NOTES ON HEATING OF FUSES WITH ORDINARY SUBSTITUTION ELEMENTS AND STANDARD UNITS

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The theoretic and experimental considerations are presented as a consequence of tests made on real unit fuses and standard substitute unit fuses, recommended by the IEC draft project [1] and VDE [2].

Out of the brief analytical thermal computations it results that the overtemperatures of the tested standard fuses are higher than the overtemperatures of the steady - state substitute units.

These conclusions have been checked experimentally as well.
On the basis of these results, the paper suggests a new standard substitute unit which generates a thermal mode close to the one developed by real fuses.

1. INTRODUCTION

It is a well known fact that in many cases, the tests imposed by standards have a more or less conventional character. Anyhow, the conditions of the conventional tests must be as close as possible to the operating real conditions. In the field of electric fuses, the conventional tests are generally referred to the determination of breaking capacity and to overtemperatures. As regards the breaking capacity, it is measured to all the imposed test currents ($I_1;I_2;I_3;I_4;I_5$ etc.) in the cold state of fuses, although in operation, the greatest majority of fuses interrupt the short-circuit currents after having worked for a certain time with currents close to the rated current.

The present paper, we shall deal only with heating tests on industrial fuses (type gI and type aM etc.) with standard units and real substitution units.

The analysis was made both analytical and on the basis of experi - mental results, thus demonstrating that the standard substitution unit element proposed by IEC [1] and VDE [2] is not close enough to the behaviour of real substitution unit fuses.

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2. NORM SPECIFICATIONS REGARDING STANDARD UNITS

In conformity with the suggestion made by IEC 32 B (Secretariat) 91 [1] the overtemperature of support terminals is measured by means of standard substitution units, also, with respect to VDE 0636 [2], the overtemperature at support terminals of fuses type NH is determined by using, also, a standard substitution unit, whose dimensions are given by the respective norm. The structures of these standard substitution units are shown in Fig. 1, and their dimensions are given by the respective norme and partially by Table 1.

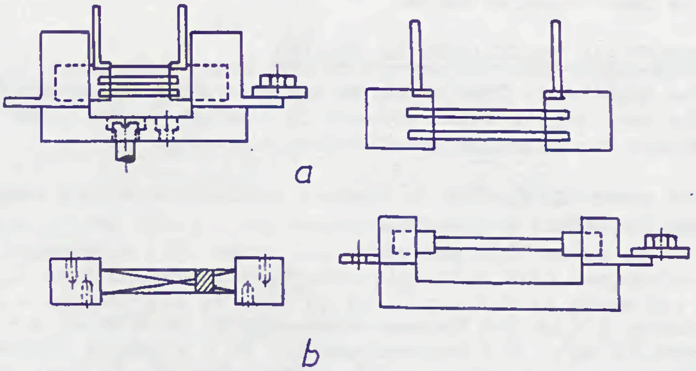


Fig. 1 Standard substitute unit fuses

The conductors of the standard unit which simulate the fusible are made of CuNi 56/44, in conformity with VDE [2] and of CuMn 12 Ni, in conformity with IEC [1] whose resistivity, practically does not vary with temperature.

Table 1

Dimensions of standard substitute unit fuses

Size	b* (mm)		P	R	Proposes CEI		Proposes CE.Roman	
					CU Mn 12 NI - Bars			
	CEI	CER	(W)	(m Ω)	Number (mm)	Diameter (mm)	Number (mm)	Diameter (mm)
00	$30.5^{\,0}_{-3}$	45 ±1.5	12	0.47	1	7	1	7.3
0	$46^{\,0}_{-4}$	$62 \pm^{3}_{1.5}$	25	0.97	1	6	1	6
1	$46^{\,0}_{-4}$	62 ±2.5	32	0.51	1	8	1	8.2
2	$46^{\,0}_{-4}$	62 ±2.5	45	0.281	2	8	2	7.9
3	$46^{\,0}_{-4}$	62 ±2.5	60	0.151	3	9	3	8.8
4	$54^{\,0}_{-6}$	62 ±2.5	90	0.09	3	12	3	11.3
4a	$54^{\,0}_{-6}$	84 ±3	100	0.07	4	12	4	11.6

See Fig. 2 p 20 from 32B (secretariat) 91

The powers dissipated by these standard substitution units are selected for the fuse class of the highest admissible powers for substitution units with corresponding rated currents. As it can be seen in Fig. 1.a.and Fig.1.b, the conductor or the conductors of the standard unit which simulate the fuse element are placed in the open, unlike the real fuse elements which are located in an extinction place (quartz send) which constitutes a heat transfer medium as well. Between the standard substitution element and the real fusible of electric fuses, there are qualitative differences, as for example : differences between the cross section and the lateral surface of fusibles and standard conductor; different heat transfer at the ends of fuses and standard conductors etc. These differences lead-though the dissipated power might be the same- to a different heat transfer, both by thermal conduction and thermal convection and to different overtemperatures. In order to make prominent, at least qualitatively, these discrepancies, we present a brief analytical calculation of the heat transfer below.

