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світлотехніки та
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Electrical Engineering

LABORATORY WORKS

література

навчально–методична

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Схвалено й рекомендовано до друку методичною радою електромеханічного факультету Тернопільського національного технічного університету імені Івана Пулюя.
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Посібник складено відповідно до робочих програм курсів "Електротехніка, електроніка та основи МПТ", "Електротехніка в будівництві", "Теорія електричних та магнітних кіл".

LABORATORY WORK 1
Investigation
of energy transfer from source to consumer

<u>The purpose of the work</u>. To investigate the energy transfer from source to consumer, electrical source operating modes and to learn practically how to determine the source parameters.

Homework

At given voltage V, load resistance R, and efficiency factor η of the circuit on fig.1.8 to define source internal resistance R_0 and electromotive force E, source and consumer powers P_E, P_R. To calculate the efficiency factor when the load will be $R/10$. Tasks variants are listed in the table 1.1.
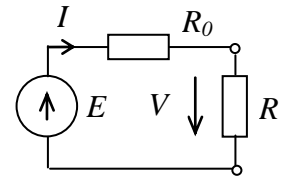

Fig. 1.8

Table 1.1

Var	1	2	3	4	5	6	7	8	9	10
η	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
R, Ω	51	62	73	84	95	106	117	128	139	150
V, V	110	120	130	140	150	160	170	180	190	100

Elements of laboratory settings

Laboratory settings consist of the power supply *БП*4822−2, clamps terminal, board 5, measuring devices.

The elements of the board 5: variable resistors $R_{ЛГ}$ «Грубо», $R_{ЛТ}$ «Точно», R_C − switch of the resistors $R_2 \div R_{10}$.

Measuring devices: $PV(P\Omega)$ − multimeter *Щ*4300 to measure voltage, options: $<->$, $<V>$, $<200\ V>$; to measure resistance, options: $<->$, $<R>$, $<2\ к\Omega>$; PmA − milliamperemeter *Э*536, limit of measuring $<100\ mA>$. The way of measuring devices placement is shown in fig. 1.9.

The work execution order

1. Connect the multimeter $P\Omega$ to clamps 3–4 and by using the switch R_C measure the resistances $R_2 \div R_{10}$. Write down the results to the table 1.2.
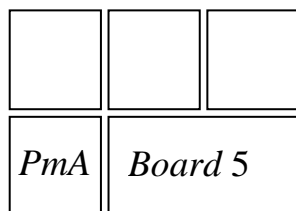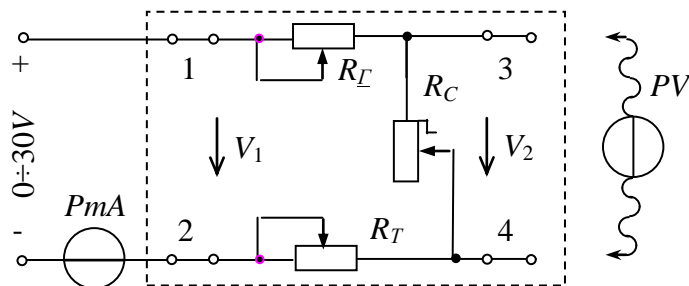

Fig. 1.9

Fig. 1.10

2. Connect the multimeter $P\Omega$ to clamps 1–2, short clamps 3–4 and set the line resistance $R_L = R_6$ by variable resistors $R_{ЛГ}$ «Грубо», $R_{ЛТ}$ «Точно».

3. Collect the circuit (fig. 1.10) and connect it to the clamps $<->$ $<0 \div 30\,V>$. Place *LATR* switch in position $<->$, $<0 \div 30\,V>$.

4. Short the clamps 3–4 and set the short circuit current $I_{sc}=100\,mA$. Write down the results of measuring to the table 1.2 item sc. Open the clamps 3–4 and measure the open circuit voltage. Write down the results of measuring to the table 1.2 item oc.

5. Set the voltage across clamps 1–2 $V_1=V_{1oc}$ and maintaining it constant during the experiment ($V_1=const$), change the resistance R_C turning it from 2 to 10 positions. Write down the results of measuring to the table 1.2, items 2-10.

6. Calculate (table 1.2): the consumer resistances $R_c=V_2/I$, the voltage drops $\Delta V=V_1-V_2$, the input power $P_1=V_1 I$, the output power $P_2=V_2 I$, the power losses $\Delta P=P_1-P_2$, the efficiency factor $\eta=P_2/P_1$. Write down the results of calculations to the table 1.2.

7. Define electromotive force $E=V_{1oc}$, the source internal resistance $R_0=(V_{1oc}-V_{1sc})/I_{sc}$ and the line resistance $R_L=V_{1sc}/I_{sc}$.

8. Determine the current source parameters J, G_0 for known voltage source parameters E, R_0. Draw the current source and the voltage source substitutional schemes.

Table 1.2.

№	Measurements				Calculations					
	R_C, Ω	V_1, V	I, mA	V_2, V	R_C, Ω	ΔV, V	P_1, W	P_2, W	ΔP, W	η
sc										
oc										
2										
3										
4										
5										
6										
7										
8										
9										
10										

9. Draw graphs: $V_1(I)$, $V_2(I)$, $\Delta V(I)$ and $P_1(I)$, $P_2(I)$, $\Delta P(I)$, $\eta(I)$ by using the table 1.2

Make conclusions about electrical source working regimes, the methods of determining the source parameters, the value of losses, the efficiency factor and how the source output voltage change when the load increase.

Report on the work

The name and the purpose of the work. Homework – the calculation of the circuit. The schematic diagram of the investigated circuit (fig 1.10). The table 1.2.

The results of calculations of source parameters. The graphs. The conclusions.

Control questions

1. Give the definition of electrical circuit. Draw the simplest electrical circuit and mark the directions of electrical values in it. What are the main and the additional elements of the electrical circuit, what are their purposes?

2. Name and characterize the main circuit working regimes.

3. What devices do we call consumers? What parameter characterizes the measure of energy transfer?

4. Draw the consumer conditional designation and mark the directions of the electrical values in it. Write down the Ohm`s law and the power expression for the consumer.

5. What devices do we call the power sources? What parameter characterizes the ideal source?

6. Draw the power source conditional designation and mark the directions of electrical values in it. Write down the power expression for it.

7. How to choose the circuit current direction? What is the condition of generator working regime and consumer working regime of the electrical source?

8. What are the main parameters of the voltage source? What is the difference between real and ideal voltage source?

9. Draw the serial substitution scheme of electrical source. Write down the voltage source equation.

10. Draw the parallel substitution scheme of electrical source. Write down the current source equation.

11. How can we determine the voltage source parameters experimentally? Write down the relevant expressions.

12. Draw the external characteristics of real and ideal voltage source and current source.

13. Describe the work of electrical source in the voltage generator regime. What is the working regime condition?

14. Describe the work of electrical source in the current generator regime. What is the working regime condition?

15. Describe the agreed working regime of the electrical source. What is the working regime condition?

16. Write down the electrical source efficiency factor expression using the parameters of the source and consumer. Analyze the dependence between the source working regime and the efficiency factor.

LABORATORY WORK 2
Investigation
of mixed connection of resistive elements

The purpose of the work. To learn how to use Ohm's and Kirchhoff's laws to calculate the forked DC circuits. To compare experimental and calculated data, obtained during the investigation of linear DC circuits with mixed connection of

resistive elements.

