The Ministry of Education and Science of Ukraine

ZAPORIZHZHIA POLYTECHNIC NATIONAL UNIVERSITY

Methodical Instructions

to the term work in the discipline:
"Fundamentals of Theory of Electrical Apparatus"
for students majoring in

141 – Electrical power, electrical and electro-mechanic engineering
(Educational program **– Electric and Electronic Apparatus)**

2020

Methodical instructions to the term work in the discipline: “Fundamentals of Theory of Electrical Apparatus” for students majoring in 141 – Electrical power, electrical and electro-mechanic engineering (educational program “Electric and electronic apparatus”) / Compiled by O.V. Blyzniakov. – Zaporihzhzya: Zaporihzhzia Polytechnic National University, 2020. – 14 p.

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Approved at the meeting of the department
"Electric and Electronic Apparatuses".
Minutes No. 2 dated September 7, 2020

Recommended for publication by
educational-and-methodical commission
of Electrical Engineering Department.
Minutes No.1 dated September 17, 2020

CONTENT

INTRODUCTION

Thermal phenomena play a very significant role in the process of functioning electrical apparatuses. Moreover, both positive and negative. In some cases, thermal phenomena are positive and has wide application for the operation of electric apparatuses, for example:

- melting a fuse link of a safety device and interrupting the electrical circuit in the event of an emergency situation (overload, short-circuit);
- bending of a bimetallic strip under its heating resulted from the flowing overcurrent resulting in interrupting the electric circuit, etc.

The negative role of thermal phenomena consists mostly in that thermal energy necessarily generated by the current carrying components of the electrical apparatuses should be driven out to its surroundings. This problem takes especial importance in semiconductor-based electrical apparatuses, wherein great thermal power is generated in small volumes. In such cases, effective cooling systems are applied to dissipate thermal energy, such as:

- heat sinks (devices with an extended cooling surface);
- forced cooling (artificially generated currents of cooling medium);
- transpiration cooling (application of phase change of liquid at heating and cooling).

This problem becomes urgent due to the tendency to increase in current ratings of electrical apparatuses, when artificial cooling is often necessary. On the other hand, it should also be noted that the calculated analysis of the thermal behavior of electrical apparatuses, regardless of the cooling technology is a rather difficult task. The aim of the present term work is to give students the primary experience to perform thermal calculations of the simplest current-carrying systems.

1. GENERAL INSTRUCTIONS ON EXECUTION OF THE TERM WORK

To execute the term work the student receives an individual task, which is issued by the adviser. The subject of the term work can be either typical (for example "Thermal calculation of the busduct ") or non-typical under mutual agreement of the student and the adviser. Variants for the typical tasks offered in the course work are represented in the appendix A.

The explanatory note for the term work should include the following elements:

1. Title page drawn up in compliance with the form 17 (https://zp.edu.ua/novi-blanki-zntu).
2. The task on the term work drawn up in accordance with the form approved by the educational department of the university and signed by the adviser.
3. Abstract, drawn up in accordance with the requirements of ДСТУ 3008: 2015.
4. Contents of the explanatory note.
5. Body of the explanatory note with the following sections:
   - Introduction;
   - Scoping calculation of the busduct;
   - Précised thermal design of the busduct;
   - Analysis of the busduct for short-time withstand current;
   - Conclusions;
   - Reference list (list of used literature).

The explanatory note must contain all necessary schemes, drawings, formulas with disclosure of the quantities, which it contains; explanations of the performed calculations, as well as conclusions on their results. There is no need to repeat the same type calculations; their results should be presented in the form of tables. The explanatory note should not exceed 20-25 pages of the manuscript text. The explanatory note must be drawn up in compliance with requirements of ДСТУ 3008: 2015.