3. ANALYTICAL CALCULATION OF HEATING

The hypothesis from which we start is that the power developed within the real substitution element is similar to the power developed within the standard substitution element.

The power dissipated by thermal conduction within conductors of fuses is given by the relation:

$$P_\lambda = -\lambda \frac{\partial \theta}{\partial x} A \tag{1}$$

where: λ - is the thermal conductivity in W/cm °C; A - cross section area in cm^2; θ - temperature in °C; x - length of conductor in cm. Therefore, the values which differ sensibly in real steady-state unit as compared to standard substitution units are λ and A.

The power dissipated by thermal convection is given by the relation:

$$dP_c = K(\theta - \theta_a) S \tag{2}$$

Where: K-overall coefficient of heat transfer, in W/cm^2 °C; S-lateral surface heat transfer area of conductors, in cm^2.
As it can be noted, in relation (2) too, K and S are different for standard substitution units as compared to real substitution units. Consequently, P_λ and P_c being different for the real substitution unit and for the standard substitution unit, it results that the overtemperatures will be different.

In order to throw light on the qualitative differences between the standard element and the real substitution unit, we note down a brief thermal calculation.

Thus, from Fig.1, it results the power developed within the standard unit is constant, practically independent of the temperature, due to the fact that the coefficient of variation of resistivity with temperature of CUMN 12 Ni is about 10^{-5} 1/°C, and of CuNi 56/44 is of the same order, consequently an overtemperature of the conductor of 400°C leads to an increase in resistivity with 4% and implicitly of the dissipated power. At the same temperature (400°C) the resistivity of copper increases with 170 % and the dissipated power implicitly
Another qualitative difference is connected to the analytical expression of the overtemperature variation with the lenght of the fuse element.

Thus, in the case of the standard substitution unit, the overtemperature of the standard element is given by [3] :

$$\tau(x) = \frac{\rho_a A J^2}{Kl}\left[1 - \frac{g\,ch\,a'x}{a\,sh\,a'x_1 + g\,ch\,a'x_1}\right] \qquad (3)$$

where: K- heat transfer coefficient, in W/cm^2 °C; ρ_a - resistivity at ambiant temperature in Ω cm; l- length of conductor perimeter, in cm; $g = \frac{\lambda}{\eta}$; η - represents the heat transfer coefficient at the end of the fuse element, given in W/cm^2 °C.
The value of "a'" is given by the relation:

$$a' = \sqrt{\frac{Kl}{\lambda A}} \qquad (4)$$

In the case of fuses with which resitivity varies with temperature the overtemperature is given by the relation [3] :

$$\tau(x) = \frac{\rho_a A J^2}{Kl - \alpha_0 \rho_0 A J^2}\left[1 - \frac{g\,ch\,ax}{a\,sh\,ax_1 + g\,ch\,ax_1}\right] \qquad (5)$$

where the data of the above - written relation have the significance of those in expression (3), whith the following difference or additions: α_0 - coefficient of resitance variation with temperature, in 1/°C; ρ_0 - resistivity at zero °C, in Ω cm, "a" is given by:

$$a = \sqrt{\frac{Kl}{\lambda A} - \frac{\rho_0}{\lambda}\alpha_0 J^2} \qquad (6)$$

In case the temperature at the distance x_1 is known, there can be used formulae, where the heat transfer coefficients are not required. This formula has the following expression for the standard element [3] :

$$\tau(x) = \tau_1 \frac{ch\,a'x}{ch\,a'x_1} + \frac{\rho_a A J^2}{Kl}\left[1 - \frac{ch\,a'x}{ch\,a'x_1}\right] \qquad (7)$$

and in the case of a real substitution unit, heating is given by the expression [3] :

$$\tau(x) = \tau_1 \frac{ch\,ax}{ch\,ax_1} + \frac{\rho_a A J^2}{Kl - \alpha_0 \rho_0 A J^2}\left[1 - \frac{ch\,ax}{ch\,ax_1}\right] \qquad (8)$$

