ELECTRIC CONDUCTIVITY OF ARC EXTINGUISHING MEDIA FOR LOW-VOLTAGE FUSES

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1. INTRODUCTION

Fuses are the only type of low-voltage switching devices where the arc shape can be considered at least approximately defined. This, in principle, makes also possible to describe the dynamic behaviour of the arc mathematically by means of the Mayr, Cassie, and other equation models presuming a rotationally symmetrical arc shape. This paper deals with the activities resulting from the analysis of fuse conductivity in the period of arcing and leading to a selection of a suitable mathematical arc model.

2. DESCRIPTION OF THE EXPERIMENTS

This study draws from experimental material gathered during a research searching for new kinds of arc extinguishing media for low-voltage fuses and directed to reduce the Joule integral i^2dt. Different kinds of arc extinguishing media were applied in semiconductor fuses of the type PC 100, rated current 100 A, of Czechoslovak origin. Factory produced fuses were tested as a comparative standard for evaluation of the suitability of the corresponding arc extinguishing medium.

PC 100 fuse-elements have the following characteristics:

fuse-element material	Ag
active length	97 mm
number of bridges	7
cross section reduction in a bridge	8 %
fuse-link cavity volume	18.78 cm^3

Breaking tests were carried out in a single-pole circuit at 550 V, 1800 A, cos fi = 0.2. The breaking current corresponded to the current I_2 according to the IEC Publication 169-4, at which the arc energy has the highest value. Individual arc extinguishing media were either poured in, or applied straight on the fuse-element which

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was then placed into the filling of quartz sand of the same grain size as in factory produced fuses (0.3 - 0.4 mm). During the tests the curves of voltage (u) and current (i) were registered by means of a cathode oscillograph TEKTRONIX 5103 N as well as the curves of power and uidt integral derivated from voltage and current by means of the electronic device working on the principle of Hall effect. According to the Czechoslovak standard ČSN 35 4715 the fuse was being held under a recovery voltage for 5 minutes and when the test ended, its resistance was checked.

The values $\int i^2 dt$ and conductivities G = i/u were determined from oscillograms by means of graphic construction and computation. The u and i values were read by means of BAK recorder together with MEDA analogue analyzer, the total breaking time being divided into 50 time sections. VA characteristics and dependences G = f(t) were drawn by means of the WANG 2200 table computer and a plotter. The total of 28 arc extinguishing media was tested, on 5 samples each.

3. OBTAINED TIME DEPENDENCES OF CONDUCTIVITY G = f(t)

The time conductivity curves were evaluated only for perspective arc extinguishing media showing at least the same extinguishing capacities as quartz sand and complying with the requirements of the Czechoslovak standard ČSN 35 4715 as to their behaviour after breaking. There were 7 of them and 3 additional measurements were carried out on factory produced fuses using quartz sand as an arc extinguishing medium. The shape of the dependence G = f(t) was similar at all the evaluated samples and it can be illustrated in an ideal form according to Fig. 1 drawn on a semi-logarithmic paper (the t scale is linear, the G scale is logarithmic). The dependence G = f(t) is divided into 4 or eventually 5 sections. In the first time section $0 - t_1$ the conductivity may fall steeply or gradually (the branches a, b according to Fig. 1) or it may be constant (the branch c) or it may also rise mildly along with the increasing time (the branch d). Further the curve falls monotonously in the sections 2 (the branch between the points A - C in the time interval $t_1 - t_2$) and 3 (the branch f between the points C - E in the time interval $t_2 - t_3$) and in the section 4 (the branch g starting from the point E in the time interval $t_3 - t_h$). Except the branch g all other branches may be approximated with a straight line. In some cases the number of sections increases to 5 by means of shortening the section 2 (the branch e between the points A - B in the time interval $t_1 - t_2$), inserting the branch e' (the section 2' between the points B - D in the time interval $t_2' - t_2''$) and further by continuation of the branch f from the point D. The transitions between the sections 1 and 2 are steep mostly, the transitions between the sections 2 and 3 or 2 and 2', 2'and 3'are steep or gradual with a little bow. The branch f is very short sometimes and it may be approximated with a straight line only with difficulties. In that case the branch g starts already from the point C or D.