Homework

To calculalate the current in a circle (fig. 2.16), if known the resistances of resistors R_2, R_3, R_4, R_5 and the maximum power P_n allocated to the resistor R_n in the unforked circuit. To define total current, input voltage and subcircuits voltages, branches currents, power of the sircuit and the powers of subcircuits. To write down the results to the table 2.2 item 1. Tasks variants are listed in the table 2.1.
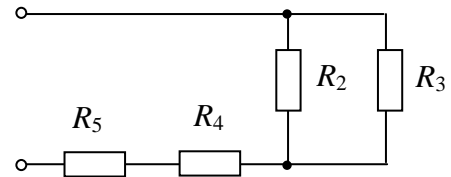

Fig.2.16

Table 2.1

Var №	1	2	3	4	5	6	7	8	9	10
P_n, W	7.1	7.2	7.3	7.4	7.5	7.1	7.2	7.3	7.4	7.5
R_2, Ω	150	155	160	165	170	165	155	160	165	170
R_3, Ω	204	186	232	197	203	205	195	181	203	228
R_4, Ω	198	193	228	198	196	197	199	208	191	231
R_5, Ω	198	212	235	193	201	202	164	211	192	229

Elements of laboratory settings

Laboratory settings consist of the power supply *БП4822 − 2*, clamps terminal, board 1, measuring devices.

The elements of the board 1: resistors R_1, R_2, R_3, R_4.

Measuring devices: *PV(PΩ)* – multimeter *Щ4300* to measure voltage, options: $<->$, $<V>$, $<200\ V>$; to measure resistance, options: $<->$, $<R>$, $<2\ к\Omega>$; *PA* – ammeters *Э536*, limit of measuring $<0.5\ A>$; *PW* – wattmeter for measuring power, limit of measuring: $<75\,V/0.5\,A>$. The way of measuring devices placement is shown in fig. 2.17.
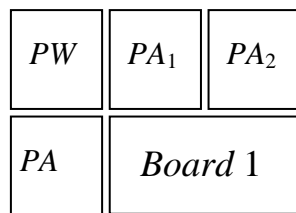

Fig. 2.17

Fig. 2.18
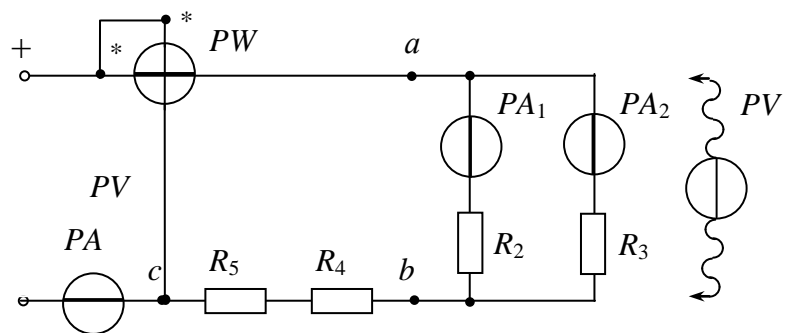
The work execution order

1. To collect the circuit (fig. 2.18) and connect it to the clamps $<->$ $<0 \div 120\ V>$. To place *LATR* switch in position $<->, <0 \div 120\ V>$.

2. To investigate the circuit with mixed connection of resistors (fig. 2.18). To set the input voltage given by tutor ($80 \le V \le 100\,V$). To write down the results to the table 2.2 item 2.

Table 2.2

6

	Measurements									Calculation	
№	V, V	V_{23}, V	V_{45}, V	V_4, V	V_5, V	I, A	I_2, A	I_3, A	P, W	P_{23}, W	P_{45}, W
1											
2											

To verify the results for the balance of power: $P = P_{23} + P_{45}$.

3. To investigate the circuit with parallel connection of resistors R_2, R_3. To short the series subcircuit R_4, R_5 (points b, c fig. 2.18). To set the input voltage given by tutor ($14 \leq V \leq 18\,V$).To write down the results to the table 2.3.

Table 2.3

	Measurements					Calculations		
№	V_{23}, V	I, A	I_2, A	I_3, A	P, W	R_2, Ω	R_3, Ω	R_{23}, Ω
1								

To verify the results for the first Kirchhoff's law: $I = I_2 + I_3$. To calculate the resistances of resistors R_2, R_3 and the equivalent resistance of a parallel connection R_{23}.

4. To investigate the circuit serial connection of resistors R_4, R_5. To shorten the parallel subcircuit R_2 R_3 (points a, b fig. 2.18). To set the circuit current given by tutor ($170 \leq I \leq 200\,mA$). To write down the results to the table 2.4.

Table 2.4

	Measurements					Calculations		
№	I, mA	V_{45}, V	V_4, V	V_5, V	P, W	R_4, Ω	R_5, Ω	R_{45}, Ω
1								

To verify the results for the second Kirchhoff's law: $V_{45} = V_4 + V_5$. To calculate the resistances of resistors R_4, R_5 and the equivalent resistance of a series R_{45}.

5. To draw the circuit of current divider $R_2 R_3$. To define analytically currents I_2, I_3 at given current I (table 2.3.).

6. To draw the circuit of voltage divider $R_4 R_5$. To define analytically voltages V_4, V_5 at given voltage U_{45} (table 2.4.).

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 2.18). Tables 2.2, 2.3, 2.4. The schemes of circuits of current divider and voltage divider. The results of calculations. Conclusions.

Control questions

1. Which device is called a one-port network? To provide the examples of one-port networks. What one-port networks are called active, and what – passive?

2. Give the definition of branch, node and loop of the electrical circuit.

3. What types of the electrical connections in the circle are called simple? What is main difference the complex connection?

4. Write down the circuit electrical status equation consisting of three serially connected resistors and expression of equivalent resistance of this circuit.

5. Write down the circuit electrical status equation consisting of three parallel connected resistors and expression of equivalent conductivity of this circuit.

6. Write down the equivalent resistance of the circuit with mixed connected resistors (parallel-serial and serial-parallel).

7. What types of connections in the circuit are called complex?

8. Write down the expressions of the equivalent transformation of "delta" in „wye".

9. What is the essence of the method of simplification of electrical circuit?

10. To draw the circuit of voltage divider. Write down proper expressions for it.

11. To draw the circuit of current divider. Write down proper expressions for it.

LABORATORY WORK 3

Investigation

of resistor, inductance and capacitor in AC circuit

The purpose of the work is to define the parameters of resistor, inductance and capacitors in AC circuit.

Homework

To calculate the impedance, input voltage, phase shift angle, active and reactive powers, coil quality factor in a circuit (fig. 3.9), at given current I, inductivity L, active resistance R. To write down the results to the table 3.3 line 1. Tasks variants are listed in the table 3.1.
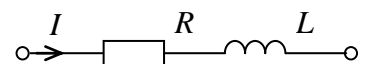

Рис. 3.10

Table 3.1.

Var.№	1	2	3	4	5	6	7	8	9	10
I,A	0.21	0.22	0.23	0.24	0.25	0.21	0.22	0.23	0.24	0.25
L, H	0.79	1.08	1.01	1.10	1.09	1.12	1.13	1.15	1.18	1.20
R, Ω	163	181	175	185	182	186	189	187	197	195

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 2, measuring devices.

