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POWER CYCLING ANALYSIS OF ENAMELED ALUMINIUM WINDING WIRES CONNECTIONS PPREPARED WITH THE USE OF SHARK-AL® TYPE CONNECTORS

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The article presents the research results of current cyclic thermal tests performed on enamelled aluminium wires connections, made with the use of a new type of Shark-Al quick-connectors. In particular, the main purpose of the conducted research was to analyse the effect of cyclic heating on the contact resistance change during the tests which allows to test the stability of the connections in simulated working conditions under current flow. Tests included a total of 300 thermal cycles, of which the first 200 were carried out to the 65 °C temperature measured in the connector at above the ambient temperature, and then additional 100 cycles were performed for the temperature of the connector at 140 °C (tolerance +5 °C). During the tests, the resistance of samples was monitored, which allowed to verify the correctness of performed connections.

Keywords: enameled wires, copper alloy, Shark connectors, power cycling tests, resistance

INTRODUCTION

The main subject of this article is related to the world innovative system dedicated to the connection of enameled aluminium wires which are used in production of power transformers which was registered as SHARK-Al® [1]. Above mentioned quick connection system consists of specially designed connectors with mechanically aggressive surfaces that are made to have micro edges (so called tooth's). Micro edges were designed and implemented in order to mechanically puncture electric insulation of enameled wire and to penetrate into the metallic core allowing the current to pass insulation layer and flow through performed connection [2].

It was not an easy task due to materials that are used for insulation layer of enameled wires (for both copper and aluminium) which are known to have high mechanical properties and relatively large amount of plasticity [3-5] which makes them hard to penetrate with the use traditional connection system without the stripping process [6-8]. One of the most important research and exploitational problems during the development phase of new type of SHARK connectors, which are dedicated to connect aluminium enameled wires, were power cycling analysis. This type of tests allow to indicate the correctness of joining process in the means of proper electric contact between the connector and enameled wire.

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EXPERIMENTAL PROCEDURE

Power cycling analysis was performed for previously prepared serial circuit consisting in total of 6 SHARK-Al connectors (type R1 according to [1]) used to join 7 separate aluminium enameled wires with 2,65 mm diameter. Within above mentioned chain 3 of the SHARK connectors were made out of CuAg0.1 material and the other 3 were made out of CuSn0.15 alloy in order to compare and test if the material of the connectors has an influence on obtained contact resistance of connection after performed power cycling analysis. The current intensity was selected in such a way to enable the heating of a measuring chain to the acceptable temperature assumed in a given experiment. As part of this task, two types of research on current cycles were carried out. The first part of the test was set up to 200 cycles and the targeted temperature was set at 65 °C above ambient temperature. The second part of the test was additional 100 cycles with a targeted temperature of 140 °C and maximal tolerance +5°C). A detailed research scheme for both parts of the research is presented in Figure 1 below.

Next the research set up was prepared in order to enable the current flow through each of the connector (all parts of the chain were serially connected). The specific value of current was selected experimentally before the first cycle on separate circuit in a way to obtain desired temperature of the circuit which was measured on the enamelled wire. Before and after each connector within the chain, additional connectors with copper cables were installed and used to measure the contact resistance of the connection area. In addition, a thermocouple was mounted on each connector to control the temperature

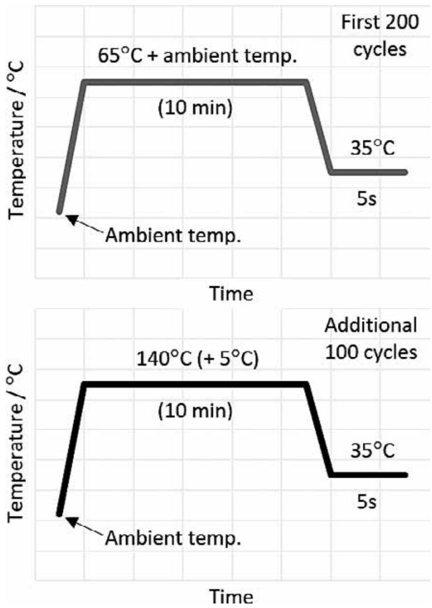

Figure 1 Research scheme for power cycling analysis of SHARK-Al R1 connectors and 2,65mm enameled aluminium wire

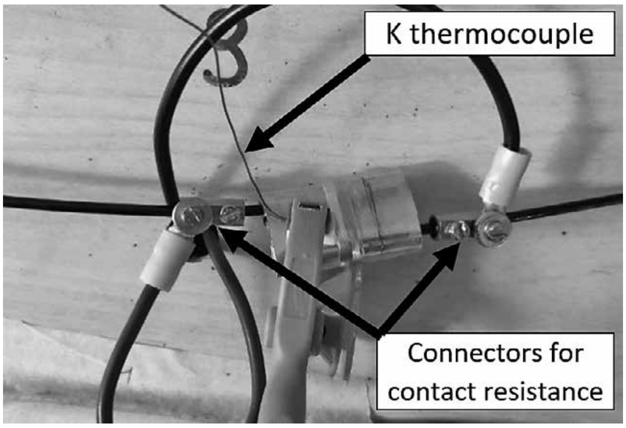

Figure 2 Example of a SHARK connector on aluminium enameled wire with mounted K type thermocouple and additional connectors for contact resistance analysis during cycles

change during the current cycles. An example of a SHARK connector in a measuring chain with installed cables for measuring resistance and a thermocouple for measuring temperature is shown in Figure 2.

