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EXPERIMENTAL INVESTIGATIONS ON MATERIAL INFLUENCES OF SILVER-METAL-OXIDE CONTACT MATERIALS FOR CONTACTOR APPLICATIONS

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ABSTRACT

Silver-metal-oxides are widely used as contact materials for industrial contactors. The use of contact materials with reduced silver content to be more cost effective and the miniaturization of devices establish new demands on the performance of contact materials. Furthermore these tendencies are enforced by reductions in the volume of contact material and lower contact forces. This paper presents basic material influences on the switching behavior in contactor application. Experiments performed by usage of a break-only model switch and in contactor applications show the impact of metal-oxide content to contact resistance and erosion rates. Furthermore the influence of metal-oxide content on welding tendencies has been studied by experiments applying a make-only model switch. Based on these studies the paper summarizes the basic material influences of metal-oxides on the switching performance of industrial contactors.

Index Terms - Contactor, contact material, silver-metal-oxide, silver-tin-oxide

1. INTRODUCTION

Miniaturization, power consumption and of course cost efficiency have become the driving factors in modern power systems. This leads to switching device designs with smaller contact tips and/or usage of contact materials with reduced silver content. Furthermore devices and actuating mechanisms are miniaturized to the limit. Economizer circuits are used to reduce the power consumption while the contacts are closed in contactor design.

Silver tin-oxide materials are manufactured with metal-oxide contents of 2 wt% to 15 wt%. Basic guidelines for the selection of silver metal-oxides for contactor applications are given in [1]. Silver tin-oxides are composite materials in which oxide particles are embedded in the metallic matrix of silver. The metal-oxides cause severe brittleness in the material, which in turn considerably reduces the tendency to weld. The metal-oxides also increase the viscosity of the melt in response to arcing and hence reduce erosion of the contacts caused by spattering.

Besides the basic components, silver and tin-oxide, additives can be used to specifically influence the mechanical and switching properties. For example, other metal-oxides such as WO_3, MoO_3 and Bi_2O_3 are known in combination with Ag/SnO_2. In comparison to the SnO_2 content they are added in much smaller quantities [2-4]. This advantage had a very decisive influence on the breakthrough of Ag/SnO_2 [2-4]. Not only the contact resistance may be improved by additives, they can also be used to control the resistivity against welding and the erosion rate [5, 6].

Therefore contact and switching properties of silver-tin-oxides are determined to a great extent by the manufacturing process, the type of composite powders used, and of course the composition.

2. IMPACT OF METAL-OXIDE CONTENT ON EROSION ON BREAK AND CONTACT RESISTANCE

Silver metal-oxide contact materials with high oxide contents are desired to produce well-priced contactors. For the following tests the tin-oxide content of a powder blended and extruded material (Ag/SnO_2 SP) has been varied in a range from 4 wt% to 17 wt%. The impact of the metal-oxide content on the switching performance will be shown.

The influence of tin-oxide content on contactor service life has already been studied in [7]. These studies were based on Ag/SnO_2 materials doped with different contents of Bi_2O_3. Therefore the achieved results do not only depend on the total metal-oxide content. They are also influenced by using Bi_2O_3 as additive.

Test utilizing a break-only model (Fig. 1) switch were performed to show the effect of different metal-oxide contents on erosion rates, arc movement and contact resistance.

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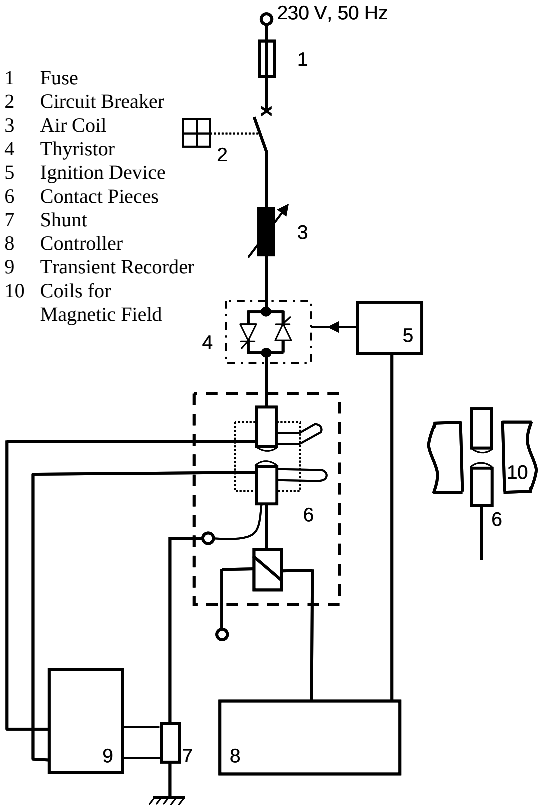