Taking into consideration the relation (1) and the expressions of overtemperatures in (3); (5); (7) and (8) the powers conveyed by thermal conductance have the following forms. For the standard unit they are obtained out of the relation:

$$P_{\lambda_e} = -2\lambda A a' \tau_1\, th\,a'x_1 + \frac{2\lambda a'}{Kl}\rho_a I^2\, th\,a'x_1 \qquad (9)$$

$$P_{\lambda_e} = \frac{2\lambda a'}{Kl}\rho_a I^2 \frac{g\,sh\,a'x_1}{a\,sh\,a'x_1 + g\,ch\,a'x_1} \qquad (1o)$$

and for the real substitution unit, they are given by :

$$P_{\lambda_r} = -2\lambda A a \tau_1 \, \mathrm{thax}_1 + \frac{2\lambda_a \rho_a I^2}{Kl - \alpha_0 \rho_0 A J^2} \, \mathrm{thax}_1 \qquad (11)$$

$$P_{\lambda_r} = \frac{2\lambda a \rho_a I^2}{Kl - \alpha_0 \rho_0 A J^2} \cdot \frac{g\,\mathrm{shax}_1}{a\,\mathrm{shax}_1 + g\,\mathrm{chax}_1} \qquad (12)$$

The powers developed in continuous mode within the substitution unit, the contacts of the test support being included, and taking into consideration the variation of the conductor's resitivity and of the electrical contacts with temperature, are given by [4] [5] :

$$P(\Theta) = R_f I^2 + 2R_c I^2 = R_{af}\left[1 + \alpha(\Theta - \Theta_a)\right] I^2 + 2R_{pc}\left[1 + \frac{2}{3}(\Theta - \Theta_a)\right] I^2 \qquad (13)$$

where: R_f-is the fuse resistance in Ω ; R_c-resistance of support contacts in Ω; I-current in A; R_{pc} - resistance of contacts at the ambiant temperature.

We admit that the power conveyed by fuses by means of thermal conduction P_λ is equal to the power conveyed by convection, P_c, which is practically real for low voltage fuses, thus it results that $P_c = P_\lambda$. Also, we suppose that P has the same value for the standard unit and for the real element.

By a real substitution unit we understand the substitution element which has fuses or conductors and which are tested within ceramic hoses filled with quartz sand.

The power conveyed by convection by the standard substitution unit, taking into consideration (2), is given by the relation:

$$P_{ce} = K_e \, l \, \pi n d \, (\Theta - \Theta_a) \qquad (14)$$

where: l - standard conductor's lenghth, in cm;
d - diameter of standard conductors, in cm;
n - number of standard conductors in parallel

The output of the real substitution unit at the external ceramic hose in a rectangular shape with sides e_1 and e_2 is given by the relation:

$$P_{cr} = 2K_r \, l \, (l_1 + l_2)(\Theta - \Theta_a) \qquad (15)$$

The report between the overall output of the real unit P_{tr} and the overall power conveyed by the standard substitution unit P_{te}, is:

$$\frac{P_{tr}}{P_{te}} = \frac{P_{cr} + P_\lambda}{P_{ce} + P_\lambda} = \frac{2P_{cr}}{P_{ce} + P_\lambda} = \frac{2}{1 + \frac{P_{ce}}{P_{cr}}} = \frac{4(l_1 + l_2)}{\pi n d + 2(l_1 + l_2)} \qquad (16)$$

In relation (16) is was considered $K_e \cong K_r$, an acceptable fact, because the heat transfer is made in both cases by convection. Also, it was supposed highly approximately, that the temperature θ of the ceramics is equal to the temperature of the standard conductor.

The real calculation value of the relation between P_{tr}/P_{te} for fuses of 630 A, size 3, with the dimensions given by IEC[1], is equal to 1.56, taking into consideration the following values of the data in the relation (16): $e_1=76$ mm; $e_2=75$ mm; $n=3$; $d=9$ mm.
Taking into account the dimensions of the standard unit in VDE 0636 [2], the following expression of the relation P_{tr}/P_{te} is obtained:

$$\frac{P_{tr}}{P_{te}} = \frac{4c}{a+b+2c} \qquad (17)$$

Having the concrete values for a, b and c from VDE 0636 [2], for size [3], the report P_{tr}/P_{te} becomes equal to 1.51.