The measurement base of the resistance of the connection of the winding wires with the Shark-Al connector was equal to the length of the given connector plus 10 mm (5 mm each at the front and on the back of the connector). The contact resistance measurements were carried out on a portable low-resistance micro-ohmmeter VIGO System MSV-103. The resistant measurements were in all cases done made with a measuring current of 10 A. Verification of contact resistance changes in for first 200 cycles were performed every 25 cycles of current heating, while for additional 100 cycles, the contact resistance was measured twice i.e. at the beginning and at the end of testing. Temperature measurements for both connectors and the reference wire were done using type K thermocouples, which were connected to a HBM QuantumX MX1609 data acquisition module. All temperature measurements were carried out continuously during all stages of research. Before the start of actual power cycling analysis all installed connections were tested for their contact resistance to verify that the difference in resistance is not more than 30 % (test start condition). Research procedure was carried out in temperature controlled environment (stable ambient temperature). The main goal of the research was to verify that the initial resistance of the chain did not increase more than twice after all 300 cycles and that connectors do not exceed the maximum temperature of the enameled wire.

RESULTS AND DISCUSSION

Obtained research results which are shown in Figure 3 in form of exemplary temperature characteristics during power cycles show that the maximal temperature for both stages of performed tests were obtained for enameled wires (reference sections). Within the first stage of tests (see Figure 3a) a maximum temperature of connector was at the level of around 70 °C while the temperature of the wire was at targeted temperature of around 90 °C.

Also similar dependence were observed for second stage of tests were reference section of enameled wire reached the temperature of 140 - 145 °C and the maximum temperature of 100 °C for all connectors which is around 30 % less. Another research results in form of cumulative contact resistance data after every measurement step that are presented in Table 1 shows that initial resistance of connections within the measurement chain did not increase more than twice after the tests taking into account all 300 cycles. The maximum percentage

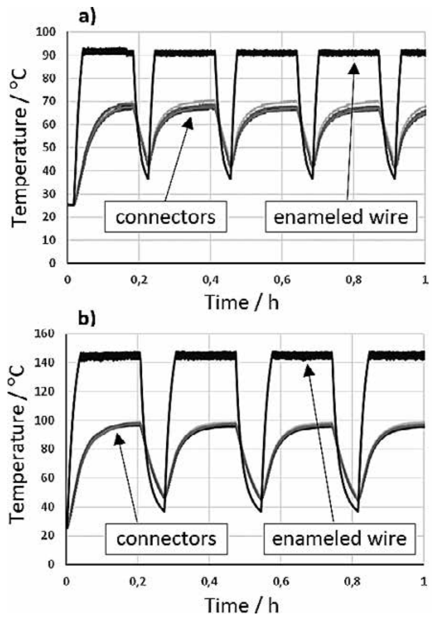

Figure 3 Exemplary temperature graphs for performed power cycles: a) first stage of tests (temperature at 65 °C + ambient temperature) and b) second stage of tests for targeted temperature of 140 °C (+5 °C)

Table 1 **Cumulative results of connections resistance for all cycles with given percentage contact resistance increase and contact resistance difference in tested chain**

Connector material	Connector no.	Contact Resistance / mΩ										Contact resistance increase / %
		Number of cycles for given targeted temperature										
		65 °C + ambient temperature									140 °C	
		0	25	50	75	100	125	150	175	200	300	
Wire	ref	0,168	0,169	0,168	0,168	0,168	0,169	0,168	0,169	0,169	0,168	**0**
Cu-Ag	6	0,149	0,149	0,15	0,151	0,151	0,151	0,151	0,152	0,152	0,157	**5,37**
Cu-Ag	5	0,142	0,142	0,143	0,144	0,145	0,146	0,146	0,147	0,147	0,153	**7,75**
Cu-Ag	4	0,145	0,146	0,146	0,147	0,147	0,147	0,147	0,148	0,148	0,151	**4,14**
Cu-Sn	3	0,144	0,145	0,146	0,147	0,148	0,148	0,149	0,15	0,15	0,156	**8,33**
Cu-Sn	2	0,149	0,15	0,15	0,151	0,152	0,152	0,152	0,154	0,154	0,157	**5,37**
Cu-Sn	1	0,149	0,15	0,151	0,152	0,153	0,153	0,153	0,155	0,155	0,161	**8,05**
		Contact resistance difference between separate connectors in tested chain / %										
		4,93	5,63	5,59	5,56	5,52	4,79	4,79	5,44	5,44	6,62	

contact resistance increase was observed for connection 3 made out of CuSn0.15 alloy at the level of 8,05 % which is far less than initial requirements. The lowest increase in contact resistance increase at the level of 4,14 % was obtained for connector 3 made out of CuAg0.1 alloy. In total it is also worth mentioning that maximum difference between lowest and highest increase of resistance was only at about 4 % which also proves that all connections done with SHARK-Al type connectors were highly reproducible.

CONCLUSIONS

Based on all of results from performed research works it was concluded that:

- both used materials i.e. CuAg0.1 and CuSn0.15 alloys are suitable for use in production of SHARK-Al connectors, however slightly better results (2 % lower average contact resistance increase after all 300 cycles) are observed for CuAg0.1,
- both temperature characteristics and cumulative contact resistance research results obtained during and after all 300 power cycles prove that all connections made with the use of SHARK-Al connectors were performed correctly which also confirms that connectors itself were designed appropriately and can be further directed for final industrial tests.

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Note: The translator responsible for English language: Justyna Grzebinoga, Krakow, Poland.