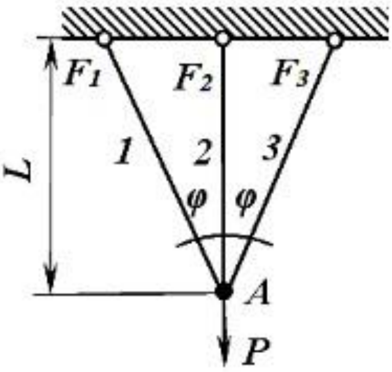


Answer: 3 kN.

Task 3 (12 points)

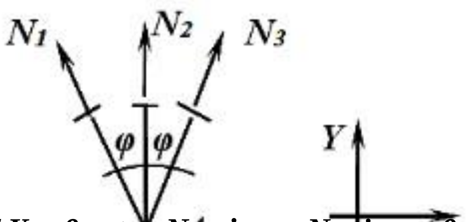
A symmetric system of three rods ***1***, ***2*** and ***3*** made of a material with a young's modulus E, having cross-sectional areas ***F1***, ***F2***, and ***F3***, respectively, is given. The length of the vertical rod ***2*** is equal to ***L***. The angles between the rods are the same and equal to φ. The upper ends of the rods are pivotally fixed to a rigid wall, and the lower ends are pivotally fixed at point ***A***, to which a vertical force is applied ***P***. ***P*** = 10 kN, ***F1 = F2 = F3 = F***, cos φ = 0.7.

Determine the value of the force ***N1*** in the rod ***1***.



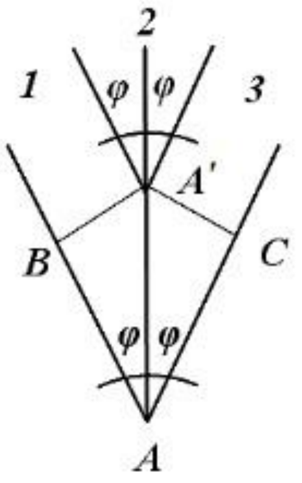
Solution:

Taking into account that the system of rods under the action of load ***P*** is in equilibrium, we cut out the rods near the node ***A*** and write the equilibrium equations, assuming that all the rods experience tension.



$\Sigma X = 0$ => $-N_1 \cdot \sin\varphi + N_3 \cdot \sin\varphi = 0$,
we get that $N_1 = N_3$ since the system is symmetrical.
$\Sigma Y = 0$ => $-P + N_1 \cdot \cos\varphi + N_2 + N_3 \cdot \cos\varphi = 0$,
or given that $N_1 = N_3$, we get $-P + 2N_1 \cdot \cos\varphi + N_2 = 0$ (1)

Let's build a deformed system. Under the action of force ***P***, the node moves from position ***A´*** to ***A***. The amount of movement of the node is determined by the deformations of rods ***1, 2*** and ***3***. Due to the smallness of deformations, we can assume that the angle φ between the rods does not change.



So *A´A* will be an extension of 2 rods, ***AB*** will be an extension of 1 rod and ***AC*** will be an extension of ***3*** rods. You can write the following mathematical relation for the sides of a right triangle ***A´AB***

$$\Delta l_1 = \Delta l_2 \cdot \cos\varphi \qquad (2)$$

We express the elongation of rods ***1*** and ***2*** in terms of forces, lengths, and stiffness and get

$$\Delta l_1 = N_1 \cdot l / EF \cos\varphi \quad \text{и} \quad \Delta l_2 = N_2 \cdot l / EF \qquad (3)$$

Substituting expressions for extensions (3) in (2) we get

$$N_2 = N_1 / \cos^2\varphi \qquad (4)$$

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

$$N_1 = P \cdot \cos^2\varphi / (1 + 2\cos^3\varphi) \quad \text{и} \quad N_2 = P / (1 + 2\cos^3\varphi) \qquad (5)$$

Substituting the value of the load ***P*** = 10 кN, cos ***φ*** = 0.7 , we get the amount of force in the rod ***1***

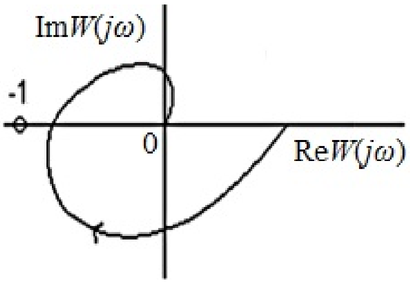
N_1 = 10·0.49 / 1.686 = 2.90 кN

Evaluation criteria:
Reached the formula and determined the correct course of the solution: 6 points;
Completed all the steps, but did not solve the problem to the end - 10 points;
Completely solved the problem and got the correct answer - 12 points.

