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Thermal Degradation of Contacts in Switching Devices Working in the Smart Buildings

***Abstract**. The article presents the problem of thermal degradation of contacts which may occur in the switching device working in smart buildings. During the activation of modern electronic and power-electronic devices (eg. LED sources), there are current surges of over 50 times greater than the maximum current in the steady state. This phenomenon can cause too rapid destruction of the surface layer of the contact, and consequently, the degradation of the contacts, which ultimately leads to damage to the switching device.*

***Streszczenie.** W artykule przedstawiono zagadnienie degradacji cieplnej styków, które może występować w łącznikach instalacyjnych pracujących w inteligentnych budynkach. Podczas załączania nowoczesnych urządzeń elektronicznych oraz energoelektronicznych (np. źródeł światła LED) występują udary prądowe ponad 50 razy większe od maksymalnej wartości natężenia prądu w stanie ustalonym. Zjawisko to może być przyczyną zbyt szybkiej destrukcji warstwy wierzchniej styku, a w konsekwencji degradacji styków, która w końcowym efekcie doprowadzi do uszkodzenia łącznika. (**Degradacja Cieplna Styków w Łącznikach Pracujących w Inteligentnych Budynkach**).*

Keywords: smart building, degradation of contacts, LED lamps.
Słowa kluczowe: inteligentny budynek, degradacja styków, lampy LED.

Introduction

In the world of technology, the word "smart" is often used in relation to the early twenty-first century. Accordingly, smart cities where there will be smart homes powered by the smart grid are planned. Thus, it is natural to expect that there will be a lot of smart devices in the smart home.

Even taking into account the slight exaggeration of this vision, it should be recognized that the development of intelligent systems on many levels becomes a fact. The authors wish to draw attention to the need for integration of modern intelligent systems with existing technical solutions.

Rapid technological progress causes the development of electrical equipment being the basic building equipment. Advanced electronic and power-electronic systems create a range of functional capabilities. The work of these devices, however, involves the strict requirements and less well-known consequences. The basic requirements include a high quality power supply, therefore, many devices have a number of power supply filtering circuits. Their proper functioning, however, is associated with a negative impact on the quality of the supply voltage, which is one of the adverse consequences.

The result of the work of power-electronic systems is a strong distortion of current and significant phase shift, which is associated with a reduction in the power factor and reactive power generation.

The third consequence of the operation of power-electronic systems is the nature of their work in transient states while switching these devices. Preliminary studies described in this paper indicate significant changes in operating parameters of the systems in transient states.

When analyzing the elementary phenomena, many issues that must be addressed can be seen. One is handling new electrical appliances using conventional contact switching device. First results of the authors' work, described in this article, show clear evidence of the need for deeper analysis of the topic and carrying out scientific and research work, allowing for finding the solutions to identified problems related to thermal degradation of contacts.

The contacts are directly involved in the most important activities performed by the switching device and play a dominant role, especially in feeding-through and switching [1-5]. While performing this work, there are many phenomena adversely affecting contacts. Due to their complex nature, in practice, the particular phenomena are not usually analyzed in detail, but only their effects.

The most important adverse effects of the phenomena occurring in the contacts include [5]:

- heating the contact,
- wearing off and deformation of the contact,
- welding of the contacts,
- "aging" of contact material,
- oxidation.

Often the considered effects occur simultaneously and are closely linked, which makes it difficult to quantify them. Not one but several effects decide whether the contact works properly under certain conditions. For example, during feeding-through operation, heating, "aging" of the material, and sometimes also welding of the contacts play a major role, whereas, during switching operation, typically all of the effects mentioned previously. In turn, the phenomena occurring in contact during switching current (melting of the material, welding and electrical discharges) cause large differences in the course of bounces and the volatility of the bounce form with the changing current, duration as well as amplitude and number of bounces.

Operating Parameters of Energy-Saving Devices

Smart building is a building which, due to its infrastructure, indicates the features which allow for assigning it to this group of buildings.

