# High-voltage thin-layer fuses

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***Abstract:*** A new design and technology of high-voltage fuses is presented in this paper. The microelectronic technology was applied to form the fuse-element shape. The arc extinguishing process in high-voltage thin-layer fuses takes place in a narrow slot between insulating plates.
The making of the fuse-element in the form of the metal layer deposited on the insulating substrate, diminishing the fuse-element sensibility to damage and improving fuse-element cooling. The arc extinction in a slot between two insulating plates makes it possible to diminish the fuse-element length and operating $I^2t$.

***Keywords:*** high-voltage fuse, thin-layer fuse, fuse-link, fuse-element, characteristics

## 1. Introduction

The hitherto existing kinds of high-voltage fuses based on classical technologies have a number of flaws. The most important of them is the relatively long fuse-element necessary for efficient interruption of overloads and short-circuit currents. The long fuse-element increases the fuse dimensions and the power dissipation of fuses. In the case of classical fuses for small rated currents, the substantial difficulty is to obtain repeatable dimensions of a fuse-element and difficult process of assembling. Very delicate notches in the fuse-elements, often of cross-sections smaller then 0,05 mm$^2$, are easy to break. Thus, if the fuse-element is made in the form of a metal layer durably deposited on the insulating substrate, the fuse-element sensitivity to damage is radically diminished. As a consequence the reliability of fuse-links is improved and the width of the band of time-current characteristics is diminished. The width of the band of time-current characteristics is also diminished due to the better repeatability of cross-section of the constrictions. Using the available technologies it is possible to make the constrictions of a cross-section smaller than 0.0001 mm$^2$ with a tolerance of ± 3%.

It is possible to make the thin-layer fuses with ultra-quick and quick characteristics. The dimensions of such the fuse-links may be considerably smaller than the fuse-links used till now. However, to ensure compatibility with the present used fuse-bases, the authors assumed that the first manufactured fuse-links should have the external shape and dimensions of hitherto existing fuse-links.

Previously the investigations on the miniature thin-layer fuses with the fuse-element deposited on insulating substrate have been carried out in the Electrotechnical Institute Gdańsk Branch [1-3].

## 2. Thin-layer fuses for rated voltages above 1 kV

The main problem in high-voltage thin-layer fuse designing is to define the influence of the fuse-element shape (the number of constrictions, the distance between the constrictions, the number of parallel modules and the distance between the modules) on the breaking capacity of the fuses. Using the vacuum deposition technology for fuse-element manufacturing gives the designer freedom in the fuse-element forming. Nevertheless a very important design restriction is related to the dimensions of the glass-crystal insulating plate, on which the fuse-element metal layers are deposited. According to the manufacturer information it is not possible to make plates longer than 60 mm. This means that one plate is sufficient for a fuse-element for a voltage of up to 2.5 kV. By serial connection of the fuse-elements it is possible to obtain fuses for higher voltages, for example for 5 kV, 7,5 kV etc, i.e. a multiplicity of 2.5 kV.

In the case of d.c. fuses this level of working voltages is satisfactory because it makes possible to use these fuses in the railway traction at 1.5 kV d.c. and 3.0 kV d.c. rated voltages.

In the case of a.c. fuses it is very interesting to use thin-layer fuses of small rated currents (smaller then 1 A) for the protection of voltage transformers for rated voltages up to 6 kV.

The investigations of high-voltage thin-layer fuse models show new problems, which are not found in the classical fuses and which are related to the new unconventional fuse design. For example, the cracking of glass-crystal insulating plates during small over-currents is observed. The reason of cracking is not only the difference between the thermal expansion coefficients of epoxy resin (fuse body) and the glass-crystal plate, on which the fuse-element is deposited, but also the resin contraction owing to the cure process (a few percent).

To increase the fuse breaking capacity of overloads currents, the classic method of partitioning of the fuse element for parallel modules (strips) was used. For working voltages higher then 2.5 kV, the fuse construction should consist of two or even three serially connected glass-crystal plates with the deposited fuse-elements. To overcome interruption problems of low overcurrents the single modules shall be connected in series which is important in the case of interrupting the overloads. The bridging of the modules at the single plate terminal makes it impossible the correct switching of the arc between the modules in the area of the whole fuse-link. This is confirmed during the breaking capacity tests.

## 3. Fuse design

It was assumed that due to the assembly reasons, a fuse-link should not contain more then three plates with deposited fuse-elements connected in series.

The construction of the fuse-link was extended using the additional cover-plates (Fig. 1), which considerably diminish the influence of temperature stresses on the fuse-element. These stresses are generated by thermal shrinkage of the epoxy resin during air-tight sealing process. The efficient way to prevent cracking of the plates is by separation of the resin layer from the glass-crystal plate using another insulating plates also made from glass-crystal material.