4. CALCULATION AND EXPERIMENTAL RESULTS

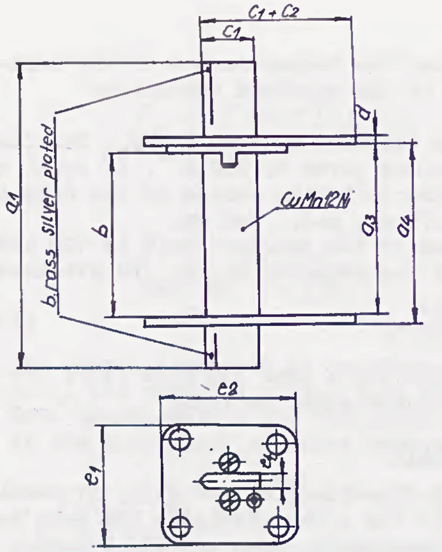
Out of the calculations made with formulae (16) and (17), it results that the real substitution unit of 630 A can dissipate 56% more heat than the standard unit with the dimensions given in IEC [1] and respectively 51 % more than the standard substitution unit with the VDE 0636 [2] dimensions.

The dissipated power depends on the contact system, as can be seen in relation (13). Two types of supports with the same real substitution element have been experimented at ICPE-Bucharest. With the first type, the dissipated power was of 60 W and the overtemperature at terminals of 55.4°C, and with the second type (of less pressure on the contact), the dissipated power of the same substitution unit was of 73.7 W while the overtemperature at terminals was 64.9°C. This test shows that the support, due to the different contact resistance R_{pc}, can influence the fuse heating, owing to the increase of resistivity with temperature.

The increase of resistivity leads to the implicit rise of dissipated power with the real substitution unit, the first data in relation(13) Since the thermal calculations developed above are aproximate there have been experimented standard unit proposed by IEC [1] and VDE[2], and the standard unit we wish to propose and which is shown in Fig. 2.

The fundamental dimensions, the number and the sizes of the standard conductors for size 00; 0; 1; 2 ; 3 and 4 are shown in Table 1. The standard substitution units in Fig. 2 are mounted within the ordinary ceramics, taking the shape of the real substitution units, as in Fig. 3.

Thus, out of Fig. 3, it results that the suggested standard substitution unit has at its basis the standard substitution unit of IEC [1] supplemented with ceramic within which quartz sand is introduced. In this way, two important requirements are met: firstly, the heating of the standard conductor and secondly, the heat transfer is made in similar conditions to those of steady - state fuses.



Size \ Dimensions (mm)	a_1	a_3	a_4	a
1	135	60	65	58.5

c_1	c_2	e_1	e_2	e_4
22	28	47	46	6.1

Fig. 2 Standard substitute unit fuses proposed by C.E. Român

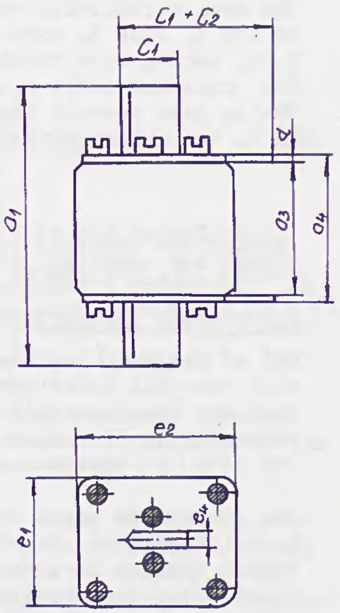


Fig. 3 Standard substitute unit fuses mounted within the ceramic

The experimental results of tests performed on both the standard substitution unit in conformity with IEC and on the one that we proposed, have demonstrated the validity of the aproximate analytical calculations presented above.

The calculation and experimental data for the real substitution unit, applied to the above written formulas are the following:
- for the standard substitution unit: $I=25o$ A; $1=4.2$ cm; $\lambda=o.21$ W/cm°C $\rho_a=o.435\times1o^{-4}\,\Omega$ cm; $K=o.oo5$ W/cm$^{2\,o}$C; $\eta=2$W/cm$^{2\,o}$C; $A=o.54$ cm^2; $\tau=82^\circ$C; $J=463$ A/cm^2;
- for the real substitution unit: $I=25o$ A; $1=5.32$ cm; $\lambda=3.93$ W/cm°C; $\rho_a=o.o18\times1o^{-4}\,\Omega$ cm; $\rho_o=o.o17\times1o^{-4}\,\Omega$ m; $K=o.oo9$ W/cm$^{2\,o}$C; $\eta=12$W/cm$^{2\,o}$C $A=o.o4$ cm^2; $\tau=69^\circ$C; $J=625o$ A/cm^2.

Thus, at a dissipated power of 32 W of the first group standard unit (see Fig.3), built in a strap of CuMn 12 Ni, the experimental results are those shown in Table 2.