The elements of the board 2 are capacitors C_1, C_2, C_3, resistor R, coil L.

Measuring devices are: $PV(P\Omega)$ – multimeter Ц4300 to measure voltage, options: $<\sim>$, $<V>$, $<200\ V>$; to measure resistance, options: $<->$, $<R>$, $<2\ \kappa\Omega>$; PA – amperemeter Э536, limit of measuring $<0.5\ A>$; PW – wattmeter for measuring power, limit of measuring: $<150\ V/0.5\ A>$. The way of measuring devices placement is shown in fig. 3.11.
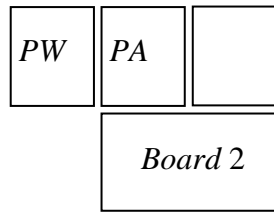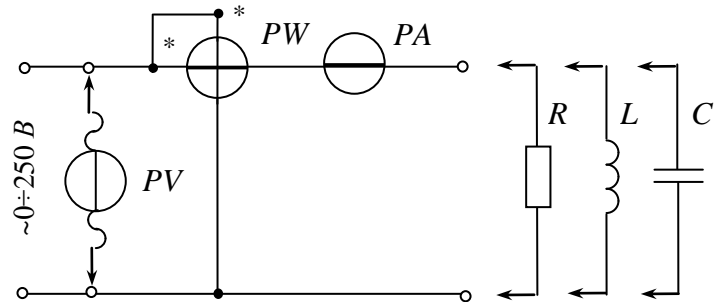

Fig. 3.10   Fig. 3.11.

The work execution order

1. To collect the circuit (fig. 3.11) and connect it to the clamps $<\sim>$ $<0 \div 250\ V>$. To place *LATR* switch in position $<\sim>$, $0 \div 250\ V$.

2. To investigate the circuit with resistor R. To set the input voltage as given by tutor ($100 \le V \le 120\ V$). To write down the results to the table 3.2.

Table 3.2

Measurements				Calculations			
$R,$ Ω	$V,$ V	$I,$ A	$P,$ W	$R,$ Ω	G mSm	$cos\varphi$	$\varphi,$ deg

Calculate (table 3.2): active resistance $R = V/I$, conductivity $G = I/V$, phase shift angle φ, power factor $cos\varphi = P/VI$. Draw the vector diagram.

3. Investigate the circuit with coil L without core. Set the input voltage as given by tutor ($70 \le U \le 80\ V$). Write down the results to the table 3.3, line 2.

Table 3.3

	Measurements			Calculations						
№	$I,$ A	$V,$ V	$P,$ W	$Z,$ Ω	$R,$ Ω	$X,$ Ω	$\varphi,$ deg	$Q,$ VAr	$L,$ H	d
1										
2										

Calculate and put in table 3.3: coil impedance $Z = V/I$, active resistance R ($P = RI^2$) and reactance X ($Z = \sqrt{R^2 + X^2}$), phase shift angle φ ($tg\varphi = X/R$), reactive power $Q = XI^2$, inductance L ($X = \omega L$) and coil quality factor $d = Q/P$. Draw the vector diagram.

4. Investigate the circuit with capacitances: C_1, C_{12} serial, C_{12} parallel. Set the input voltage as given by tutor ($60 \le U \le 90\ V$). Write down the results to the

table 3.4.

Table 3.4

Measurements				Calculations						
№	V, V	I, A	P, W	Y, mSm	G, mSm	B, mSm	C, µF	Q, VAr	tgδ	φ, deg
1										
2										
3										

Calculate and put in table 3.4: admittance Y ($I = YV$), active G ($P = GV^2$) and reactive B ($Y = \sqrt{G^2 + B^2}$) conductivities, capacity C ($B = \omega C$), reactive power $Q = BV^2$, dissipation factor $tg\delta = P / Q$, phase shift angle φ ($\varphi = 90 - \delta$). Draw the vector diagram.

5. Draw the coil parallel substitution scheme. Calculate the conductance G' and inductance L' of parallel substitution scheme according to the parameters of serial substitution scheme R, X (table 3.3, item 2), using formulas $G' = R / Z^2$, $B' = X / Z^2$, $L' = B' / \omega$.

6. Draw the capacitor serial substitution scheme. Calculate the resistance R' and capacitance C' of serial substitution scheme according to the parameters of parallel substitution scheme G, B (table 3.4, line 2), using formulas $R' = G / Y^2$, $X' = B / Y^2$, $C' = B / \omega$.

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 3.11). Tables 3.2, 3.3, 3.4. The substitutional schemes of coil and capacitor and calculations of their parameters. Vector diagrams for resistance, coil and capacitor. Conclusions.

Control questions

1. Give a definition of alternating current. What's the period of alternating current?
2. What are the parameters of alternating current?
3. Explain what is it instantaneous value of alternating current and phase shift angle.
4. Explain what is it the effective value of alternating current and its connection with the amplitude value.
5. Write down the amplitude-phase relationship for R-element.
6. Write down the amplitude-phase relationship for L-element.
7. Write down the amplitude-phase relationship for C- element.
8. Draw vector diagrams for resistive, inductive and capacitive element.
9. Write down the expressions of reactance, conductivity and power for inductive element.
10. Write down the expressions of reactance, conductivity and power for capacitive element.
11. Explain the physical essense of the coil substitutional schemes elements

and draw these schemes.

12. Explain the physical essense of the capacitor substitutional schemes elements and draw these schemes.

13. Write down the expressions for the coil quality factor and capacitor dissipation factor.

LABORATORY WORK 4
Investigation
of coil and capacitor serial connection

The purpose of the work is to investigate serial connection of coil and capacitor and the voltage resonance in AC circuit.

Homework

Calculalate the input voltage, coil voltage, capacitor voltage active and reactive powers, the

Fig. 4.9

resistances of the elements and phase shift angles (fig. 4.9), at given current I, inductivity L, active resistance R, capacitance C. Write down the results to the table 4.2 line 1. Tasks variants are listed in the table 4.1.
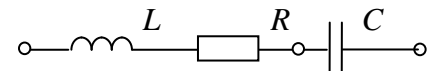
Table. 4.1

Var	1	2	3	4	5	6	7	8	9	10
I, mA	180	185	190	195	200	180	185	190	195	200
R, Ω	186	189	187	197	195	186	189	187	197	195
L, H	1.12	1.13	1.15	1.18	1.20	1.12	1.13	1.15	1.18	1.20
C, μF	3.92	3.76	3.78	3.86	3.87	6.15	6.33	6.02	6.51	6.34

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 2, measuring devices.

The elements of the board 2 are capacitors C_1, C_2, C_3, coil L.