Figure 1 Break-only model switch

The contacts are opened synchronous to the voltage phase angle (at natural current zero) and the current flows for one half-cycle until next current zero. The arc is forced to commutate onto copper arc-runners by a self-induced magnetic field (10). The range of magnetic fields can be chosen in a typical range for contactors with rated currents $I_r > 100$ A. The test current setting is realized by air coils.

Table 1
Parameters - break-only model switch

Parameter	Value
voltage *V*	230 V
current (peak value) $\hat{\imath}$	350 A
magnetic field *B*	30 mT/kA
opening velocity *v*	0.4 m/s
number of switching cycles *n*	1,000

After current zero the contacts are re-closed without current flow for contact resistance measurement. The voltage drop across the contacts is measured at a 10 A DC current. Thereafter the supply voltage is applied again and the controller starts to open the contacts again. The electrical parameters chosen for the break-only model switch tests – representing a medium sized contactor – are summarized in Table 1. The tests are done with an alternating polarity of the electrodes to avoid influences by material migration.

The break arc can be driven off the contact material and commutate onto arc runners by applying a magnetic field. The tests showed that the lower the metal-oxide content the better the arc root mobility. Better arc root mobility and therefore shorter dwell times, consequently lead to lower energies at break stressing the contact material. Therefore material loss has to be divided by this energy for comparing the different materials. This specific erosion rate (Fig. 5) was investigated for metal-oxide contents from 4 wt% to 17 wt%. This dependency was already examined for automotive relay applications under resistive and lamp load in [6, 8] and therefore at significantly lower breaking energies.

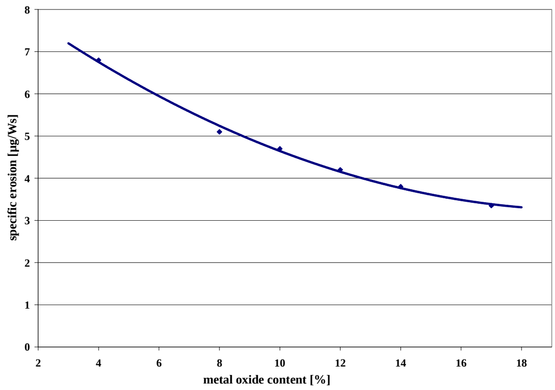

Figure 2 Specific erosion against metal-oxide content

Better specific erosion rates for higher metal-oxide contents can be observed. Of course these advantages in erosion rates for high contents of metal-oxide come along with a rise in contact resistance with increasing metal-oxide content. This rise in contact resistance (99% quantile) may lead to temperature rise problems in the device, if contact forces are too low.

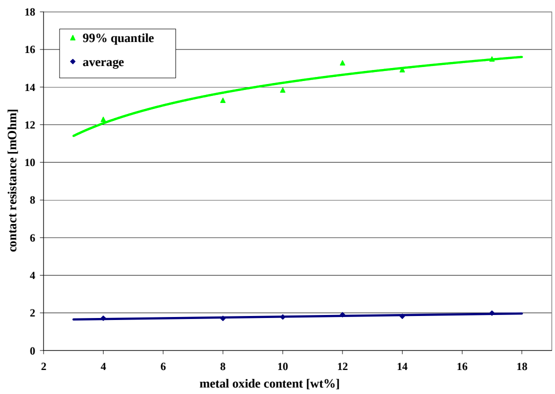

Figure 3 Contact resistance against metal-oxide content

Contactor lifetime tests have also been performed in addition to this model switch tests. The following test parameters have been chosen:

Table 2
Parameters – contactor lifetime test

Parameter	Value
voltage V	400 V
make/break current $I_{make/break}$	324 A
power factor $\cos\varphi$	1
switching frequency	250 1/h

Figure 4 shows the observed erosion rate per switching cycle during this test. Erosion behavior in contactor application shows 30% less erosion of a 14 wt% material in comparison to a 12 wt% material. Therefore the electrical lifetime, especially for contactors with high nominal current, can be increased by applying a contact material with higher metal-oxide content (Ag/SnO_2 86/14 PMT3).

