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CONTRIBUTIONS CONCERNING NEW EXTINCTION MEDIA IN ULTRA-FAST FUSES UP TO 2000 V a.c.

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The authors' intention as it results from this paper is to present some of the researches made in our Institute in order to find out new extinction media for high-speed fuses. The new obtained extinction media have allowed significant improvements in these fuses perforformance: increase of electrical performances, decrease of the constructive overall dimensions comparing to the constructive version which uses the quartz sand as filler silver replacement by copper in fuse element manufacturing.

1. Introduction

The research of a new arc filler for high-speed fuses,another one different from the quartz sand,became more than necessary only two years ago when, by our government order the silver tape delivery was completely stopped. From that moment all our efforts were directed to find out a new filler which could allow the use of copper in fuse element manufacturing.

This new filler, which is a compact-rigid material, not only that it practically prevents copper oxidation whose negative effects are very well known, but, by its special properties concerning arc quenching and heat transfer, has allowed the decrease of the constructive overall dimensions and the increase of the nominal current within the given dimensions.

Up till now, our researches have resulted in the certification in prototype phase,according to IEC 269-4-1986[1] of the following copper fuses:

- high-speed fuses of 660 V a.c, sizes 1, 2 and 3, fixing distance 80 mm, 100-630 A
- high-speed fuses of 660 V a.c, size 00, fixing distance 80 mm, 16-200 A
- high-speed fuses of 1000 V a.c, size 3, fixing distance 110 mm, 500 A and 630 A
- high-speed fuses of 1250 V a.c, size 3, 400 A, 800 A, 1150 A
- high-speed fuses of 1500 V a.c, sizes 2 and 3, fixing distance 140 mm, 350 A and 400 A
- high-speed fuses of 2000 V a.c, size 3, fixing distance 170 mm, 350 A

All these sizes are in conformity with DIN 43653 standard[2].

The last two types of fuses presented above have been made of silver fuse-elements and a compact-rigid filler. That is because of the ceramic body which, in our country hasn't reached the performance level obtained by the industrially developed countries.

Of course, this compact-rigid filler may be also applied to high-speed fuses with silver fuse-elements. Their performances will be clearly superior to those with copper fuse but their cost will be higher.

2. The compact-rigid filler

The compact-rigid filler generally consists of a refractory material with high resistivity and high dielectric rigidity and of an organic or anorganic binder. As refractory materials it is better to use oxides or nitrides of metals such as: silicon, magnesium, aluminium, beryllium, calcium or strontium and their mixtures. SiO_2 having the highest electric resistivity among all the known insulators and being easily available as quartz sand, is generally much used for this purpose. Such materials are well settled within the fuse, the settling degree being maintained between exact limits.If these limits are exceeded the damping effect is no longer obtained. The refractory material is reinforced under the form of a rigid body by mixing it, before or after filling with an organic or anorganic binder which is added in an enough quantity to cover each particle of the refractory material without sensibly diminishing its porosity.

The used binder must not entail a degradation of the electric characteristics of the filler which is added to, when the fuse operates and the compact mass (material+binder) is subject to the electric arc high temperature.

The filler main role is to interrupt as rapidly as possible the electric arc which appears within the fuse when the shortcircuit cuts the current. A secondary but important role is that of the heat transfer within the fuse to the insulating body and from this one to the air.

The voltage on a single notches range,as Mr.Turner[3] says, is limited and can't be significantly raised without introducing current limits which condition fuse operation.

However, if the notches range number could be reduced (more volts on each notches range) this would mean a corres corresponding reduction of the dissipated power and of the fuse dimensions. All these advantages resulted from the new filler we have obtained as a better alternative to the quartz sand. During the latest years,we have developed a number of compact-rigid filler among which we have chosen the filler consisting of quartz sand and a reinforcing binder. This compact-rigid filler can be obtained by applying a special compaction and reinforcing technology. As a result of the experiments made on electric fuses,it was found that this filler had higher properties comparing to quartz sand, concerning particularly three directions.

The first direction consists of finding out a compact material which could prevent oxygen permeation to fuse elements and consequently their oxidation. The filler compaction was characterized by porosity determinations and water absorption. The filler porosity is 17%. The second direction was that of eliminating as much possible,the air thus improving the heat transfer. The third direction consists of laminating and cooling the electric arc, extinguishing it as rapidly as possible, with a strong decreasing evolution of the arc current. There fore the fuses with compactrigid filler have a cut limited current and I^2t smaller than the fuses with quartz sand as filler.