2. INSTRUCTIONS TO THE SCOPING CALCULATION OF THE BUSDUCT

The task of the scoping calculation is generally to determine geometrical parameters of the apparatus' current carrying parts based upon a predetermined current load and given cooling conditions. In this case, basing upon the predetermined structure of the busduct, its geometrical parameters, cooling conditions, as well as current load and operational duty presented in appendix, it is necessary to determine the required cross-sectional area of the bus and select its material and dimensions according to the available gauge. For this purpose the following operations should be performed:

1. Identify thermal sources in the busduct and heat exchange ways between the thermal source and environment; to construct the thermal equivalent circuit and to agree it with adviser of the work.
2. Calculate the total thermal resistance between the current-carrying bus and ambient medium per one meter of the busduct, as well as the thermal time constant of the bus. To do this, it is necessary to pre-set the outer diameter of the bus.
3. Based upon the nominal current load and the busduct operational duty, calculate the equivalent long-term current.
4. Set up the heat balance equation for the bus, then calculate its required cross-sectional area.
5. Using the available gauge [6, 7, 13] and the cross-sectional area found, select a standard solid or tube-shaped bus; calculate its précised cross-sectional area and current density.
6. Draw conclusions from the calculations.

3. INSTRUCTIONS ON THE PRECISED THERMAL CALCULATION OF THE BUSDUCT

In general case, the main task of the précised thermal design to is find the apparatus temperatures field at the given current load, its geometrical parameters and cooling conditions. In this case based upon the predetermined current load, operational duty of the busduct, given and found geometrical parameters, as well as cooling conditions, it is necessary to determine the bus temperature. To do this, the following operations should be performed:

1. Finally determine the thermal sources in the busduct and calculate their total thermal power, taking into account additional losses in the bus and losses in non-current-carrying parts (casing). The operating temperature of the bus can be accepted equal to permissible one.

2. Determine the temperature on the outer surface of the casing. For this purpose, first and foremost, determine the ways of heat transfer from the outer surface of the casing to the ambient medium, and then calculate the corresponding total thermal resistance. The temperature on the outer surface of the casing is determined by the following expression:

$$\vartheta_{\mathrm{outer}} = \vartheta_{\mathrm{a}} + P \cdot r_{\mathrm{th.c-a}}, \qquad (3.1)$$

where ϑ_{a} is ambient temperature, which in compliance with valid standards is +40ºC (for temperate climate);

P is the total thermal power losses per 1 meter of the busduct.

$r_{\mathrm{th.c-a}}$ is the total thermal resistance between the casing outer surface and its surroundings per 1 meter of the busduct.

This equation is non-linear because the value of thermal resistance $r_{\mathrm{th.c-a}}$ is dependent on the temperature of the casing outer surface $\vartheta_{\mathrm{outer}}$. To solve this equation, it is necessary to use one of conventional numerical methods: successive iterations, successive half-divisions, etc. The solution can be done by means of PC with the help of the appropriate software (MathCad, MathLab etc). As an initial approximation, the midvalue between operating temperature of the bus (permissible value) and ambient temperature may be accepted.

3. Determine the temperature on inner surface of the casing. For this purpose, it is necessary also to identify the heat transfer ways from the inner to outer surfaces of the casing and then, to calculate the corresponding total thermal resistance. The temperature on inner surface of the casing is expressed as:

$$\vartheta_{\text{outer}} = \vartheta_{\text{inner}} + P \cdot r_{\text{th.c}}, \tag{3.2}$$

where $r_{\text{th.c}}$ is total thermal resistance between the inner and outer surfaces of the casing (thermal resistance of the casing) per 1 meter of the busduct.

It should be noted that if the casing is made of metal (i.e., material with high thermal conductivity), the temperature drop between its inner and outer surfaces can be neglected.

4. Determine the temperature of the bus. For this purpose, it is necessary at first to identify the heat transfer ways from the outer surface of the bus to the inner surface of the casing and then, calculate the corresponding thermal resistance. The temperature of the bus is expressed as:

$$\vartheta_{\text{bus}} = \vartheta_{\text{inner}} + P_{\text{bus}} \cdot r_{\text{th.inter.}}, \tag{3.3}$$

where $P_{\text{Ш}}$ is total thermal loss in the bus per 1 meter of the busduct;

$r_{\text{th.inter.}}$ is total thermal resistance between the outer surface of the bus and the inner surface of the casing (thermal resistance of the interlayer) per 1 meter of the busduct.

Since the magnitude of thermal resistance $r_{\text{th.inter}}$ is dependent on the bus temperature, equation (3.3) is non-linear. To solve this equation, one of conventional numerical methods should be used: successive iterations, successive half-divisions etc. The solution can be done by means of PC with the help of the appropriate software (MathCad, MathLab etc). As initial approximation the bus operating temperature (permissible value) may be accepted.