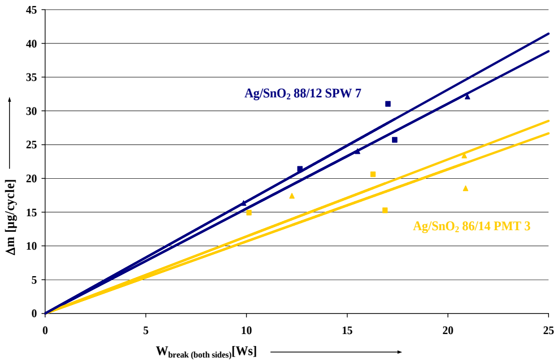

Figure 4 Erosion rates in contactor application

Furthermore temperature rise tests were performed during the electrical lifetime test. The temperature rise was measured on the contactor's contact bridges at a current $I = 100$ A. After one hour constant current flow the temperature of the hottest bridge is memorized. After performing a dry switching the current is applied again. For statistics 24 cycles are recorded and analyzed. At least five such temperature rise tests are performed during the electrical lifetime test. Typical values of materials with different metal-oxide contents, verified in several tests, are shown in Fig. 5. The temperatures on the contact bridge are approximately 7 K higher for a material containing 2 wt% more metal-oxide in this type of contactor. In this case a remarkable increase in electrical lifetime, coming along with moderate higher temperature rise values, can be achieved by applying an Ag/SnO_2 86/14 PMT3 material to the contactor.

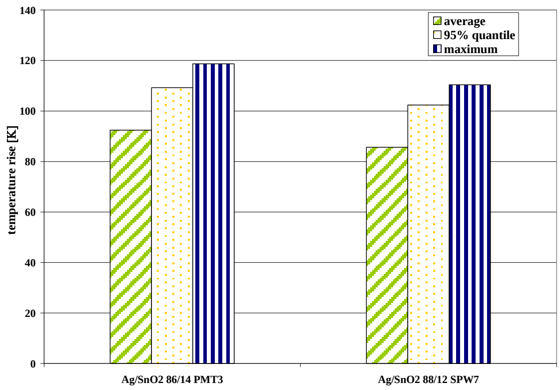

Figure 5 Temperature rise test results

3. IMPACT OF METAL OXIDE CONTENT ON WELD BREAK FORCES AND EROSION ON MAKE

The weld behavior of 2% to 8% metal-oxide in Ag/SnO_2 (doped with CuO or CuO + Bi_2O_3) has been studied in [9]. It was shown that a small increase in oxide content can significantly change the welding behavior for a current range from 100 A to 400 A.

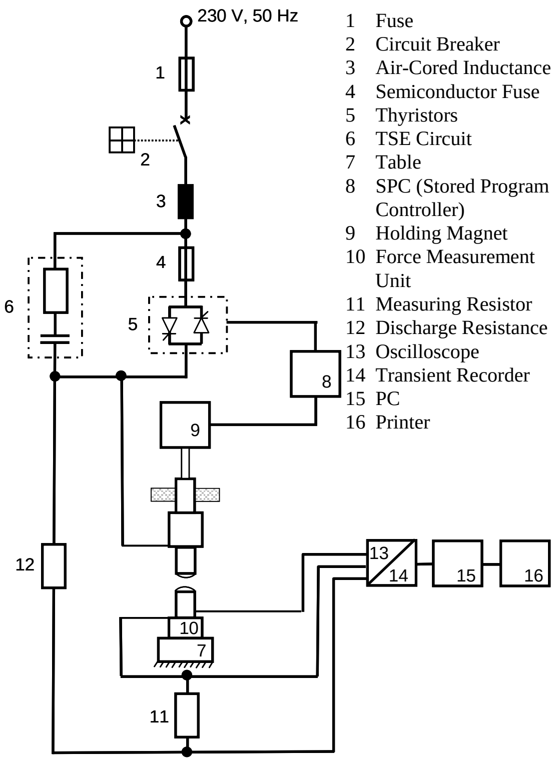

Figure 6 Make-only model switch

To study the influence of metal-oxide content on erosion on make and weld break forces for contactor application a make-only model switch (Fig. 6) was applied. In accordance to the break-only model switch the test current is set by air coils (3), too.