From Table 2 we could note that the highest overtemperatures are obtained when the IEC proposed standard unit is used, and the lowest when our standard unit is used.

Table 2

Experimental results

Kind of dummy fuse-link / Over temperature	Dummy fuselink in air see fig. 2	Dummy fuse-link in ceramic corp without any quartz sand	Dummy fuse link in ceramic corp filled with quartz sand see fig 3	Real fuse link
0	1	2	3	4
Over temperature measured at E point [°C]	74	71	65	63
Over temperature measured at S point [°C]	85	84	82	69
Maximum over temperature of the conductor of the ceramic corp [°C]	136	40	47	51
Power transfered by convection [W]	14	15	18	20
Power transfered by therminal conduction [W]	18	17	14	12
Total disipated power [W]	32	32	32	32

It is obvious that the standard unit we propose simulates the best the thermal phenomena which take place within real fuses. The experimental differences presented above would have been higher, in case a IEC [1] standard substitution unit had been employed, a unit which is made of a round conductor with a diameter of ∅ 8 mm, whouse lateral surface (of heat transfer by convection) is of 11.56 cm^2 compared to 23.4 cm^2 of the standard substitution element on which the present tests have been made, or 24.85 cm^2 of the VDE [2] standard substitution unit.

Another phenomenon which influences the change of heat transfer conditions with real fuses as compared to standard units, is the heat transfer by thermal conduction at the fuse ends or at the standard element ends. Thus, Table 3 shows the values of A for real fuses of the Romanian type of fuses NH and for the standard units in conformity with IEC [1] and VDE [2].

As it can be seen, the respective value is almost double with the real fuses, as compared to standard units. Though these values are a lot different, $P\lambda$ being influenced by the variation of temperature with distance ($\frac{\partial \theta}{\partial x}$), it is possible that this derivation to balance the discrepancies among λ A. In case the work group is interested in this, The Romanian Electrotechnical Committee may continue the researches and supply additional information.

Table 3

The values of λ A for real fuses and for
the standard units

Size / Parameters	00	0	1	2	3
Romanian fuse links $\lambda_f \cdot A_f$ $(W \cdot m/°C) \times 10^{-6}$	990	1540	2358	6539	9808
Dummy fuse link see IEC [1] $\lambda_{ce} \cdot A_{ce}$ $(W \cdot m/°C) \times 10^{-6}$	808	594	1056	2111	4008
Dummy fuse links see VDE [2] $\lambda_{ce} \cdot A_{ce}$ $(W \cdot m/°C) \times 10^{-6}$	462	735	1449	2772	5145
$\frac{\partial \theta}{\partial x}$ $\left[°C / cm \right]$	Will be calculated with the relations (3) and (5) see appendix 1				

5. CONCLUSIONS

Taking into consideration the thermal calculations presented above and the experimental results obtained from the tests on standard units proposed by IEC [1] and the Romanian Electrotechnical Committee, we can notice the following:

5.1. The heat dissipation with standard units proposed with a view to determining the heating of supports is disimilar as compared to the heat dissipation with real fuses. As a consequence of this understanding, the heating is different too, resulting higher overtemperatures (with about 10°C) with fuses tested with standard units proposed by IEC [1] .

5.2. If the heating tests are to be more reproducible, it is necessary for the standard units to have a constant dissipated power, independent of their heating. This can be achieved with two standard units. made of conductors whose resistivity does not vary with temperature ($\alpha_0 \simeq 0$) . It is the case of the conductors proposed by IEC [1].

5.3. If we require the thermal phenomena with real fuses, to be found to a large extent within tests on standard units, the should be made of conductors with strap shape as well as the fuse elements, and the respective bands to be constructed out of materials whouse resistivity does not vary with temperature.

These fuses should be introduced within ceramic hoses, or hoses in other materials (similar to those used in real operation), and the respective hoses should be filled with extincting substances of the electric arc.

5.4. Suice the variant presented by 4.3. is difficult to be practically, we consider that the Romanian proposition shown in Fig. 2 Appendix 1 satisfies the requirements and the compromises needed for these tests.

As it can be seen, it satisfies the need to have a constant dissipated power and to obtain a heat transfer close to that of real steady - state fuses.

5.5. In our opinion, the ideal standard unit could be made without a quartz-filled ceramic hose, but establishing an equivalence among the convection heat transfer surfaces and the thermal conduction of real substitution units and standard units. The standard units, we think, should be made of a number of bands in CuMn 12 Ni (for exemple), whouse surface S should be as close as possible to the surface S of ceramic bodies and very similar to the two types of units.

6. BIBLIOGRAPHY

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