Section 4. Automatic Control Theory

Task 1 (1 point)

All roots of the transfer function $W(s)$ of an open-loop system are located in the left half-plane, and its Nyquist stability plot has the form:



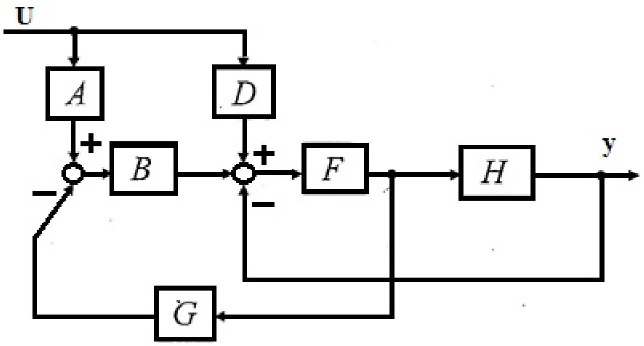
Then, according to the Nyquist criterion, the closed-loop system is
(a) asymptotically stable;
(b) unstable

Solution: The hodograph does not encircle the point (–1, j0). Since the transfer function of the open-loop system has no poles in the right half-plane, the closed-loop system is asymptotically stable.
Answer: (a)

Evaluation criterion: answer (a) – 1 point; (b) – 0 points.

Task 2 (6 points)

According to the block diagram, determine the transfer function W from the variable U to the variable y, using the rules of equivalent transformations of block diagrams.



Options: (a) $W = \dfrac{(AB+D)FH}{1+BFG}$; (b) $W = \dfrac{F(AB+D)}{1+FH+FBG}$; (c) $W = \dfrac{(AB+D)FH}{1+FH+BFG}$

Choose an answer:

Solution. Rearrangement of the left summing point and the block with transfer function *B*.
Answer: (c).

Evaluation criterion: answer (c) – 6 points; (a) or (b) – 0 points.

Task 3 (12 points)

Given a system

$$\begin{cases} \dot{x}_1 = -x_1^3 - 2x_2, \\ \dot{x}_2 = 2x_1 - x_2^3, \end{cases}$$

investigate the stability of the origin using the method of Lyapunov functions.

Answer options:

(a) the origin is Lyapunov stable;

(b) the origin is unstable;

(c) the origin is asymptotically stable;

(d) the origin is globally asymptotically stable.

Solution.

Define a Lyapunov function as a positive definite quadratic form with respect to variables x_1 and x_2:

$$V(x) = x^T P x; \quad x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix},$$

where $P = P^T > 0$ is a symmetric positive definite matrix. To find a suitable function $V > 0$, we will look for the matrix P in the form

$$P = \begin{bmatrix} a & b \\ b & 1 \end{bmatrix}.$$

According to the Sylvester criterion,

$$V > 0 \quad \Leftrightarrow \quad P > 0 \quad \Leftrightarrow \quad \begin{cases} a > 0, \\ a - b^2 > 0. \end{cases} \tag{1}$$

Since $V(x_1, x_2) = ax_1^2 + 2bx_1x_2 + x_2^2$, then

$$\dot{V} = \frac{\partial V}{\partial x_1}\dot{x}_1 + \frac{\partial V}{\partial x_2}\dot{x}_2 = (2ax_1 + 2bx_2)(-x_1^3 - 2x_2) + (2bx_1 + 2x_2)(2x_1 - x_2^3) =$$

$$= -2ax_1^4 - 2x_2^4 + 4(1-a)x_1x_2 + 2b(2x_1^2 - 2x_2^2 - x_1^3x_2 - x_1x_2^3).$$

To ensure $\dot{V} < 0$, it suffices to take $a = 1$ and $b = 0$. Then conditions (1) are also satisfied.