Measuring devices are: $PV(\,P\Omega\,)-$ multimeter $Щ4300$ to measure voltage,

Fig. 4.10
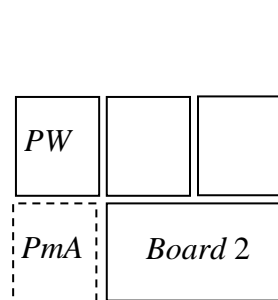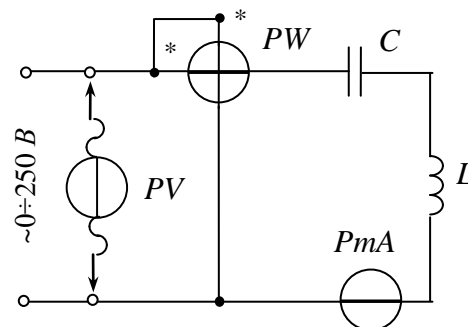
Fig. 4.11

options: $<\sim>$, $<V>$, $<200\ V>$; $PA-$ amperemeter $Э536$, limit of measuring $<0.5\,A>$; PW – wattmeter for measuring power, limit of measuring: $<150\,V/0.5\,A>$. The way of measuring devices placement is shown in fig. 4.10.

The work execution order

1. Collect the circuit (fig. 4.11) and connect it to the clamps $<\sim>$ $<0 \div 250\,V>$. Place *LATR* switch in position $<\sim>$, $0 \div 250\,V$.

2. Investigate the circuit with the serial connection of coil without core and capacitor C_2. Set the circuit current as given by tutor ($180 \leq U \leq 200\,mA$). Write down the results to the table 4.2, line 2.

3. Investigate the circuit with the serial connection of coil without core and capacitors C_{23} (parallel connection of C_2 and C_3). Set the circuit current as given by tutor ($180 \leq V \leq 200\,mA$). Write down the results to the table 4.2, line 3.

Table 4.2

№	Measurements					Calculations							
	I, mA	V, V	V_C, V	V_L, V	P, W	Z, Ω	R, Ω	Z_L, Ω	X_L, Ω	φ_L, deg	X_C, Ω	X, Ω	φ deg
1													
2													
3													

Calculate and put in table 4.2: circuit impedance $Z = V/I$, coil impedance $Z_L = V_L/I$, active resistance R ($P = RI^2$) and coil reactance X_L ($Z_L = \sqrt{R^2 + X_L^2}$), coil phase shift angle φ_L ($tg\varphi_L = (X_L/R)$), capacitor reactance $X_C = V_C/I$, circuit reactance $X = X_L - X_C$, circuit phase shift angle φ.

4. Investigate the circuit with serial connection of coil and capacitor C_1. Set the input voltage as given by tutor ($50 \leq V \leq 70\,V$):

− coil without a core (minimal inductivity) and write down the results to the table 4.3, line 1;

− coil with a core (maximum inductivity) and write down the results to the table 4.3, line 2;

− in resonance regime (moving the core in the coil till the current will be maximum (the indication of resonance) and write down the results to the table 4.3, line 3.

Table 4.3

№	Measurements					Calculations							
	V, V	I, mA	V_C, V	V_L, V	P, W	Z, Ω	R, Ω	Z_L, Ω	X_L, Ω	φ_L, deg	X_C, Ω	X, Ω	φ deg
1													
2													
3													

Calculate and put in table 4.3: circuit impedance $Z = V/I$, coil impedance $Z_L = V_L/I$, active resistance R ($P = RI^2$) and coil reactance X_L ($Z_L = \sqrt{R^2 + X_L^2}$), coil phase shift angle φ_L ($tg\varphi_L = (X_L/R)$), capacitor reactance $X_C = V_C/I$, circuit reactance $X = X_L - X_C$, circuit phase shift angle φ ($tg\varphi = (X/R)$). Draw three vector diagrams using the data from table 4.3. Losses in capacitors are negligible,

that's why the capacitor phase shift angle will be $\varphi_C = -\pi/2$.

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 4.11). Tables 4.2, 4.3. The substitutional schemes of coil and capacitor and calculations of their parameters. The vector diagrams. Conclusions.

Control questions

1. Write down the electrical status equation for the circuit with serial connection of *RLC*-elements in vector form and draw the vector diagram for this circuit.

2. Draw resistances calculated triangle for the circuit with serial connection of *RLC*-elements and write down the corresponding relations for it.

3. Explain what is it the active and reactive voltage constituents.

4. Draw powers calculated triangle for the circuit with serial connection of *RLC*-elements and write down the corresponding relations for it.

5. Give the definition of voltage resonance, write down the resonance condition and explain the resonance indication.

6. Give the definition of voltage resonance frequency, circuit wave resistance and explain the ways of resonance reaching.

7. What is the impedance, phase shift factor and total power of the voltage resonance circuit? How voltage resonance is being applied?

8. Draw the voltage resonance circuit frequency characteristics.

9. Draw the resonance curve for the voltage resonance circuit. Explain why the current at resonance is the biggest.

LABORATORY WORK 5
Investigation
of coil and capacitor parallel connection

<u>The purpose of the work</u> is to investigate parallel connection of coil and capacitor and the current resonance in AC circuit.

Homework

Calculalate the current in the unforked subcircuit, coil current I_L, capacitor current I_C, active and reactive powers, the conductivities of the elements and phase shift angles in the circuit (fig. 5.9), at given voltage V, inductivity L, active resistance R, capacitances C. Write down the results to the table 5.2 line 1. Tasks variants are listed in the table 5.1.
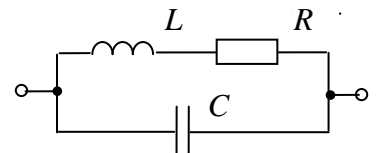

Fig.5.9

Table 5.1

Var	1	2	3	4	5	6	7	8	9	10
V, V	50	55	60	65	70	50	55	60	65	70

R, Ω	186	189	187	197	195	186	189	187	197	195
L, H	1.12	1.13	1.15	1.18	1.20	1.12	1.13	1.15	1.18	1.20
$C, \mu F$	3.99	3.77	3.83	3.82	3.79	4.17	4.15	4.12	4.17	4.11

Elements of laboratory settings

Laboratory settings consist of the power supply *БП*4822 − 2, clamps terminal, board 2, measuring devices.
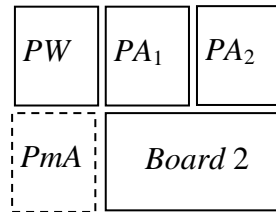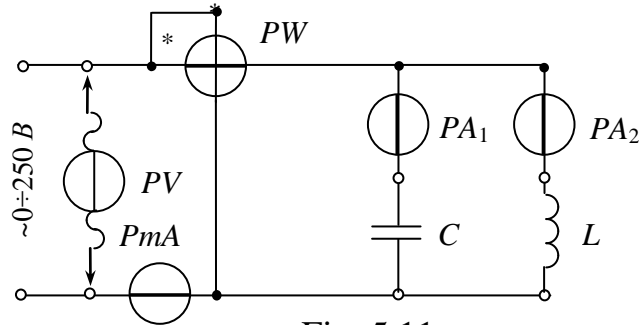

Fig. 5.10

Fig. 5.11

The elements of the board 2 are capacitors C_1, C_2, C_3, coil L.

Measuring devices are: PV − multimeter *Щ*4300 to measure voltage, options: $< \sim >$, $< V >$, $< 200\ V >$; PA − ammeters *Э*536, limit of measuring $< 0.5\ A >$; PmA − miliamperemeter, limit of measuring $< 200\ mA >$, PW − wattmeter for measuring power, limit of measuring: $< 150\ V / 0.5\ A >$. The way of measuring devices placement is shown in fig. 5.10.