As we have shown above, the base compact-rigid filler component is the quartz sand which in out country is mainly obtained at the Miorcani quarry. The quartz sand quality must provide a strong pressure and cooling of the electric arc. Thus, as Mr.Barbu[4] considers, a good quartz sand must include in its composition over 99% SiO_2; under 0.03% Fe_2O_3; under 0,5% Al_2O_3; under 0.2% CaO; under 0.04% TiO_2. The quartz sand action is connected with the metal vapour quantity produced by the material which constitutes the fuse-element. For instance, the silver or copper fuse-elements produce a smaller quantity of metal vapours in the electric arc, fact that favours its extingnishing. In their papers, Mr. Lipski[5] and Mr.Bratinov[6] mention that from the point of view of gases which are developed during the electric arc, the quartz sand produces the minimum pressure among all friable media. The quartz sand grains can store an energy of approximatively 2 kJ.

A very important problem is that of filler settling. The fuse ceramic body volume must be filled in proportion of 60...80% from the total volume, taking into consideration the dimensions, the particle distribution and their settling degree, the rest representing the vacancies among which the metal vapours can diffuse in order to cool and extinguish the arc.

The experimental results indicate the fact that, by the filling density increase, a series of fuse operation characteristics regarding fault current intrerruption are improved: arc time decrease, arc I^2t, arc energy and fulgurite length decrease.

However, as it also results from Mr.Namitokov's paper[7], there are two parameters which deteriorate concurrently with the filling density increase: the arc voltage and the pressure of the ceramic body wall. While the arc voltage continuously raises together with the filling density, the pressure raises together with the filling density up to 1,73 g/cm^3 value, and then strongly decreases together with the filling density increase. Consequently, the compaction density was chosen at minimum 1.74 g/cm^3 when all the fuse characteristics are considerably improved.

As we all know, with high speed fuses, the maximum admissible arc voltage in operation is 2,5 x utilization voltage for utilization voltages between (0.7...1.1) xthe nominal voltage. There must also be attentively analysed the quartz sand components and their effects. For instance the components which can develop gases within the electric arc, such as $CaCO_3$, must be eliminated. $CaCO_3$ elimination is made by quartz sand heating at approx.950°C, obtaining in this way the following chemical reaction:

$CaCO_3 \rightarrow CaO + CO_2 + 17800$ J/kg.

The water content is eliminated from the quartz sand by heating it at approx.100°C before filling. The metal oxide content (Al_2O_3 and Fe_2O_3) has negative effects.

As not all the quartz sand deposits are rich in SiO_2, in many cases the respective sand must be enriched. One of the methods consists of its wash in HCl.

3. Fuse elements

The compact-rigid filler made possible, for the first time in our country, the use of copper instead of silver in the manufacturing of fuse elements meant to high-speed fuses. Our laboratory has, besides the research concerns in the field of low voltage fuses, also an operation plant for high-speed fuses meant as spare parts in different driving models in the cement industry, the aluminium industry, oil-field exploitation, transport, a.s.o. Therefore, for a couple of years we have manufactured high-speed copper fusesand their operation behaviour is very good.

Material choice for fuse element construction depends on the metal physical-mechanical parameters and of the fuse type. The main parameters that must be taken into account are presented comparatively for several metals, in Table 1.

Table 1

Material/ Parameters	Al	Ag	Cu
Resistivity 10^{-6} [Ω.cm]	2.55	1.51	1.63
Density [g/cm^3]	2.7	10.5	8.9
Specific heat [W.s/g°C]	0.86	0.23	0.38
Thermal conductivty [W/cm°C]	2.26	4.18	3.9
Melting temperature [°C]	659	961	1083
Vaporization temperature [°C]	2400	1950	2350
Mayr constant $10^8[(A/cm^2)^2s]$	2.94	6.64	9.55

It can be observed that silver has the best electrical properties and it's necessary to be used to high speed-fuses with excellent performances: small operation I^2t, reduced dissipated powers, high lifetimes, a.s.o.

It is also known the fact that silver oxidizes during fuse operation,but the thickness of Ag_2O layer is ranged at 10^{-9} m and the oxide formed in this way prevents the further oxidation of silver, silver oxide being a good conductor of electricity.

Copper is the most used in fuse element manufacturing for low voltage fuses mainly those of general use: rapidly fuses (gG type) and slow fuses (aM type), where notches have larger sections than high-speed fuses.

The use of copper in fuse elements manufacturing for high-speed fuses is avoided due to copper pronounced oxidation. We know from the literature[8] that copper oxide layer thickness which is not a good electricity conductor, increases in time, following the relation:

$$g = 30\,(1 + \sqrt{t}\,.\,e^{0.013.\Theta}) \qquad [\text{Å}]$$

where: t-is the operation time, in hours; Θ is the operation temperature in K.