4. INSTRUCTIONS ON THE ANALYSIS FOR THE SHORT-TIME WITHSTAND CURRENT

The task of the analysis is to verify the stability of the busduct in flowing short-circuit current for the certain time span. In this case the bus the bus temperature must be computed using the found dimensions of the busduct and the predetermined parameters of the short-circuit current. The computation is carried out with the help of adiabatic heat curves

$$A(\vartheta_{\text{sc}}) = A(\vartheta_{\text{init.}}) + j_{\text{sc}}^2 t_{\text{sc}}$$

where $\vartheta_{\text{init.}}$ is the temperature of the bus prior to the passing of short-circuit current, i.e. the temperature under flowing a long-term nominal current with regard to the operating duty;

j_{sc} is the density of the short-circuit current;

t_{sc} is the duration of passing the short-circuit current; at relatively high nominal currents ($I_{\text{н}} \geq 5000\text{ A}$), when computing the thermal impulse, the so-called virtual time of short-circuit is to be used; relation of the initial sc current to the steady-state value is to be taken equal to 2.0.

The found value of ϑ_{sc} must be compared with the permissible temperature for short-circuit conditions; one should make corresponding conclusions.

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Appendix A

Initial data for the thermal design of the busduct

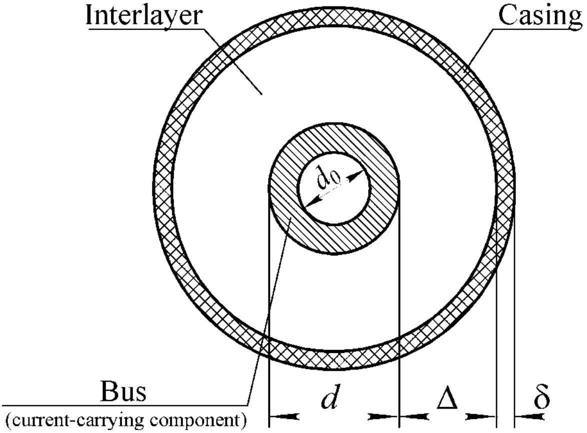

Figure A.1 – Structure and basic parameters of the busduct

Table A.1 – Initial data and basic parameters of the busduct

№ var.	**Bus** (current carrying component)				**Interlayer**		**Casing**	
	Nominal conditions		**Short-circuit conditions**					
	$I_н$, A	Operating duty	$I_{т.ст}$, кА	$t_{т.ст}$, с	Medium	Δ, мм	Material	δ,mm
1	25	long-term	6	1	air	25	steel	2
2		ПВ%=60%			vacuum	20	fluoroplastic	3
3		ПВ%=40%			transformer oil	15	steel	6
4		long-term			SF_6-gas	15	steel	2
5	40	long-term	6	3	air	30	steel	2
6		ПВ%=60%			vacuum	20	fluoroplastic	3
7		ПВ%=40%			transformer oil	15	steel	6
8		long-term			SF_6-gas	15	steel	2
9	63	long-term	6	5	air	32	steel	2
10		ПВ%=60%			vacuum	30	fluoroplastic	3
11		ПВ%=40%			transformer oil	20	steel	6
12		long-term			SF_6-gas	20	aluminium	2