The work execution order

1. To collect the circuit (fig. 5.11) and connect it to the clamps $< \sim >$ $< 0 \div 250\ V >$. To place *LATR* switch in the position $< \sim >$, $0 \div 250\ V$.

2. To investigate the circuit with parallel connection of coil without a core and capacitor C_1. To set the input voltage as given by tutor ($50 \le U \le 70\ V$). To write down the results to the table 5.2, line 2.

3. To investigate the circuit with parallel connection of coil without a core and capacitors C_{13} (parallel connection of C_1 and C_3). To set the input voltage as given by tutor ($50 \le U \le 70\ V$). To write down the results to the table 5.2, line 3.

Table 5.2

№	Measurements					Calculations						
	$V,$ V	$I,$ mA	$I_C,$ A	$I_L,$ A	$P,$ W	$G,$ mSm	$B_L,$ mSm	$Y_L,$ mSm	$\varphi_L,$ deg	$B_C,$ mSm	$B,$ mSm	$\varphi,$ deg
1												
2												
3												

Calculate and put in table 5.2: coil admittance $Y_L = I_L / V$, coil active $G = R \cdot Y_L^2$ ($R = P / I_L^2$) and reactive B_L ($Y_L = \sqrt{G_L^2 + B_L^2}$) conductivities, coil phase shift angle φ_L ($tg\varphi_L = (-B_L / G)$); capacitor reactive conductivity $B_C = I_C / V$, circuit reactive

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conductivity $B = B_C - B_L$, circuit phase shift angle φ ($tg\varphi = (B/G)$).

4. To investigate the circuit with parallel connection of coil and capacitor C_2. To set the input voltage as given by tutor ($90 \leq V \leq 110\,V$):

– coil without a core (minimal inductivity) and write down the results to the table 5.3, line 1;

– coil with a core (maximum inductivity) and write down the results to the table 5.3, line 2;

– in resonance regime (by moving the core in the coil till the current will be minimum – what is an indication of resonance) and write down the results to the table 5.3, line 3.

Table 5.3

№	Measurements					Calculations						
	V, V	I, mA	I_L, A	I_C, A	P, W	G, mSm	B_L, mSm	Y_L, mSm	B_C, mSm	B, mSm	φ_L, deg	φ, deg
1												
2												
3												

Calculate and put in table 5.3: coil admittance $Y_L = I_L / V$, coil active $G = R \cdot Y_L^2$ ($R = P / I_L^2$), reactive B_L ($Y_L = \sqrt{G_L^2 + B_L^2}$) conductivities, capacitor reactive conductivity $B_C = I_C / V$, circuit reactive conductivity $B = B_C - B_L$, coil phase shift angle φ_L ($tg\varphi_L = (B_L / G)$), circuit phase shift angle φ ($tg\varphi = (B/G)$). Draw three vector diagrams using the data from table 5.3. Losses in capacitors are negligible, that's why the capacitor phase shift angle should be $\varphi_C = -\pi / 2$.

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 5.11). Tables 5.2, 5.3. The vector diagrams. Conclusions.

Control questions

1. Write down the electrical status equation for the circuit with parallel connection of *RLC*-elements in vector form and draw the vector diagram for this circuit.

2. Draw conductivities calculated triangle for the circuit with parallel connection of *RLC*-elements and write down the corresponding expressions for it.

3. Explain what is it the active and reactive current constituents.

4. Draw powers calculated triangle for the circuit with parallel connection of *RLC*-elements and write down the corresponding expressions for it.

5. Give the definition of current resonance, write down the resonance condition and explain the resonance indication.

6. Give the definition of voltage resonance frequency, circuit wave resistance and explain the ways of resonance reaching.

7. What is the admittance of the circuit, phase shift factor and full power of the current resonance circuit? How current resonance is applied?

8. Draw the current resonance circuit frequency and phase characteristics.

9. Draw the resonance curves of currents of the current resonance circuit. Explain why the current at resonance is at minimum.

LABORATORY WORK 6
Investigation
of „wye" connection of three-phase circuit

The purpose of the work is to investigate „wye" connection of three phases circuit with balanced and non-balanced loading, to investigate the role of the neutral.

Homework

Write down the phase voltages in complex form for the three-phase power source with linear voltage $V_L = 220\,V$. To calculate phase active resistances, phase complex currents, neutral complex current for the three-phase consumer (fig.6.7), at given phase powers. Tasks variants are listed in the table 6.1.
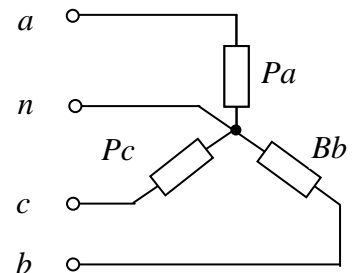
Fig. 6.7

Table. 6.1

Var	1	2	3	4	5	6	7	8	9	10
Pa, W	20	40	60	80	100	20	40	60	80	100
Pb, W	40	60	80	100	20	40	60	80	100	20
Pc, W	60	80	100	20	40	60	80	100	20	40

Elements of laboratory settings

Laboratory settings consist of the power supply *БП* $4822 - 2$, clamps terminal, board 3, measuring devices.

The elements of the board 2 are: consumers (lamps $L1 - L9$ ($220\,V, 25\,W$)),
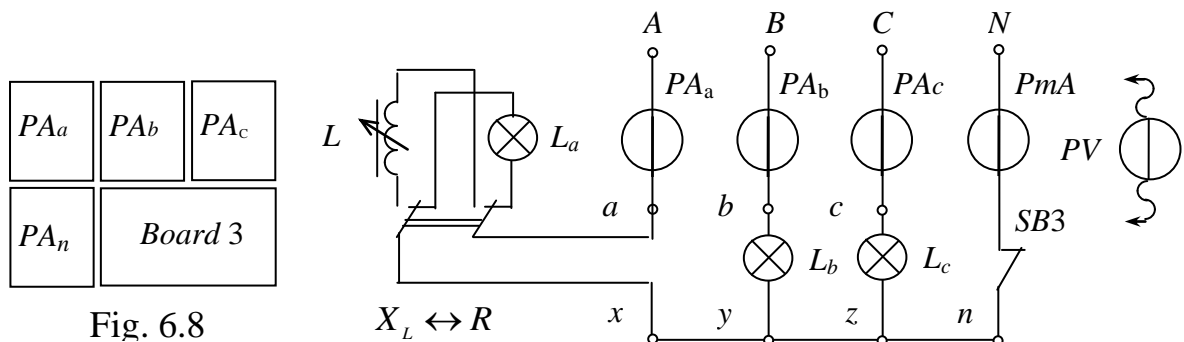
Fig. 6.8

Fig.6.9

phase switches $SB1$, $SB2$, neutral switch $SB3$, coil, switch « $X_L \leftrightarrow R$ ».

Measuring devices are: $PV(\,P\Omega\,)$ – multimeter *Ц* 4300 to measure voltage, options: $<\sim>$, $<V>$, $<200\,V>$; PA – ammeters *Э*536, limit of measuring $<0.5\,A>$; PmA – miliamperemeter, limit of measuring $<200\,mA>$. The way of

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measuring devices placement is shown in fig. 6.8.

The work execution order

1. To collect the circuit (fig. 6.9) and connect it to the clamps *A, B, C, N* of the three-phase voltage power source $< 3 \sim 220\ V >$.