A holding magnet (9) is triggered via a controller (8), thus realizing a time controlled make in the range of 0.1 ms synchronous to voltage phase angle. Contacts are closed and current flows through the contacts. To investigate the erosion on make, the bouncing behavior of the switch was realized in accordance to the conditions of a medium size contactor. A piezoelectric force sensor (10) will measure the weld break force at currentless opening of the contacts, if the contacts are welded together during the make process. Electrical parameters chosen for the test are summarized in Table 3.

Table 3
Parameters - make-only model switch

Parameter	Value
voltage *V*	230 V (50 Hz)
current (peak value) *î*	700 A
power factor *cosφ*	0.35±0.05
contact force *F*	3.5 N
closing velocity *v*	1 m/s
number of switching cycles *n*	500

Weld break forces of contact materials with varying tin-oxide content are shown in Fig. 7. A reciprocal exponential dependency between metal-oxide content and weld break forces can be seen. This effect is valid as well for the average as for the 95% quantile weld break force values.

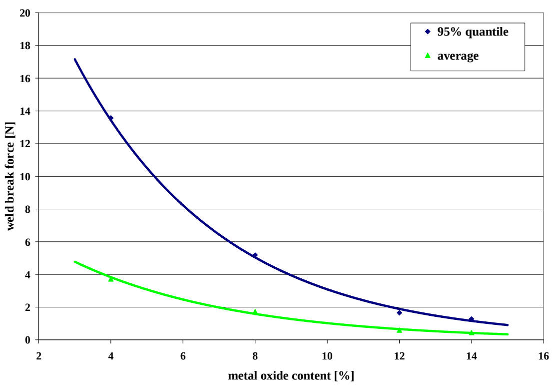

Figure 7 Weld break forces against metal-oxide content

The erosion on make is measured by weighing the contacts before and after test. Most of the evaporated contact material will re-condense on the electrodes, due to the small gap between the electrodes during contact bouncing. Therefore the erosion rates on make (Fig. 8) are influenced by the mechanical behavior of the contact material and production processes. But, a tendency towards lower erosion at higher metal-oxide contents can also be seen.

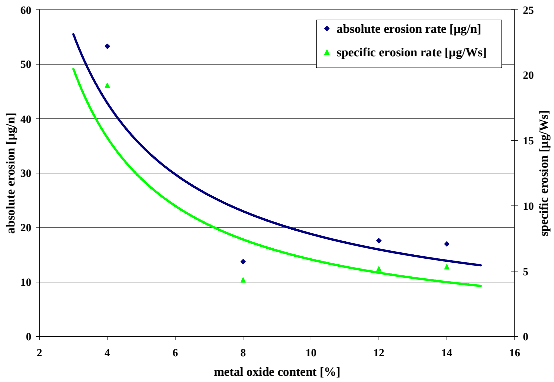

Figure 8 Erosion rates on make against metal-oxide content

4. CONCLUSIONS

Silver-tin-oxide contact materials are widely used for industrial contactor applications. The technical requirements on these materials are influenced by actual trends in contactor design. Temperature rise is a critical failure mode for contactors in industrial application and the consequences of design changes on the contact resistance have to be considered carefully. Therefore studies on influence of metal-oxide content and usage under different utilization categories on the switching behavior of contactors have been performed.

Silver-tin-oxide materials with higher metal-oxide content offer precious metal saving capacities to device manufacturers. Materials like Ag/SnO_2 86/14 PMT3 provide better erosion rates and therefore increased electrical lifetimes in comparison to 88/12 materials or possibilities for contact tip size reduction, if slightly higher temperature rise values can be tolerated or eliminated by the design of the contactor.

Furthermore the weld break forces can be reduced by applying Ag/SnO_2 materials with high metal-oxide content. But, a saturation of this effect seems to be reached for materials with more than 12 wt% metal-oxide content. Here, doping the contact material with different types of metal-oxides as additives can lead to further improvements.

Studying influences on erosion rates, contact resistance and temperature rise, the switching load and device kinematics have to be considered carefully. The energies converted during the make and break process by arcing have great impact on the contact material surface and therefore on the contact resistance. Reasonable tests have to consider device, material and load parameters.

5. ACKNOWLEDGEMENTS

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