Despite many scientific and development papers, there are no clear indicators that definitively qualify a building as smart. Today, it is rather a set of characteristics that can be achieved in various ways, which, as a whole, gives the building the status of "smart".

The above description allows for considerable subjectivity in assessing the level of "building intelligence". Therefore, certain evaluation standards of buildings such as LEED[1] certification or BREEAM[2] are introduced [6-8]. It should be kept in mind that one of the basic characteristics of the smart building is its energy efficiency. Thus, it is adequate to see one of the most objective forms of evaluation and comparison of buildings in the energy performance of the building.

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[1] LEED - Leadership in Energy and Environmental Design.
[2] BREEAM - Building Research Establishment Environmental Assessment Method.

To improve the energy efficiency of buildings, building automation system integrating subsystems and resources contained within the building is of key importance. However, to achieve the maximization of profits resulting from energy consumption, what should be sought is minimization of energy consumption at the level of electrical devices that constitute the equipment of the smart and energy-efficient building. Works in this area were and are being implemented by the authors [9-11]. The intermediate results of these works have focused the attention of the authors on the issues of switching phenomena during switching energy-efficient appliances by switching devices.

To illustrate these switching phenomena, the authors carried out measurements for energy efficient light sources based on LEDs. These devices are modern, very popular, and they are gaining a growing group of supporters, mainly due to the economic benefits that result from lower power of the installed light sources. The object of the test was a lamp (LED Bulb Light, Power: 9W, U_N: 85-265 V; Color: warm white, CCT: 2700-3300K).

The measurements were carried out by the Lecroy WaveSurfer 454 oscilloscope and Fluke 1735 power logger. Fig. 1 shows the oscillogram of the LED lamp operating in steady state. On channel 1, the signal from the shunt (R_B = 10 Ω) is observed allowing the observation and analysis of the course of the current flowing in the circuit (probe 1 ÷ 10). Channel 2 is the voltage supply course (probe 1 ÷ 100).

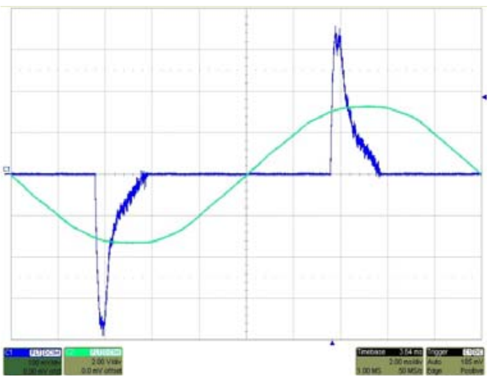

Fig. 1. Steady state during operation of the tested LED lamp

The maximum voltage drop across the shunt is 3.8 V (380 mV x 10), corresponding to the current of 380 mA. There is also evidence of considerable distortion of the current waveform, which is far from the sinusoidal. Based on the results from the logger Fluke 1735, THD for the current reached the value of 97.8%. The RMS value of this flowing current is I_{RMS} = 96 mA. Active power consumption is compliant with this specified by the manufacturer and equals 9W. Apparent power is about 21 VA with a power factor equal to 0.42. This confirms the first two consequences of these devices described in the introduction, namely the influence on the quality of power supply voltage and reactive power generation. Of course, as shown in Fig. 1, the steady-state supply voltage waveform is not distorted. This is due to the stability of the source, that is mains power, and above all, low power receiver. It should be noted, however, that, with an increase in the number and capacity of receivers, distortion can affect the voltage waveform.

Transient Operating State of The Led Lamp

The study analyzed transients during switching the LED lamp. Fig. 2 shows the waveform of the receiver switching process. To observe the entire switching process, changing the scale on channel 1, to which shunt signal is connected, was necessary. In the oscillograms (Fig. 2 and Fig. 3), it was 5 V/div, which means that the instantaneous maximum value of the current was 20 A, that is more than 50 times greater than the maximum current value in the steady state.