2. To investigate the circuit (fig. 6.9) with balanced loading $R_a = R_b = R_c = R_p$ (*SB*1 and *SB*2 closed, switch «$L \leftrightarrow \varPi$» in position $\varPi$) with neutral (*SB*3 closed) and without neutral (*SB*3 open). To write down the results to the table 6.2.

Draw the vector diagram of currents using the data from table 6.2, line 1.

Table 6.2

№	Measurements										
	V_A,	V_B,	V_C,	V_a,	V_b,	V_c,	I_a,	I_b,	I_c,	V_{nN},	I_n,
	V	V	V	V	V	V	A	A	A	V	mA
1											
2											

3. To investigate the circuit (fig. 6.9) with non-balanced loading $R_a \neq R_b \neq R_c$ (*SB*1 and *SB*2 are open, switch «$L \leftrightarrow \varPi$» in position $\varPi$) with neutral (*SB*3 closed) and without neutral (*SB*3 open). To write down the results to the table 6.3.

Draw the vector diagram of currents using the data from table 6.3, line 1.

Table 6.3

№	Measurements										
	V_A,	V_B,	V_C,	V_a,	V_b,	V_c,	I_a,	I_b,	I_c,	V_{nN},	I_n,
	V	V	V	V	V	V	A	A	A	V	mA
1											
2											

4. To investigate the circuit (fig. 6.9) with balanced loading $I_A = I_B = I_C$ (*SB*2 closed, switch «$L \leftrightarrow \varPi$» in position L) with neutral (*SB*3 closed) and without neutral (*SB*3 open). In order to balance the phase currents it is necessary to move the core in the coil. To write down the results to the table 6.4.

Table 6.4

№	Measurements										
	V_A,	V_B,	V_C,	V_a,	V_b,	V_c,	I_a,	I_b,	I_c,	V_{nN},	I_n,
	V	V	V	V	V	V	A	A	A	V	mA
1											
2											

Draw the vector diagram of currents using the data from table 16.4, line 1.

Report on work

The name and purpose of work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 6.9). Tables 6.2, 6.3, 6.4. The vector diagrams. Conclusions.

1. Give the definition of three-phase electromotive force system. Explain how we can receive it. When the system will be balanced? Draw the vector diagram of three-phases electromotive forces.

2. Explain what is called the order of phase changing and how we can change it. What load we call balanced and write down the condition of balanced load.

3. Write down the expressions of instantaneous phases electromotive forces and their effective value complexes.

4. Explain the main types of source and consumer connection in three-phase system.

5. Write down the expressions of active, reactive and total power of three-phase system using phase voltages and currents and line voltages and currents.

6. Write down the expressions of active, reactive and total power of three-phase system using line voltages and currents.

7. Draw the three-phase source „wye" connection and mark the phases and line voltages and currents.

8. Write down the relationships between effective values of phase and line voltages and currents for „wye" connection.

9. Explain the neutral role in three-phase system. How can the current be defined in it?

10. Write down how we can define the complex line voltages for the known complex phase voltages for the consumers' „wye" connection.

11. Explain what voltage is called neutral bias voltage and how we can define it.

12. Draw the phase and line voltages for the consumers „wye" connection at vector diagram. What is the phase shift angle for them?

13. Explain how the three-phase circuit with non-balanced „wye" connected load can be calculated.

LABORATORY WORK 7

Investigation
of „DELTA" connection of three-phase circuit

The purpose of the work is to investigate „DELTA" connection of three phases circuit with balanced and non-balanced loading.

Homework

Write down the phase voltages in complex form for the three-phase power source with a linear voltage $V_L = 380\,V$. Three groups of consumers are connected to these sources. The consumers phase powers are: P_{ab}, P_{bc},
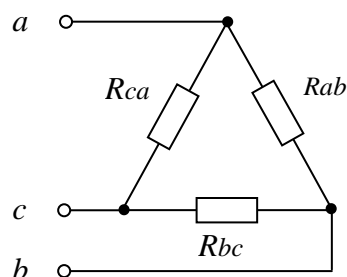
Fig. 7.3

P_{ca} (fig.7.3). Calculate phase resistances, phase complex currents. Define the power of the circuit.

Tasks variants are listed in the table 7.1.

Table 7.1

Var.	1	2	3	4	5	6	7	8	9	10
Pab, W	100	80	60	40	20	100	80	60	40	20
Pbc, W	20	100	80	60	40	20	100	80	60	40
Pca, W	40	20	100	80	60	40	20	100	80	60

Elements of laboratory settings

Laboratory settings consist of the power supply *БП* $4822 - 2$, clamps terminal, board 3, measuring devices.

The elements of the board 3 are: consumers (lamps $L1 - L9$ ($220\,V, 25\,W$)), phase switches $SB1$, $SB2$, neutral switch $SB3$, coil, switch « $X_L \leftrightarrow R$ ».

Measuring devices are: $PV(\,P\Omega\,)$ – multi-meter *Ц* 4300 to measure voltage, options: $<\sim>$, $<V>$, $<200\,V>$; PA –Ammeters *Э* 536, limit of measuring $<0.5\,A>$. The way of measuring devices placement is shown in fig. 7.4.
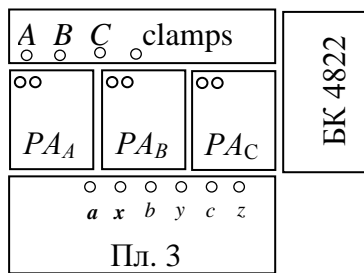

Fig. 7.4   Fig. 7.5

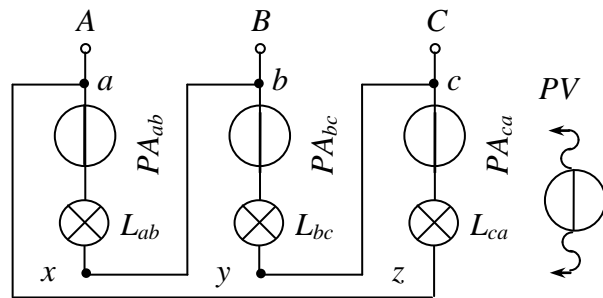### *The work execution order*

1. Collect the circuit (fig. 17.3) and connect it to the clamps $A,\,B,\,C$ of the three-phase voltage power source $<3 \sim 220\,V>$

2. Investigate the circuit (fig.7.5) with balanced loading ($SB1$ and $SB2$ closed, switch « $L \leftrightarrow Л$ » in position $Л$). Fill in the table 7.2 with results.
Draw the vector diagram of currents and voltages using the data from table 7.2.

Table 7.2

	Measuring					
	V_{ab}	V_{bc}	V_{ca}	I_{ab}	I_{bc}	I_{ca}
	V	V	V	A	A	A

3. Investigate the circuit (fig.7.5) with non-balanced loading ($SB1$ and $SB2$ opened, switch « $L \leftrightarrow Л$ » in position $Л$). Fill in the table 17.3 with results.
Draw the vector diagram of currents and voltages using the data from table 17.3.