Thus, $V = x_1^2 + x_2^2$ is a positive definite function, and $\dot{V} = -2x_1^4 - 2x_2^4$ is a negative definite function. Therefore, by virtue of Lyapunov's second theorem, the origin is asymptotically stable. Moreover, since $V(x) \to \infty$ for $\|x\| \to \infty$, the origin is globally asymptotically stable.

Answer: (d) – 12 points, (c) is allowed – 10 points.

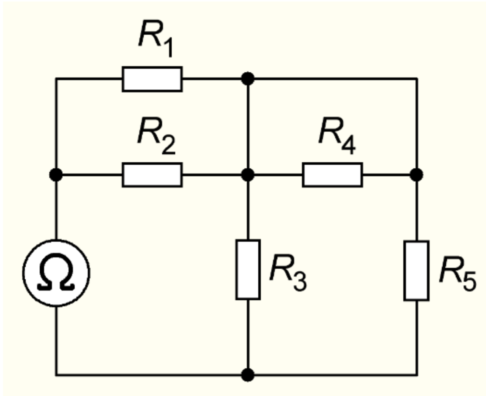
Evaluation criterions:

1. A suitable Lyapunov function is found: 4 points.
2. An expression is found for the derivative of the Lyapunov function: 6 points.
3. The sign of the derivative is provided opposite to the sign of the Lyapunov function: 8 points.
4. A conclusion is made about the asymptotic stability [answer (c)]: 10 points.
5. A conclusion is made about the global asymptotic stability [answer (d)]: 12 points.

Section 5. Electrotechnics

Task 1 (1 point)

A DC circuit diagram is given. Determine the ohmmeter reading if $R_1 = 6\ \Omega$, $R_2 = 4\ \Omega$, $R_3 = 6\ \Omega$, $R_4 = 3\ \Omega$, $R_5 = 3\ \Omega$.

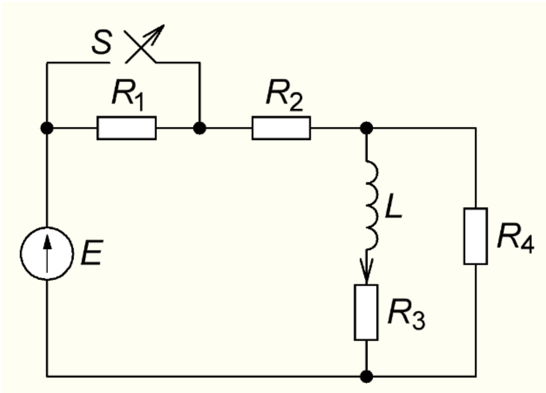


A) 22
B) 2.4
C) 4.4
D) 5.4
E) 1.09

Correct answer: C

Task 2 (1 point)

The circuit diagram is given. Source voltage $E = const$. Choose one possible solution from the suggested ones for the current function $i_L(t)$ after opening the ideal key $"S"$.

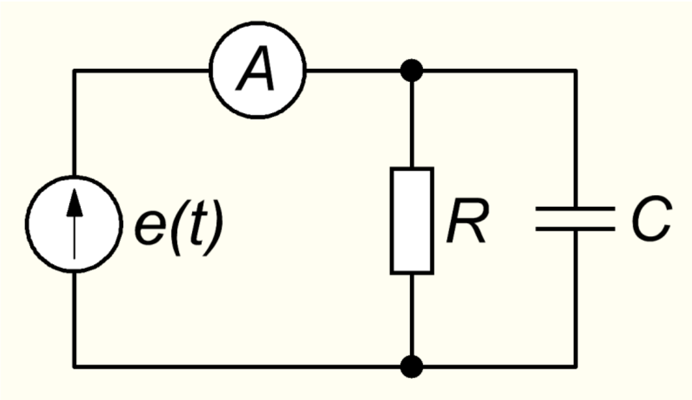


A) $i_L(t) = 4 + 2 \cdot e^{-t}$
B) $i_L(t) = 4 + 2 \cdot e^{t}$
C) $i_L(t) = 2 \cdot e^{-t}$
D) $i_L(t) = 4 - 2 \cdot e^{-t}$
E) $i_L(t) = 4 - 4 \cdot e^{-t}$