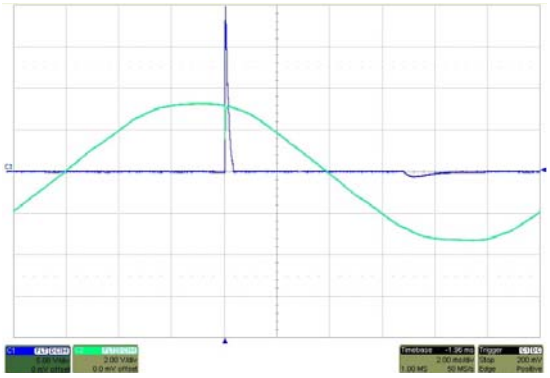

Fig. 2. Transient state during switching the tested LED lamp

Fig. 3 presents the oscillogram of the initial current at the time base of 500 μs/div. It can be argued that the current surge lasted 400 microseconds.

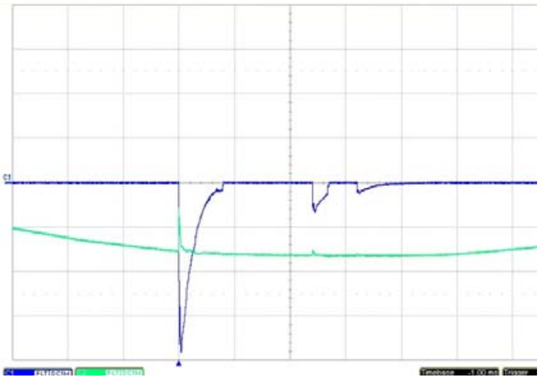

Fig. 3. Surge current during switching the tested LED lamp

Impact of Current Surge on Contact In Switching Device

The phenomenon of welding of contacts can occur during operation of the switching device in the case of the high overload of current flow through the contacts of the switching device or short circuit. Due to the complexity of the phenomena causing welding of the contacts and their dependence on the number of values and factors, often accidental, evaluation of resistance to welding of the contact material is carried out on the basis of experimental results obtained in special testing equipment in model conditions. The tests performed can be [5]:

- static welding in closed contact loaded with one half-wave of current with a frequency of 50 Hz [12]
- dynamic welding that reproduces the case of switching device operation when switching high current. They are carried out under the presence of bounce of contacts at closing the contact or at forcing a single model bounce in a closed contact [13].

Manually-operated switching devices are widely used in household appliances and the like. Currently, a large variety of these switching devices can be met on the domestic market. All design solutions of the switching devices must meet the requirements of Polish Standard PN-IEC 60669-1 [14], in accordance with the international standard IEC 669-1 [15]. More and more often, companies from the electrical industry have problems with these switching devices because they can be damaged after a month of work. This is due to the phenomenon of an electrodynamic bounce which, when repeated many times, in the end, leads to the lasting welding of contacts. This phenomenon has already been observed by Walczuk [16] who classified the characteristic course of bounces at loading the contact with current and who set the relationship of welding force and peak switching current during closing contact for different contact materials. In conclusion, it can be said that current surges exceeding many times nominal currents occur during switching (Fig. 2), and these currents cause electrodynamical bounces which are the cause of thermal impact of electric arc on the contact, resulting in the welding of the contacts after the reclosing of the contact.

