A COMPARISON OF CURRENT INTERRUPTION BY SAND SiO_2 AND SAND SiO_2/GAS SF_6 FUSES

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Abstract: The comparison described below is based on the interrupting currents of test duty 1, 2 and 2a according to IEC Publ. 269-4. Special test arrangement for SiO_2/SF_6 has been applied. Semiconductor SiO_2 and SiO_2/SF_6 fuses with friable and stone sand of 1000 V, 160 A were tested. The conclusions show on needs of further more detailed investigations mentioned at the end of paper. The results show superiority of SiO_2/SF_6 fuses with friable sand as concerns the post-arc behaviour.

1 Introduction

In 1890 Modrey was invented widely used since seven decades the sand SiO_2 high breaking capacity fuses (h.b.c.), in this report briefly denoted: SiO_2 fuses. The information about this one can trace in [1]. These fuses do offer a very good short-circuit current limiting ability. It is also well known that their ability to interrupt small overloads is insufficient. Although SiO_2 fuses with special improvements are in position to correct interruption of even prospective currents smaller than their rated current (so-called full-range fuses), but their costs are relatively high. It is world wide practice to avoid such fuses by an application of two-component protection. For example, in medium voltage (MV) distribution systems a routine solution is a load-switch-fuse combination. The former provides small overload protection, whereas the latter ensures effective short-circuit protection.

But the problem how to get a cheap full-range fuse still occupies the brains of fuse designers.

One of the possible classical way to get the full-range MV fuses are two-chain fuses [e.g. 2,3,4]: of which one is SiO_2 fuse while the second is gas-expulsion, or vacuum, or SF_6 fuse. Many other suggestions how to solve practically the problem one can trace especially in the patent documents. For instance, one such document [5] offers SF_6 gas generation during arcing process from a piece of material placed in the SiO_2 fuse arc-chamber.

Unavoidable design which one can expect as a successful solution should be SiO_2 fuses within air in interstices between sand grains replaced by SF_6 gas. In abbreviation they are in the following named SiO_2/SF_6 fuses. In the open literature there is lack informations about the switching behaviour of such fuses. That's why the first aim of the paper is to show the results of more systematic investigations done recently in the Chair of Electrical Apparatus of the Technical University of Gdańsk on such fuses. The investigations in question are purely experimental because of the complexity of the arc interaction with SiO_2 sand in combination with SF_6 gas.

Unfortunately due to the cost of such investigations in a short-circuit test station the report is limited only to one characteristic design SiO_2/SF_6 fuses. Although the results from this reason are not complete in order to enlight the problem generally, it seems, they speak sufficiently clear about complexity of the problems associated and therefore it is possible to formulate a number of questions for the future investigations. This task is also in view of the paper.

The next not less important conclusion eventually to withdraw from experiments is a comparison of SiO_2 versus SiO_2/SF_6 fuses in different test conditions. To enrich the conclusions two variants of SiO_2 and SiO_2/SF_6 fuses were tested: with friable and with stone-sand.

2 Test samples

It seems, the best selection of fuse samples for a comparison SiO_2 versus SiO_2/SF_6 fuses shall be based on an average practical fuse design. Such a view can be fulfilled, for instance, by considering in a comparative study the fuses for power semiconductor devices protection. A multiple combination of 4 parallel fuse-element (**Fig.1**) made from silver strips was assembled in the fuse-link shown in **Fig.2**. Half of such fuse-links were placed in a special insulating case demonstrated in the **Fig.3** to facilitate the filling they up by the gas SF_6 under absolute pressure 300 kPa. A special checking procedure showed that the SF_6 gas bakge from so arranged SiO_2/SF_6 fuses over the time between filling up by gas on the fuse interrupting test is negligible. To get glued sand corns of stone-sand fuses the processing was used as described e.g. in [6].

For assumed test procedure, which had to be comprised standard IEC test duty 1, 2 and 2a, it wasdecided that 9 samples of a given fuse variation shall be sufficient. It was constrained by the short-circuit test costs in a full power short-circuit test station. It means it was accepted 3 shots of every variation as sufficient minimum. So the total number of tested samples was 36 as it is specified below:

- 9 samples - friable SiO_2, air in pores,
- 9 samples - stone SiO_2, air in pores,
- 9 samples - friable SiO_2, SF_6 in pores,
- 9 samples - stone SiO_2, SF_6 in pores.