In order to verify electro-thermal stress effects on copper high-speed fuses with a compact-rigid filler we have made endurance tests according to IEC 269-4/1986 international standards[1]:

-100 cycles, each compound from an active time and a break time, equal between them and with 0.1 of the conventional time, the fuse current being its nominal current

-100 cycles with a total time for each of them of 0.2 of the conventional time,the active part of the cycle being of the 6 seconds, when the replacing element is traversed by the over load current equal with $1.6.I_n$ for $I_n \leqslant 100$ A, or with $2I_n$, for $I_n > 100$ A

Besides these classical tests we have also made a whole series of special tests presented in the next chapter.

4. Experimental resuts

The high-speed fuses with compact-rigid filler material presented in chapter 1 were subject to the whole test programme according to IEC 269-4/1986[1], only in alternativ current and certificated. The main electrical parameters obtained as a result of these tests, only for a few types of fuses are presented in Table 2.

As for the high-speed copper or silver fuses of 500 A, 660 V a.c and 1000 V a.c besides the tests imposed by standards, there were made a few special tests:

-the fuse of 500 A, 660 V a.c was continuously subject to a 400 A current. It already has 3321 operation hours and didn't blow. This current represents the equivalent current prescribed by the standards. As a matter of fact the firms LK-NES[9] and Ferraz[10] warrant the electric endurance of the high-speed fuses at 0.8 I_n

-the fuses of 500 A, 1000 V a.c both with copper and silver fuse-elements were subject to their nominal current in 24 minutes active cycles and 24 minutes break. The results are presented in Table 3.

Table 2

Electrical parameters Fuse type	Power loss [W]	I^2t total at U_n $[A^2s]\times10^3$	Arc voltage atU_n [V]
UR-350A-660V-Cu size 1	55	109	1050
UR-500A-660V-Cu size 2	83	245	1027
UR-630A-660V-Cu size 3	103	390	1050
UR-200A-660V-Cu size OO	49	3	1229
UR-500A-1000V-Cu size 3	122	3	1850
UR-500A-1000V-Ag size 3	112	322	1860
UR-400A-1250V-Cu size 3	110	235	1960
UR-800A-1250V-Cu size 2x3	217	680	1950
UR-1150A-1250V-Cu size 2x3	308	1700	1960
UR-350A-1500V-Cu size 2	126	165	2800
UR-400A-1500V-Ag size 3	130	145	2400
UR-350A-2000V-Ag size 3	149	196	3540

Table 3

Crt. No.	Internal resistance [mΩ]	Fuse material	Number of achieved cycles
1.	0.22	Ag	220
2.	0.26	Cu	227
3.	0.26	Cu	144
4.	0.26	Cu	484

-19 high-speed copper fuses of 500 A, 1000 V a.c which were stored during 1 year, were then tested at 1000 V.a.c. and currents between 4000 A and 38400 A. The fuses behaved very well considering the standards

-the 500 A, 1000 V a.c copper and silver fuses were subject within IPH-Berlin, to a test of the breaking capacity-160 kA, 1100 V a.c.

They worked very well. It resulted that the copper fuse parameters are close to silver fuse parameters. This is also due to the fact that the fuse system for the copper fuses is improved

-the copper fuses of 500 A, 1000 V a.c with a surrounding metal screen, were subject to 1100 V a.c, the current I_2 = 8000 A. It wasn't observed any ionization and breaking of the space between fuse and screen

-silver and copper fuses of 500 A, 1000 V a.c wadding covered were also subject to 1100 V a.c, the current I_2. It wasn't observed any exterior plasma ejection

As a result of these additional tests, we have drawn the conclusion that high speed copper fuses present guarantees in operation.

5. Conclusions

- the fuse filler based on quartz sand, is reinforced under the form of a compact-rigid body, by means of a special tehnology
- the binder quantity provides the compaction and the reinforcing but, at the same time, keeps a certain porosity of the filler necessary to extinguish the electric arc
- the compact-rigid filler doesn't change neither during fuse operation under a nominal regime nor during the electric arc discharge as it results from the special tests which high speed fuses were subject to
- the compact-rigid filler prevents oxygen permeation to fuses and therefore their oxidation, improves the heat transfer from the fuses to the ceramic body and provides the strong lamination and cooling of the electric arc
- there have been manufactured and certificated high-speed copper fuses having a compact-rigid filler
- as a result of the special tests made, mainly regarding the electrical endurance, we have found that high-speed copper fuses behaved in accordance with the standards and present guarantees in exploitation
- taking into account the analysis of the electrical parameters of high-speed copper fuses and the compact-rigid filler we can find out that their values are close to the similar parameter values of high-speed silver fuses.

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Session 4

MINIATURE FUSES