The authors conducted a study of two types of single-pole switching devices, keypad-driven 10 A, 250 V, made by two producers (A and B) in the computerized test bench for a large group of switching devices, operating in the Department of Electrical Apparatus of Lodz University of Technology [5]. This test bench allows for testing 5 switching devices simultaneously under the conditions defined by the standards. The scope of main testing parameters is: voltage 230 V AC, testing current from 2 to 20 A, and resistive or inductive load. The contacts in switching devices were made from a material AgCdO10. The tests were carried out at the rated voltage of 230 V in the resistive circuit under the current $I = 1{,}2\ I_N = 12$ A, and in inductive circuit of cosφ = 0.3 under the current $I = 1{,}25\ I_N = 12{,}5$ A. In both cases, the number of switching cycles was 200. For each series, the mean values of the number and duration of bounces and electrical energy of arc during the bounces were determined. Apart from very few cases, there was only one bounce of different duration in all switching devices. The final results showed a clear increase in the mean values of the bounce duration. The value of the thermal energy of the arc acting on the contacts was also increased because of that. Fig. 4 is an exemplary photograph of the contacts of one switching device after the switching endurance tests in the inductive circuit.

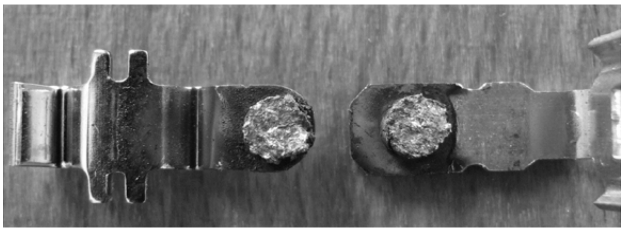

Fig. 4. Exemplary photograph of current path with AgCdO10 switching device contacts after tests

The analysis of the authors' tests allows for an unequivocal statement that, during the switching operation in the contacts, as a result of the arc operation, there occurs a process of "aging" of the material in the surface layer of the contacts, particularly visible in the contacts made of composite materials [5]. This process manifests itself by a change in the physical, chemical and electrical properties of the contact caused by changes in the structure and chemical composition of the contacts and, most commonly, causes deterioration of the contact resistance to the harmful effects of the phenomena in the contact.

Changes associated with the "aging" of contact material, in particular made of composite materials based on silver, are initiated by the melting of silver in the surface layer of the contacts which fills the capillaries of refractory material skeleton. Depending on the current value and duration of the arc, the amount of energy absorbed by the material causing a change of state of matter of the material determines the extent and depth of the region of silver melting in the refractory material skeleton and the temperature of the liquid. Melting the silver itself is usually short-lived and does not cause noticeable changes in the structure and composition of the composite. The volume increase of silver due to the change of state is negligible and results in a slight thickening of the silver film on the contact surface. There is no free flowing out of liquid silver on the surface because it is maintained in the refractory material skeleton by capillary action. Violent flowing out on the surface and even eruption of droplets of silver occurs only under the action of the vapour pressure of silver, after heating the molten silver above the boiling point [17].

The effects of this phenomenon can be observed at a deeper microscopic analysis, directly on the surface and in the surface layer of the contact (structure) as shallow or deep effects. The loss of silver from the skeleton and the deprivation of cooling of the skeleton by silver cause the secondary sintering, connected with shrinkage resulting in increase of tensile stress of the bridges connecting the individual crystallites, to the extent of exceeding the tensile strength of the bridges. Then, cracks of different orientation and extent occur in the skeleton. They can be divided into [17]:

- slot cracks (vertical, perpendicular to the contact surface or diagonal),
- layered cracks (horizontal, parallel to the contact surface),
- arched cracks (cup-shaped of limited range).

The above results of switching devices tests and preliminary observations of the phenomena occurring during the switching energy efficient light sources indicate the need to develop the issues of degradation of contacts in the switching devices resulting from the cooperation with modern receivers in smart buildings.

Conclusion

The development of smart technology enforces developing systems that integrate modern equipment with the existing technical infrastructure. One of the basic elements performing this function are contact switching devices.

The paper presents the results of switching device tests during switching energy efficient light sources (LED lamp).

The results indicate that, during the switching, the current surge reaches the value more than 50 times greater than the nominal value. This high value of current can cause thermal degradation of contacts in the switching device.

Based on the conducted tests, the authors see the need for further tests and analytical works for the solution of the proper operation of switching devices in systems equipped with modern electronic and power-electronic equipment.

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