Table 7.3

	Measuring					
	V_{ab}	V_{bc}	V_{ca}	I_{ab}	I_{bc}	I_{ca}

	V	V	V	A	A	A

4. Investigate the circuit (fig.7.5) with balanced loading (*SB* 1 and *SB* 2 closed, switch «*L* ↔ *Л*» in position *Л*) when the phase *ab* is cut (no wire between *x* and *b*). Write down the results to the table 7.4, line 1. Investigate the circuit (fig.7.5) with a non-balanced loading (*SB* 1 and *SB* 2 open, switch «*L* ↔ *Л*» in position *Л*) when the phase *ab* is cut (no wire between *x* and *b*). Fill in the line 2 of table 7.4 with results. Draw the vector diagrams of currents and voltages using the data from table 7.4.

Table 7.4

	Measuring					
	V_{ab} V	V_{bc} V	V_{ca} V	I_{ab} A	I_{bc} A	I_{ca} A

Report on work

The name and purpose of work. Homework – the calculation of the circuit. The schematic diagram of the investigated circuit (fig 7.5). The tables 7.2, 7.3, 7.4. The vector diagrams. The conclusions.

Control questions

1. Give the definition of three-phase electromotive force system. When the system is balanced?

2. Draw the vector diagram of three-phases electromotive forces.

3. Write down the expressions of instantaneous phases, electromotive forces and their effective value complexes.

4. Write down the expressions of active, reactive and total power of three-phase system using phase voltages and currents.

5. Draw the three-phase source DELTA connection and mark phase and line voltages.

6. Explain the main types of source and consumer connection in three-phase system.

7. Write down the relationships between effective values of phase and line voltages and currents for DELTA connection.

8. Write down how we can define the complex line currents for the known complex phase currents for the consumers DELTA connection.

9. Draw the phase and line currents for the consumers DELTA connection at vector diagram. What is the phase shift angle for them?

10. Explain how the three-phase circuit with DELTA connected load can be calculated.

LABORATORY WORK 8

Inductive coil with ferromagnetic core

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The purpose of the work is to investigate inductive coil with ferromagnetic core and adjustable nonmagnetic gap as well as its current-voltage characteristics.

Homework

To calculate magneto-motive force F, magnetic field tension H, magnetic flux Φ, magnetic resistance R_m, coil induction L for the coil with toroidal ferromagnetic core at given medial line magnetic circuit length l, cross-section area S, coil current I, number of winding turns w, steel relative magnetic permeability μ_r, vacuum magnetic permeability $\mu_0 = 4\pi \cdot 10^{-7}$. Tasks variants are listed in the table 8.1.

Table 8.1.

Var.№	1	2	3	4	5	6	7	8	9	10
I, A	0.5	0.7	1	1.2	1.4	1.6	1.8	2.	2.2	2.4
w	30	40	50	60	70	80	90	100	120	110
l, sm	20	19	18	17	16	15	14	12	11	10
S, sm^2	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4
μ_r	950	850	900	800	700	600	200	300	400	500

The work execution order
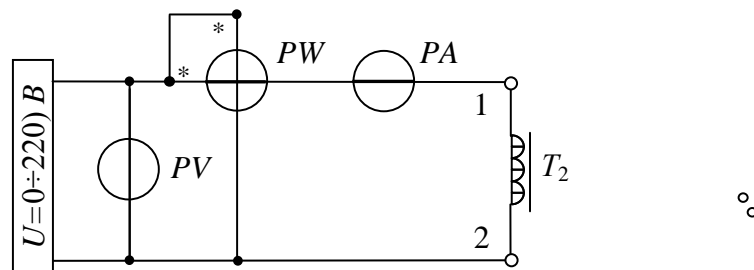
1. Collect the electrical circuit (fig. 8.11)

Fig. 8.11

PV – Volt-meter, PW – Watt-meter, PA – Ammeter.

2. Get down the set of inductive coil current-voltage characteristics $I(V)$ at different values of nonmagnetic gap δ $0 \le V \le 210V$ ($\Delta V = 35V$).

Fill in the table 8.2 with results and draw them as graphs $V(I)$.

Table 8.2

δ, mm	V, B	Measuring						
		0	35	70	105	140	175	210
0	I, mA							
1.2	I, mA							
2.4	I, mA							

3. Get the dependence of current and power from nonmagnetic gap δ, $0 \le \delta \le 2.4$ ($\Delta\delta = 0.4\,mm$) for voltage $V = 210V$.

Fill in the table 8.3 with results and draw the graphs $I(\delta)$, $Z(\delta)$ $Z = V_{NOM}/I$.

Table 8.3

δ, mm		0.0	0.4	0.8	1.2	1.6	2.0	2.4
Meas.	I, A							
Meas.	P, W							
Calc.	Z,							

4. Calculate the coil parameters for the gap δ and fill in the table 8.4 using the results from table 8.3:

– total power $S = V_{NOM} I$;

– magnetic losses $\Delta P_M = P - \Delta P_E$.

– power factor $\cos\varphi = P/S$;

– electrical losses $\Delta P_E = RI^2$ where $R = 46\Omega$;

Table 8.4

	Measuring			Calculation			
δ mm	V_{nom} V	I, A	P W	S VA	$\cos\varphi$	ΔP_e W	ΔP_m W

Report on work

The name and purpose of the work. The schematic diagram of the investigated circuit (fig.8.11). The tables 8.2, 8.3, 8.4. The characteristics graphs. Conclusions.

Control questions

1. Explain the principle of electromagnetic devices and the roles of their components.

2. State the law of electromagnetic induction. What affects the value and direction of the electromotive force?

3. State the law of electromagnetic force. What affects the value and direction of the electromagnetic force?

4. Write down full current law expression for the inhomogeneous magnetic circuit and explain the difference between the intensity and induction of magnetic field.

5. Draw a diagram of the electromagnetic induction coil with a core. What are the losses in the coil and the core?

6. What are the losses in ferromagnetic core and how they can be reduced?

7. Draw a coil series-parallel substitutional scheme and explain the physical meaning of its elements.

8. Write down the e.m.f. instantaneous and effective values expressions, induced by coil main and dissipation magnetic fluxes.

9. Write down coil electrical state equation and draw a vector diagram.

LABORATORY WORK 9
Transformer

The purpose of the work is to investigate the work of the transformer, define the basic parameters (characteristics) of the transformer by experiments of open and short circuit.

Table. 9.1

Var	1	2	3	4	5	6	7	8	9	10
S, VA	800	850	830	880	900	920	950	980	930	780
V_1, V	220	220	220	220	220	380	380	380	126	126
V_2,V	20	22	11	110	55	20	10	5	42	2
$cos\,\varphi_1$	0.7	0.75	0.8	0.73	0.82	0.72	0.71	0.81	0.85	0.83
η	0.9	0.8	0.85	0.95	0.83	0.87	0.93	0.78	0.75	0.78
$\underline{Z}$,Ω	4+j3	2+j2	5+j8	4-j3	2-j2	5-j8	3+j5	3-j5	6+j9	5-j8

Homework.

To calculate transformation ratio k, primary and secondary windings currents
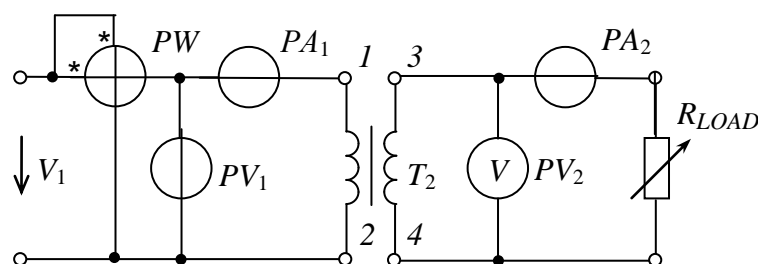

Fig. 9.13.