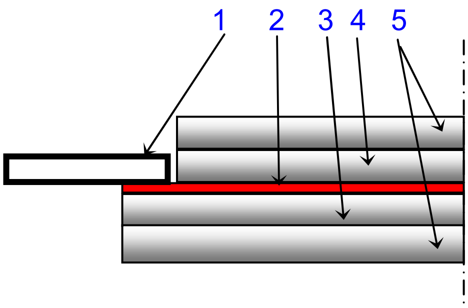


Fig. 1: The sketch of a traction thin-layer fuse after the introduction of the additional insulating cover plates – before air-tight sealing.
1 – termination, 2 – fuse-element,
3 – insulating substrate, 4 – cover plate,
5 – additional cover plates

After joining of three modules of the fuse-element (Fig.2) and solder the terminations, the fuse-element and cover plates are sealed with the epoxy resin air-tight sealing (fluidization method) (Fig.3).

The kind of shape of fuse-link was ensured by the inserting the fuse-element in the classical boron-silicate glass tube (Fig. 4).

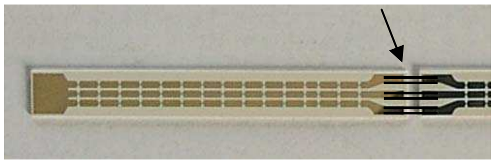

Fig.2: The insulating plate with the deposited fuse-element. The manner of joining of three modules of the fuse-element is indicated by the arrow.

Fig.3: Fuse-element of thin-layer fuse after epoxy resin air-tight sealing.

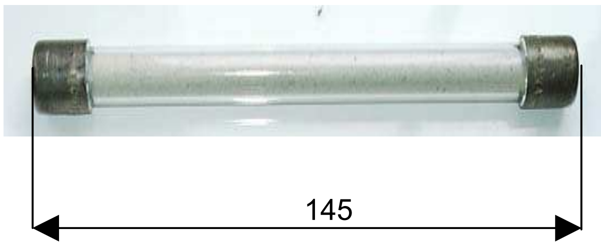


Fig.4: The traction fuse-link for the rated voltage of 3 kV d.c. and the rated current of 1.25 A.

## 4. Test procedure

The tests have been carried out on fuses, which were made using the new design and technology and designed for the rated voltage of 3 kV d.c. The test procedure included heating tests, breaking capacity tests, time-current characteristic tests and endurance tests.

### 4.1 . Heating tests

The heating tests were carried out according to the standards [4, 5]. These tests were used to estimate the rated currents, to verification of the contacts temperature rises and to evaluate the power dissipation of the thin-layer fuse-links. All test were positive. The measured power dissipations (from 2 to 6 W) were of about tens percent smaller then those presented in the catalogues of classical fuse-links.

### 4.2. Breaking capacity tests

The tests of high-voltage d.c. thin-layer fuses were carried out according to the Polish Standard [4], which is in principle based on the international standards for low-voltage and high-voltage fuses. These tests consist of:

- Rated breaking capacity test at the current $I_1$ of about 40 kA and the time constant of 9,9 ms;
- breaking capacity tests at the prospective current $I_2$ (critical current);
- Minimum breaking capacity test at the current $I_3$.

All the tested fuse-links (of a rated currents from 1.25 A to 3.15 A) correctly interrupted the $I_1$ and $I_2$ currents. The overvoltages did not exceed 13.4 kV. Fig. 5 shows the example of the records of interrupting of the prospective current $I_1$ by the traction thin-layer fuse.

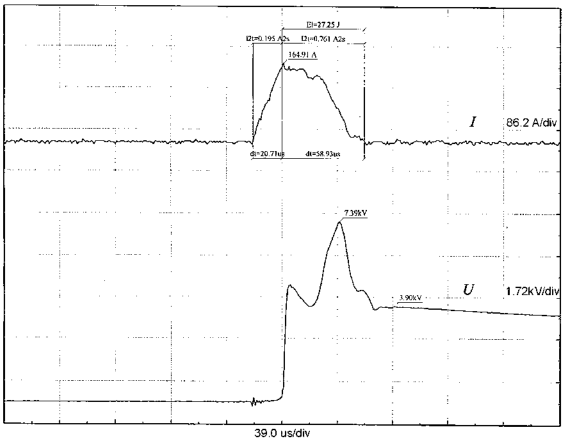


Fig.5: Records of interrupting of the prospective current $I_1$ of ab. 40 kA, 3.9 kV d.c., time constant 9.9 ms by the traction thin-layer fuse of the rated current of 3.15 A.

The results of the minimum breaking capacity tests were positive in a range of currents no smaller then 2.5 $I_n$.

### 4.3. Time current characteristics

There are no special requirements of the standards [4, 5] regarding the shape of the time-current characteristics for high-voltage fuses. There are only recommendations relating to it verification and plotting.

The time-current characteristics of d.c. thin-layer fuses are presented in Fig. 6. The broken lines mark the parts of the time-current characteristics, in which the fuses fait to break the current.

The difference between the rate of rise of a time-current characteristics of the fuse-links for rated current of 1.25 A and the fuse-links for all other rated currents is due to the fuse-element design.