The curves of dependences G = f(t) at different samples of the same kind of arc extinguishing medium were showing a great similarity and they testify of both a good reproducibility of the results and of a possibility to use the dependence G = f(t) for diagnostic purposes (see Fig. 2 for quartz sand and Fig. 3 for special ceramics NE 2).

The measured time t_1, t_2 and t_3 corresponding to transitions in the characteristic G = f(t) and the total breaking time t_h for different kinds of arc extinguishing media are shown in Table 1.

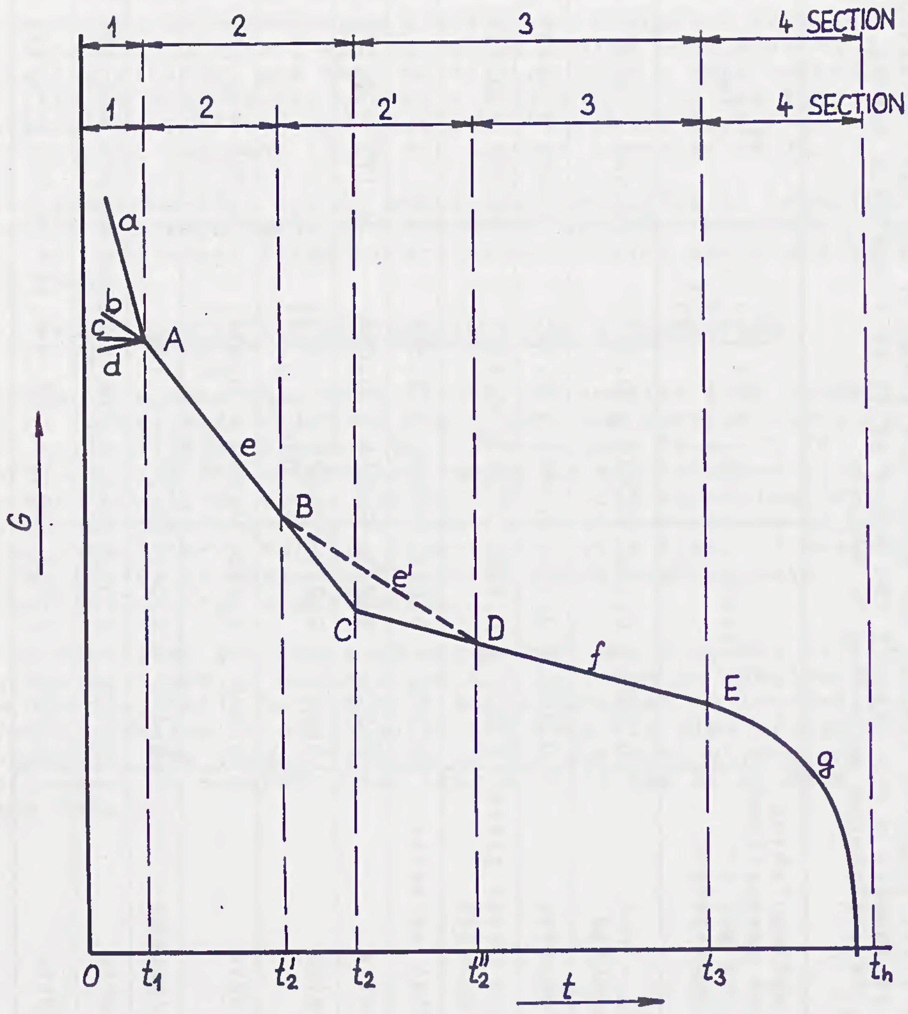
4. EVALUATION OF THE MEASUREMENTS AND A CONCLUSION

During the described experiments the complex time conductivity curves were obtained testifying the complex character of extinguishing process in a low-voltage fuse. It is evident that the extinction cannot be approximated with a simple model, as e. g. the Mayr's. Simple approximation might be possible only in individual time sections in which the conductivity fall is exponential with time. At present time limits of these sections can be determined only empirically from experiments.