Correct answer: A

Task 3 (6 points)

The scheme of the *RC* circuit in the steady-state sinusoidal mode is given, source voltage $e(t) = 10 \cdot \cos(20 \cdot t - 90°)\,,V;\; R = 10\ \Omega;\; C = 2.5\ mF.$
Determine the reading of the ideal ammeter I_A.

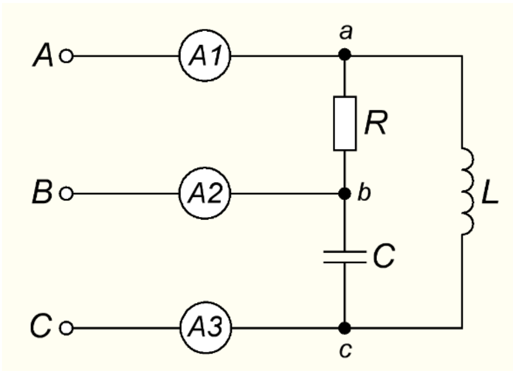


Correct answer: $I_A = 0.79\ A$

Task 4 (12 points)

The circuit diagram is given. The three–phase power supply is symmetrical, the order of the phases is straight (*ABC*).

Line voltage of the power supply $U_{Line} = 220\sqrt{3}\ V$. Determine the readings of all ideal ammeters $I_{A1} - I_{A3}$, if $R = 10\ \Omega$; $|Z_L| = 10\ \Omega$; $|Z_C| = 10\ \Omega$.



Solution of task 4:

Linear voltage complexes:

$\dot{U}_{AB} = U_{Line} \cdot e^{j\cdot 120°} = 220\sqrt{3} \cdot e^{j\cdot 120°}$;

$\dot{U}_{BC} = U_{Line} \cdot e^{j\cdot 0°} = 220\sqrt{3}$;

$\dot{U}_{CA} = U_{Line} \cdot e^{-j\cdot 120°} = 220\sqrt{3} \cdot e^{-j\cdot 120°}$;

Phase resistances for load:

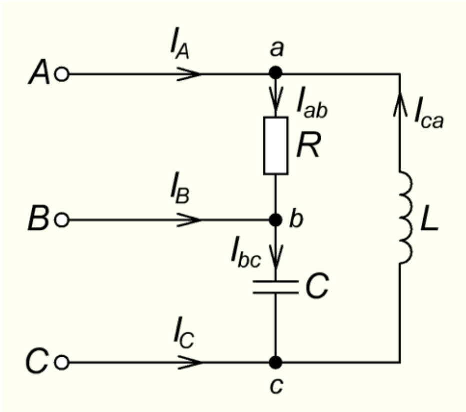
$Z_{ab} = Z_R = R, Z_{bc} = Z_C = -j \cdot |Z_C|, Z_{ca} = Z_L = j \cdot |Z_L|$;

Complexes of phase currents for the load (using Ohm's law):

$\dot{I}_{ab} = \frac{\dot{U}_{AB}}{Z_{ab}} = \frac{\dot{U}_{AB}}{R} = \frac{220\sqrt{3}\cdot e^{j\cdot 120°}}{10} = -19.053 + j \cdot 33$;

$\dot{I}_{bc} = \frac{\dot{U}_{BC}}{Z_{bc}} = \frac{\dot{U}_{BC}}{-j\cdot|Z_C|} = \frac{220\sqrt{3}}{-j\cdot 10} = j \cdot 38.105$;

$\dot{I}_{ca} = \frac{\dot{U}_{CA}}{Z_{ca}} = \frac{\dot{U}_{CA}}{j\cdot|Z_L|} = \frac{220\sqrt{3}\cdot e^{-j\cdot 120°}}{j\cdot 10} = -33 + j \cdot 19.053$;