### 4.4. Endurance test

There are no endurance tests listed in the standards [4, 5] for high-voltage fuses. However, with regard to the used unconventional fuse-link in new traction fuses it seems necessary to carry out the endurance test to repeated overloads. The endurance test according to IEC 60127-1 [6] and 60127-2 [7] was used as a base, because this test seems to be the one of the hardest endurance tests of the fuse-link. In this test the current of 1.2 $I_n$ is passed through the fuse-link for a period of 1 h. The current is then switched off for a period of 15 min. This cycle is repeated 100 times. Finally the fuse-link is loaded with the current of 1.5 $I_n$ for 1 h and the power dissipation is measured.

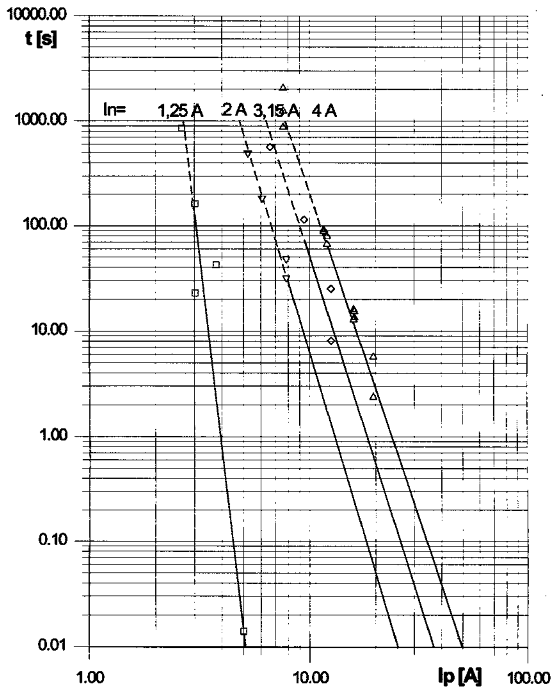


Fig.6: Example of the time-current characteristics of d.c. high-voltage thin-layer fuses.

The endurance test was performed only on the fuse-links of the highest rated current because these fuse-links are exposed to the highest temperature rises. During the cycles the condition of fuse-element was monitored by the measurement of the power dissipation before the end of same overload periods. Any ageing of fuse-element was noticed during the load current of 1.2 $I_n$. It was observed that the power dissipation diminish during endurance tests, which means diminishing of the fuse–element resistance. It was probably due to recrystallization of vacuum deposited metal layers of the fuse-element. After finishing the overload cycles the resistance of the fuse-links was measured again and the control test was performed on one of the tested fuse-links. This fuse-link was loaded with conventional non-fusing current of 1.5 $I_n$ for 1 h and next with conventional fusing current of 1.9 $I_n$. The tested fuse-link did not operate during conventional non-fusing current and the pre-arcing time measured during conventional fusing current was no shorter then the pre-arcing time of fuse-links which were not subjected to the endurance test.

As there was no noticed any ageing of the fuse-element, the endurance test was continued with the current raised to 1.5 $I_n$. Next 100 overload cycles were performed. After finishing the overload cycles test the resistance of the fuse-link was measured and the control test was performed. This fuse-link was loaded with the conventional fusing current of 1.9 $I_n$. The pre-arcing time measured for the conventional fusing current was insignificantly shorter than that of fuse-links which were not subjected to the endurance test. This means the possibility of initiation of ageing process.

As a summary of the endurance tests one can say that it is possible to state that the fuse-links with thin-layer fuse-elements are resistant to ageing process when loaded with the rated current and small overcurrents.

## 5. Conclusions

The design of high-voltage thin-layer fuses radically differs from that of existing fuses. The new technology makes it possible not only to improve technical parameters of the fuse-link but also to diminish fuse dimensions.

The essential limitation for high-voltage thin-layer fuses is the rated voltage, which should no exceed 3 kV d.c. and 6 kV a.c. Also the rated currents should not be higher then 3.15 A. The design of the thin-layer fuses for the rated voltages exceeding 3 kV d.c. and 6 kV a.c. causes essential assembling difficulty which considerably enlarge costs of production. On the other hand the design of the thin-layer fuses for rated currents exceeding a few amps makes it necessary to deposit the fuse-element layer exceeding 1.5 μm in the thickness. The tests show that in this case the benefits from arc quenching in narrow slot between glass-crystal plates are lost. The enhanced quantity of silver vapour created during the arc quenching process is not absorbed by the structure of glass-crystal material. It is possible to design thin-layer fuses for very small rated currents (considerably smaller then 1 A), which is very difficult in the case of classical fuses.

The thin-layer fuses may be manufactured as fuses of ultra-quick and quick time-current characteristics. As the thin-layer fuses have very small $I^2t$ (Joule's integral) it is possible to use them for the protection of semiconductor devices. Due to the very fast recovery of electric strength, the thin-layer fuses could be particularly useful in d.c. circuits.


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