The fuse rated data were: 160 A, 1000 V.

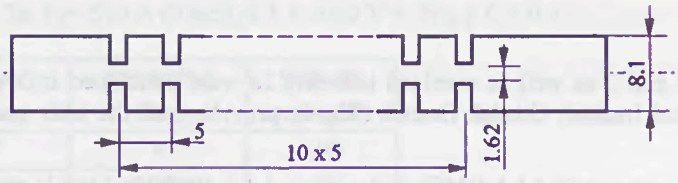
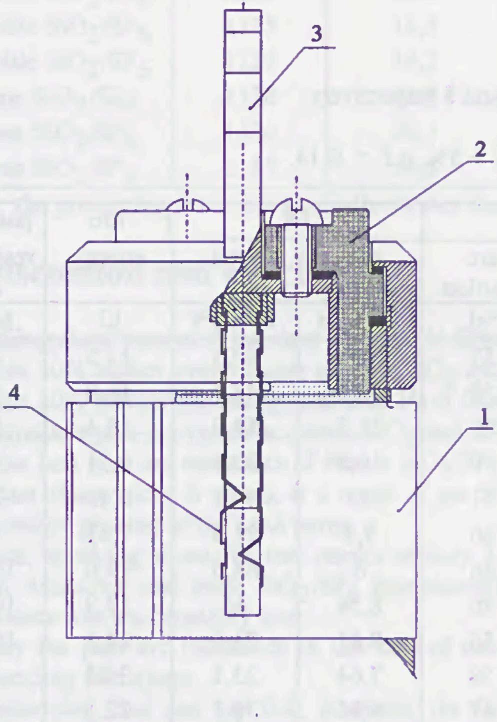


Fig.1. Tested fuse-element, Ag, 0.16mm thick
Necks additionally constricted by a groove up to 40 ± 3μm



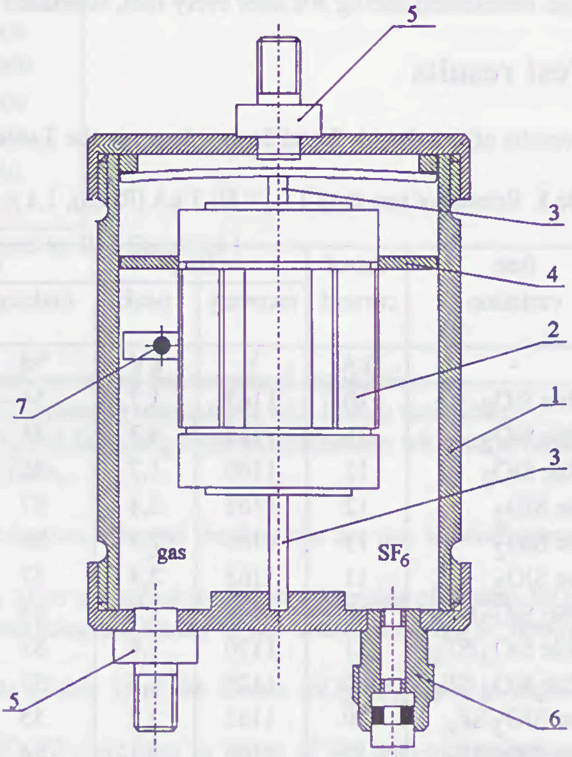


Fig.2. Partial cros-sectional view of tested fuses
1 - aluminium body, 2 - ceramic bushing,
3 - copper terminal, 4 - fuse-element

Fig.3. Fuse asembly for test with SF$_6$
1 - PCV envelope, 2 - tested fuse, 3 - fuse terminals
4 - suport ring, 5 - assembly terminals,
6 - valve for gas SF$_6$, 7 - gas inlet into tested fuse

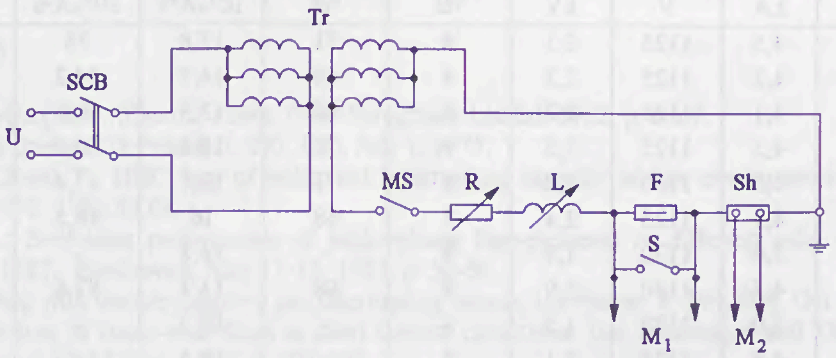


Fig.4. Test circuit
SCB - safety circuit braker, MS - making switch, S - switch,
M$_1$, M$_2$ - measurement, Sh - shunt