Complexes of linear currents (using Kirchhoff 's 1st law):

$\dot{I}_A = \dot{I}_{ab} - \dot{I}_{ca} = 13.947 + j \cdot 13.947;$

$\dot{I}_B = \dot{I}_{bc} - \dot{I}_{ab} = 19.053 + j \cdot 5.105;$

$\dot{I}_C = \dot{I}_{ca} - \dot{I}_{bc} = -33 - j \cdot 19.052;$

Readings of ideal ammeters (answer):

$I_{A1} = |\dot{I}_A| = 13.947\sqrt{2} = 19.724$ A;

$I_{A2} = |\dot{I}_B| = \sqrt{(19.053)^2 + (5.105)^2} = 19.725$ A;

$I_{A3} = |\dot{I}_C| = \sqrt{(-33)^2 + (-19.052)^2} = 38.105$ A.

Evaluation criteria:

The complexes of linear and phase voltages of the power source are correctly presented and the load phase resistances are found - 4 points

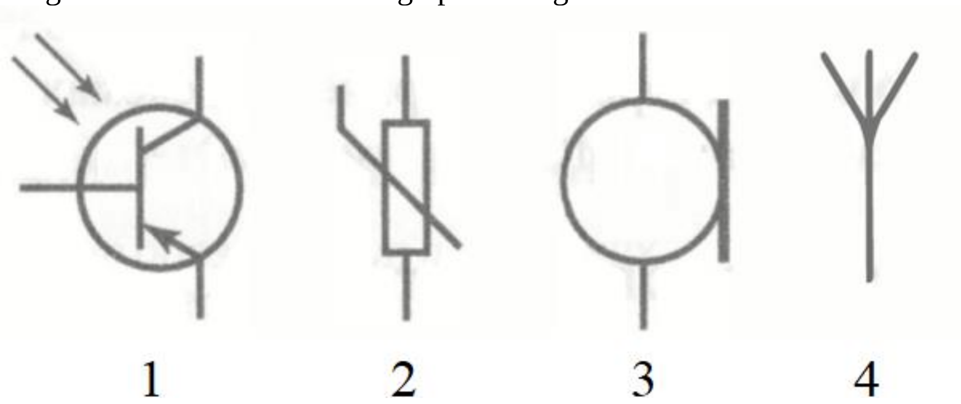
Correctly found the complexes of linear currents and the current complex of the neutral wire - 6 points

Correctly found the readings of ammeters - 12 points

Section 6. Electronics

Task 1 (1 point)

Which figure shows the conditional graphic designation of the thermistor?



Answer: 2

Task 2 (1 point)

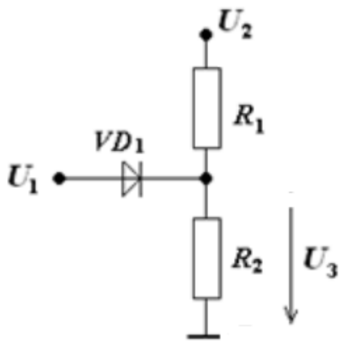
In a transistor connected according to a common emitter circuit, the base current has changed by 0.2 mA. How will the emitter current change (by how much?) if the gain factor α=0.96?

1. 1 mA
2. 2,4 mA
3. 4,8 mA
4. 5 mA
5. 5,2 mA

Answer: 4

Task 3 (6 points)

For the circuit shown in the figure, determine the voltage value U3, if it is known that R1 = R2 = 500 Ohms, U2 = 20V, U1 = 9V.



Answer: 10 V

Task 4 (6 points)

Determine the value of the ballast resistance of the voltage stabilizer shown in the figure 1, if U_{st}=12V, I_{stmin}=21mA, I_{stmax}=380mA, Input voltage U_{min}=17V, U_{max}=23V, R_n=100kOhm.

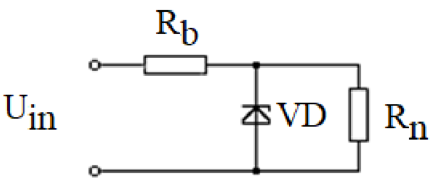


Figure 1

Answer: 25 Ohm