The described procedure of evaluating the breaking oscillograms by means of dependences G = f(t) can be considered as a new diagnostic method of breaking process in low-voltage fuses enabling to distinguish the separate time stages of breaking. The classification of the dominant elementary processes in separate time stages still has to be done in the future.

Tab. 1 Time (measured in ms) of transitions in the characteristic $G = f(t)$ t_1, t_2, t_3 and the total breaking time t_h for different kinds of arc extinguishing media. Number of samples $n = 5$, except the media NE 1, NE 2 and NE 3 having $n = 3$. Time t_1 is designated according to Fig. 1.

Arc extinguishing medium	Arc extinguishing medium composition and the way of its application	t_1 (ms)	t_2 (t_2', t_2'') (ms)	t_3 (ms)	t_h (ms)
NKB 1	borax + PPM /applied	0.480 ± 0.106	1.920 ± 0.211	3.425 ± 0.475	6.60 ± 0.219
PPM	PPM/applied	0.500 ± 0.113	1.690 ± 0.153	3.660 ± 0.339	6.32 ± 0.160
NSV 2	mica + water glass /applied	0.535 ± 0.208	2.07 ± 0.211	4.775 ± 0.325	6.68 ± 0.392
NE 1	special ceramics	0.275 ± 0.054	1.966 ± 0.047		5.80 ± 0.282
NE 2	dtto	0.500 ± 0.071	2.216 ± 0.094	4.175 ± 0.175	5.73 ± 0.188
NE 3	dtto	0.358 ± 0.025	1.075 ± 0.075/ /2.050 ± 0.071		6.26 ± 0.249
NE 7	dtto	0.510 ± 0.285	1.062 ± 0.012/ /1.800 ± 0.255	4.725 ± 0.512	6.48 ± 0.160
P 5	SIO_2/poured	0.415 ± 0.049	1.37 ± 0.108		6.20 ± 0.282
P 01	dtto	0.430 ± 0.072	0.8/1.270 ± 0.246	4.610 ± 0.224	6.48 ± 0.160
P 7	dtto	0.380 ± 0.058	0.4/1.180 ± 0.157	4.590 ± 0.445	6.46 ± 0.250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t_2
t_2''
t_3
t_h
t

FIG. 1.