3 Test circuit

Short-circuit test duty 1 and 2 as well as overload test duty 2a were performed in a professional short-circuit test station of Electrotechnical Institut, Gdańsk Branch (**Fig.4**), providing all the tests parameter agreed with the IEC Publ. 269-4., namely:

Test duty 1: prospective current 60.3 kA(RMS), test voltage 1.1 x 1000 V= 1100 V a.c., p.f.= 0.14, source recovery voltage maintained during 30s after every shot, resistance measurement abt 1 min after shot by a 500 V d.c. megger.

Test duty 2: prospective current 4.75 kA(RMS), test voltage 1.1 x 1000 V=1100 V a.c., p.f. = 0.21, source recovery voltage maintained during 30s after every shot, resistance measurement abt 1 min after shot by a 500 V d.c. megger.

Test duty 2a: prospective current 510 A(RMS), test voltage 1.1 x 1000 V= 1100 V a.c., p.f.= 0.4, source recovery voltage maintained during 30s after every shot, resistance measurement abt 1 min after shot by a 500 V d.c. megger.

4 Test results

The results of test duty 1, 2 and 2a are shown in the **Tables 1, 2** and **3** respectively.

Table 1. Results of test duty 1: I_1= 60.3 kA (RMS), 1.1 x 1000 V + 5%, p.f. = 0.14.

fuse	cut-of	voltage		angle		I^2t		arc	post-arc
variation	current	recovery	peak	making	arc ignition	pre-arcing	total	energy	resistance
-	kA	V	kV	°el	°el	10^3xA^{2}s	10^3xA^{2}s	kJ	MΩ
friable SiO_2	10	1163	1,7	54	57	8,92	40,3	14,5	40
friable SiO_2	11	1165	1,7	54	58	9,90	48,4	16,8	40
friable SiO_2	12	1160	1,7	83	86	11,7	52,9	13,4	50
stone SiO_2	12	1165	2,4	87	90	10,8	30,4	8,31	22
stone SiO_2	13	1165	2,3	88	91	13	36,1	8,43	20
stone SiO_2	11	1165	2,4	57	60	9,3	21,3	7,61	16
friable SiO_2/SF_6	10	1168	1,7	83	86	6	68,5	19,6	1000
friable SiO_2/SF_6	11	1170	1,8	83	86	8,56	46	12,9	1000
friable SiO_2/SF_6	10	1170	1,7	53	56	8,41	71,6	24,1	1000
stone SiO_2/SF_6	10	1165	2,2	55	58	7,64	23,1	9,85	7
stone SiO_2/SF_6	12	1160	2,1	84	87	9,36	38,1	12,1	16
stone SiO_2/SF_6	13	1165	2,4	86	89	11,7	35,1	7,81	45

Table 2. Results of test duty 2: I_2= 4.75 kA (RMS), 1.1 x 1000 V +5%, p.f. = 0.21.

fuse	cut-of	voltage		angle		I^2t		arc	post-arc
variation	current	recovery	peak	making	arc ignition	pre-arcing	total	energy	resistance
-	kA	V	kV	°el	°el	10^3xA^{2}s	10^3xA^{2}s	kJ	MΩ
friable SiO_2	4,5	1125	2,1	8	71	17,8	75	25,6	1000
friable SiO_2	4,2	1125	2,2	8	68	14,3	54,2	22,2	200
friable SiO_2	4,1	1125	2,2	8	66	13,3	68,6	24,1	140
stone SiO_2	4,5	1125	2,5	9	72	18,2	50,1	21	10
stone SiO_2	4,5	1130	2,7	8	71	18,7	47,4	20,3	35
stone SiO_2	4,3	1125	2,4	7	68	16	48,2	20,8	5,5
friable SiO_2/SF_6	5,0	1130	1,9	8	-	14,8	-	-	1)
friable SiO_2/SF_6	4,5	1130	2,0	8	68	14,4	87,6	26,4	1000
friable SiO_2/SF_6	5,0	1130	1,5	8	-	17,3	-	-	1)
stone SiO_2/SF_6	4,5	1125	2,1	8	-	18,5	-	-	0,2 2)
stone SiO_2/SF_6	4,6	1125	2,6	8	73	19,6	55,8	22,1	5,5
stone SiO_2/SF_6	4,5	1120	2,9	7	70	17,6	51,6	21,4	3,5