I_1, I_2 , primary and secondary windings powers P_1, P_2, transformer losses ΔP at given total power S, primary and secondary windings voltages V_1, V_2, power factor $cos\,\varphi_1$, efficiency factor η, load impedance $\underline{Z}$. Tasks variants are listed in the table 9.1.

The work execution order

1. Collect the electrical circuit (fig. 9.13), where PV – is a Volt-meter, PW – a Watt-meter and PA – Ammeter.

2. Investigate the transformer at open circuit mode with a nominal input voltage $V_{IN}=220V$. Fill in the table 9.2 with results.

3. Investigate the transformer at nominal mode with a nominal input voltage $V_{IN}=220V$ and a nominal input current $I_{IN}=1A$. Vary the current by changing load resistance. Fill in the table 9.2 with results.

4. Investigate the transformer at short circuit mode with a nominal input current $I_{IN}=1A$. Vary the current by changing input voltage. Fill in the table 9.2 with results.

Table 9.2

Regimes	Measuring				
	V_1	I_1	P_1	V_2	I_2
	V	A	W	V	A
Open circuit					
Nominal					
Short circuit					

5. Define the transformer parameters from the table 9.2.

$S_N = V_{1N} I_{1N}$ − nominal total power; $K = V_{1OC} / V_{1N}$ − transformation ratio;

$\eta_N = P_{2N} / P_{1N}$ − efficiency factor;

P_{oc} − open circuit power; P_{sc} − short circuit power;

$P_{2N} = V_{2N} I_{2N} \cos\varphi_{2N}$, $\cos\varphi_{2N} = 1$ − output nominal power;

$\cos\varphi_{1N} = P_{1N} /(V_{1N} I_{1N})$ − power factor;

$I_{oc}(\%) = (I_{1OC} / I_{1N}) \cdot 100\%$ − open circuit current;

$V_{sc}(\%) = (V_{1SC}/V_{1N}) \cdot 100\%$ − short circuit voltage.

Fill in the table 9.3 with results.

Table 9.3

Transformer parameters									
V_{1N}	I_{1N},	S_N,	K	η_{1N}	$\cos\varphi_N$	P_{oc}	I_{oc}	P_{sc}	V_{sc}
V	A	VA		%		W	%	W	%

6. Define the parameters of transformer T substitutional scheme. Fill in the table 9.4 with results:

− R_0, X_0 from open circuit mode by the following calculations:

$$Z_0 = V_{1N} / I_{OC}, \quad P_{0C} = R_0 I_{OC}^2, \quad Z_0 = \sqrt{R_0^2 + X_0^2}.$$

− R_{SC}, X_{SC} from short circuit mode by the following calculations:

$$Z_{SC} = V_{SC} / I_{1N}, \quad P_{SC} = R_{SC} I_{1N}^2, \quad Z_{SC} = \sqrt{R_{SC}^2 + X_{SC}^2}.$$

− resistances and reactances of the wires by the following calculations:

$R_1 = R_{SC}/2$, $X_1 = X_{SC}/2$ $R_2' = R_{SC}/2$, $R_2 = R_2'/K^2$, $X_2' = X_{SC}/2$, $X_2 = X_2'/K^2$.

Table 9.4

Transformer substitutional scheme parameters

Z_0	R_0	X_0	Z_{SC}	R_{SC}	X_{SC}	R_1	X_1	R_2	X_2
Ω	Ω	Ω	Ω	Ω	Ω	Ω	Ω	Ω	Ω

Report on work

The name and purpose of the work. The schematic diagram of the investigated circuit (fig 9.13). The tables 9.2, 9.3, 9.4. Conclusions.

Control questions

1. Draw a conventional graphical representation of transformers and specify their classification.

2. Explain the principle of the transformer and draw its electromagnetic scheme. Explain the role and purpose of the scheme elements.

3. Write the transformer electrical state equation and draw the transformer substitutional scheme.

4. Write the transformer magnetical state equation and write the primary winding current expression.

5. Explain how the transformation ratio is defined.

6. Draw a T-shaped transformer substitutional scheme and explain the physical meaning of its elements.

7. How the parameters of T-shaped transformer substitutional scheme can be defined experimentally?

8. Draw the transformer substitutional scheme for open circuit experiment and explain how the parameters of this scheme are determined.

9. Draw the transformer substitutional scheme for short circuit experiment and explain how the parameters of this scheme are determined.

10. Explain what the specific transformer parameters are.

11. Draw a graph - a dependence of the trnsformer external characteristics from loading. Why does the voltage increase with the active-capacitive loading?

12. Draw the transformer power diagram and explain its losses.

13. Write down the transformer expressions for power (input, output, losses).

14. Write down the expression for transformer efficiency factor. What is the load factor?

15.Draw and explain the dependence between efficiency factor and transformer loading.

Attachment

№	Greek letters		
1	A	α	*alfa*
2	B	β	*beta*
3	Γ	γ	*gamma*
4	Δ	δ	*delta*
5	E	ε	*epsilon*

6	Z	ζ	dzeta
7	H	η	eta
8	Θ	θ,	teta
9	I	ι	jota
10	K	κ	kapa
11	Λ	λ	lambda
12	M	μ	miu
13	N	ν	niu
14	Ξ	ξ	ksi
15	O	o	micron
16	Π	π	pi
17	P	ρ	ro
18	Σ	σ,ς	sigma
19	T	τ	tau
20	Y	υ	ipsilon
21	Φ	φ	fi
22	X	χ	hi
23	Ψ	ψ	psi
24	Ω	ω	omega

Physical values designation and units

Value	Designation	Dimension
Resistance	R, Ω	Om
Reactance	X, Ω	Om
Impedance	Z, Ω	Om
Conductance	G, Sm	Simens
Susceptance	B, Sm	Simens
Admittance	Y, Sm	Simens
Capacity	C, F	Farada
Inductance	L, H	Henry
Inductance mutual	M, H	Henry
Electromotive force	E, V	Volt
Potential	φ, V	Volt
Voltage	V, V	Volt
Current	I, A	Amper
Active power	P, W	Watt

Reactive power	Q, VAr	**Volt-Amper reactive**
Total power	S, VA	**Volt-Amper**
Magnetomotive force	F, A	**Amper**
Magnetic induction	B, T	**Tesla**
Magnetic field tension	H, A/m	**Amper per meter**
Magnetic stream	Φ, Wb	**Weber**
Linkage	ψ, Wb	**Weber**
Magnetic permeability (absolute)	μ_a, Гн/м	**Henry per meter**
Magnetic permeability (relative)	μ	
Magnetic constant	μ_0, Гн/м	**$4\pi \cdot 10^7$**
Frequency	f, Hz	**Herz**
Angular frequency	ω, rad/s	**radian per second**
Length	1, m	**meter**
Hight, depth	h, m	**meter**
Layer	δ, d, m	**meter**
Arial	S, m^2	**square meter**
Magnetic resistance	R_m	
Number of turns	w	
Force	F, N	**Newton**
Work (energy)	W, J	**Joule**
Charge	Q, C	**Coulomb**

Content