Continuation of table A.1

№ var.	**Nominal load**		**Thermal stability**		**Interlayer**		**Casing**	
	$I_{н}$, A	Operating duty	$I_{т.ст}$, кA	$t_{т.ст}$, с	Medium	Δ, mm	Material	δ,mm
13	100	long-term	10	3	air	35	steel	2
14		ПВ%=60%			vacuum	30	fluoroplastic	3
15		ПВ%=40%			transformer oil	20	steel	6
16		long-term			SF_6-gas	20	steel	2
17	160	long-term	10	5	air	35	steel	2
18		ПВ%=60%			vacuum	30	fluoroplastic	3
19		ПВ%=40%			transformer oil	25	porcelain	6
20		long-term			SF_6-gas	25	aluminium	2
21	200	long-term	16	3	air	35	steel	2
22		ПВ%=60%			vacuum	30	fluoroplastic	3
23		ПВ%=40%			transformer oil	30	porcelain	6
24		long-term			SF_6-gas	30	aluminium	2
25	250	long-term	16	5	air	40	steel	2
26		ПВ%=60%			vacuum	35	fluoroplastic	3
27		ПВ%=40%			transformer oil	32	porcelain	6
28		long-term			SF_6-gas	30	aluminium	2
29	400	long-term	20	3	air	45	steel	2
30		ПВ%=60%			vacuum	40	fluoroplastic	3
31		ПВ%=40%			transformer oil	40	porcelain	6
32		long-term			SF_6-gas	35	aluminium	2
33	630	long-term	20	5	air	60	steel	2
34		ПВ%=60%			vacuum	50	fluoroplastic	4
35		ПВ%=40%			transformer oil	50	porcelain	8
36		long-term			SF_6-gas	50	aluminium	2
37	1000	long-term	20	8	air	80	steel	2
38		ПВ%=60%			vacuum	70	fluoroplastic	4
39		ПВ%=40%			transformer oil	70	porcelain	8
40		long-term			SF_6-gas	60	aluminium	2

Continuation of table A.1

№ var.	**Nominal load**		**Thermal stability**		**Interlayer**		**Casing**	
	$I_н$, A	Operating duty	$I_{т.ст}$, кА	$t_{т.ст}$, с	Medium	Δ, mm	Material	δ,mm
41	1600	long-term	31,5	5	air	120	steel	2
42		ПВ%=60%			vacuum	100	fluoroplastic	4
43		ПВ%=40%			transformer oil	100	porcelain	8
44		long-term			SF_6-gas	90	aluminium	2
45	2000	long-term	31,5	5	air	140	steel	2
46		ПВ%=60%			vacuum	120	fluoroplastic	4
47		ПВ%=40%			transformer oil	120	porcelain	8
48		long-term			SF_6-gas	100	aluminium	2
49	2500	long-term	40	3	air	180	steel	2
50		ПВ%=60%			vacuum	150	fluoroplastic	4
51		ПВ%=40%			transformer oil	150	porcelain	8
52		long-term			SF_6-gas	120	aluminium	2
53	3200	long-term	40	5	air	200	steel	2
54		ПВ%=60%			vacuum	180	fluoroplastic	4
55		ПВ%=40%			transformer oil	170	porcelain	8
56		long-term			SF_6-gas	160	aluminium	2
57	4000	long-term	80	5	air	250	steel	2
58		ПВ%=60%			vacuum	220	fluoroplastic	5
59		ПВ%=40%			transformer oil	220	porcelain	10
60		long-term			SF_6-gas	200	aluminium	2
61	6300	long-term	80	3	air	300	steel	2
62		ПВ%=60%			vacuum	250	fluoroplastic	5
63		ПВ%=40%			transformer oil	250	porcelain	10
64		long-term			SF_6-gas	200	aluminium	2
65	10000	long-term	80	3	air	350	steel	2
66		ПВ%=60%			vacuum	300	fluoroplastic	5
67		short 18 c			transformer oil	300	porcelain	10
68		long-term			SF_6-gas	280	aluminium	2

Continuation of table A.1

№ var.	**Nominal load**		**Thermal stability**		**Interlayer**		**Casing**	
	$I_{н}$, A	Operating duty	$I_{т.ст}$, кА	$t_{т.ст}$, c	Medium	Δ, mm	Material	δ,mm
69	16000	long-term	100	1	air	400	steel	2
70		ПВ%=60%			vacuum	350	fluoroplastic	5
71		short 15 c			transformer oil	350	porcelain	10
72		long-term			SF$_6$-gas	300	aluminium	2
73	20000	long-term	100	3	air	450	steel	3
74		ПВ%=60%			vacuum	400	fluoroplastic	6
75		ПВ%=40%			transformer oil	400	porcelain	12
76		short 12 c			SF$_6$-gas	300	aluminium	2
77	24000	long-term	160	3	air	500	steel	3
78		ПВ%=60%			vacuum	450	fluoroplastic	6
79		short 10 c			transformer oil	450	porcelain	14
80		long-term			SF$_6$-gas	400	aluminium	3