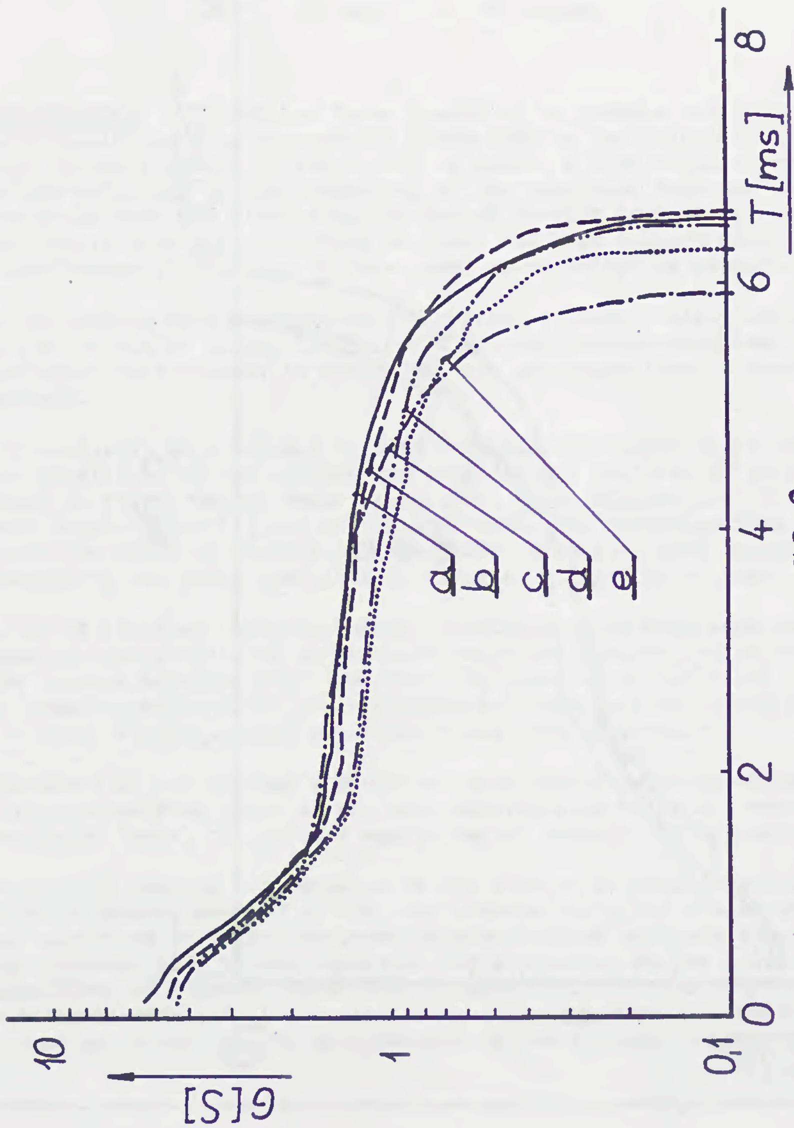

FIG. 2.

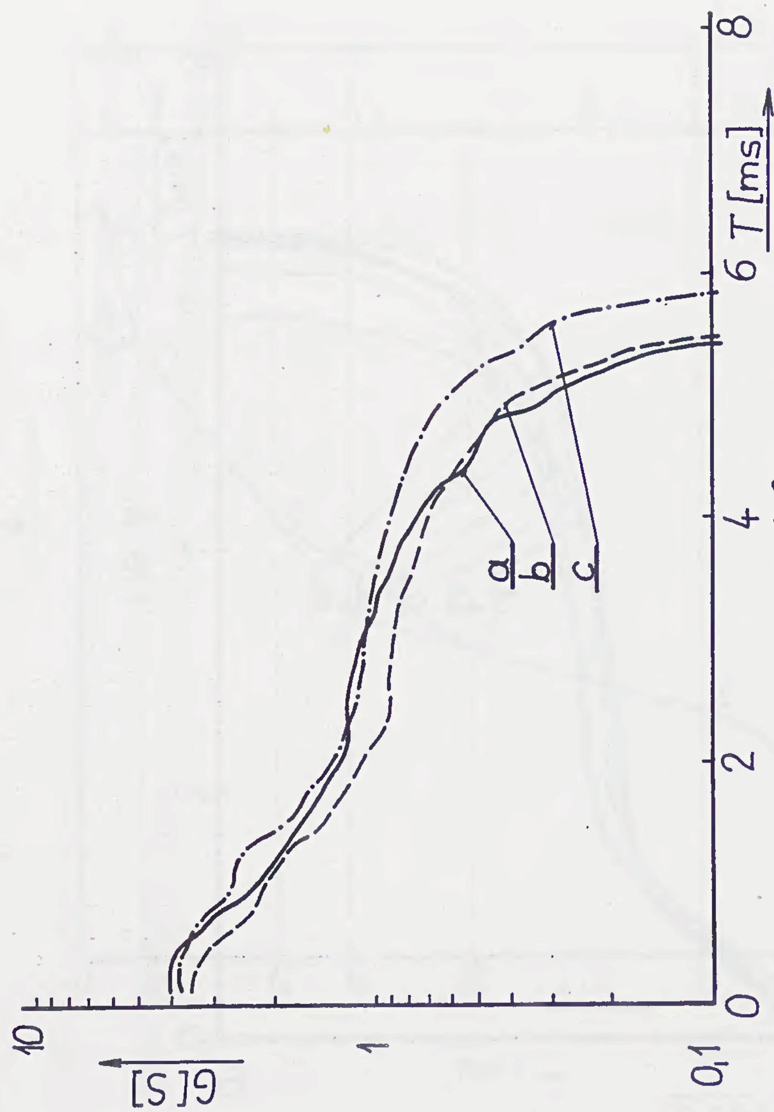

FIG. 3.