1) the fuse failed

2) late regnition, but the interruption without visible failure

Table 3. Results of test duty 2a: I_3= 510 A (RMS), 1.1 x 1000 V + 5%, p.f. = 0.4.

fuse variation	recovery voltage	pre-arcing time	post-arc resistance
-	V	s	MΩ
friable SiO_2	1120	19,8	45
friable SiO_2	1115	17,3	140
friable SiO_2	1115	15,7	75
stone SiO_2	1120	26,9	4,5
stone SiO_2	1125	30,2	7
stone SiO_2	1120	36,4	7
friable SiO_2/SF_6	1125	15,2	400
friable SiO_2/SF_6	1125	14,5	1000
friable SiO_2/SF_6	1120	14,2	600
stone SiO_2/SF_6	1120	26,8	29
stone SiO_2/SF_6	1120	30,3	40
stone SiO_2/SF_6	1115	30,8	30

Note: the pre-arcing times are generally shorter than required by IEC Standard !

5 Discussion and conclusions

Thinking about results of test duty 1 (Table 1) first of all one can admit four expected regularities:

- abt 30% higher overvoltages of stone SiO_2 and SiO_2/SF_6 fuses in comparison with friable variations,
- abt 50% greater arc energy and total I^2t of friable SiO_2 and SiO_2/SF_6 fuses in comparison with stone variations,
- smallest post-arc resistance stone SiO_2 and SiO_2/SF_6 fuses,
- the best post-arc resistance of friable SiO_2/SF_6 fuses.

The last observation, it seems, is a result of gas SF_6 introduction, whereas the first two are due to reinforcement of the sand by glueing of the sand corns.

In turn, speaking about the test results of duty 2 (Table 2) to underline is that two samples of friable SiO_2/SF_6 failed. Moreover one stone SiO_2/SF_6 fuse showed late restriking but finally it did interrupt correctly, however its resistance was unacceptably low.

Finally the post arc resistance in the case of test duty 2a (Table 3) of the friable SiO_2/SF_6 fuses is higher that outstanding variations.

Summarising, one can say that, it seems, the friable SiO_2/SF_6 arc best in terms of the post-arc resistance. But generally, the advantages of friable and stone SiO_2/SF_6 fuses are not so distinct as it was expected.

A univocal phisical interpretation of results of § 4 is dangerous because in fact particularly the samples with SF_6 can react very in unpredictable way on the arc quenching. There are at least 3 different influences and/or their combinations on the fuse behaviour: sand, SF_6, chemical substances used for sand grain glueing. That's why the following minimal program of the future investigations in question is desirable:

- widen the scope of fuse-element materials and shapes,
- to provide different processing of sand grain fastening [e.g. 7,8],
- to use different grain sizes.

6. References

[1] Wright A., Newbery P.G.: Electric Fuses. Peter Peregrinus Ltd Ed. 1982, p. 6 a.7.
[2] Harner H.: Fuse device. US-Patent, 3, 893, 056, July 1, 1975.
[3] Kacprzak B., Lipski T.: HBC fuse of unlimited interrupting capacity of low overcurrents (in Polish). Polish patent. No. 259452, 1986.05.08.
[4] König D. et. al.: Switching performance of high-voltage fuse-elements in different solid and gaseous filling media. ICEFA-1987, Eindhoven, May 11-13, 1987, p. 50-56.
[5] Blewitt D.D.: Fuse with electro-negative gas interrupting means, US-Patent, 4, 544, 908, Oct. 1, 1985.
[6] Lipski T.: Behaviour of stone-sand fuses in short circuits conditions. Gas Discharges and Their Applications, X Int. Conf., Swansea 13-18 Sept. 1992, p. 204-207.
[7] Frind G., Owen U., Damsky B.L. US-Patent No. 3, 838, 375, 1974.
[8] Goldstein M.: Electrical fuse. 4, 893, 106, Jan. 9, 1990.