Scientific Papers of
the Department of Electrical Power Engineering of
the Wrocław University of Science and Technology

PRESENT PROBLEMS OF POWER SYSTEM CONTROL

8

Wrocław 2017

Cover design
Piotr PIERZ

Printed in the camera ready form

Department of Electrical Power Engineering
Wrocław University of Science and Technology
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
phone: +48 71 320 35 41
www: http://www.weny.pwr.edu.pl/instytuty,52.dhtml; http://www.psc.pwr.edu.pl
e-mail: wydz.elektryczny@pwr.edu.pl

OFICYNA WYDAWNICZA POLITECHNIKI WROCŁAWSKIEJ
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław
http://www.oficyna.pwr.edu.pl
e-mail: oficwyd@pwr.edu.pl
zamawianie.ksiazek@pwr.edu.pl

ISSN 2084-2201

Print and binding: beta-druk, www.betadruk.pl

CONTENTS

switching arc DC,
low voltage and low power installation,
arc-to-glow transition

Grzegorz WIŚNIEWSKI*

ARC TO GLOW TRANSITION FOR USING DC LOW POWER SWITCHES IN LOW VOLTAGE ELECTRIC GRIDS

This paper presents and discusses results of analysis and investigations of arc to glow transformation phenomenon at contact opening, under DC inductive loads of low power (≤10 J) and low voltage (≤250 V). The proportion in duration of arcing and glowing is investigated in dependence on current and voltage value, contact material properties. The transition phenomenon is analyzed by means of fast photography and emission spectroscopy to complete the study. On the basis of investigated results the conclusions about the possibility of control of the arc to glow transformation for practical use in DC low voltage and low power electrical grids are formulated.

1. INTRODUCTION

Recently can be seen a rising interest in using the DC grids in residential houses. This is due to increasing application of renewable DC energy sources (mainly photovoltaic cells) and the tendency to reduce both wiring and utility costs by elimination a lot of DC/AC power supplies and electronic power converters to one central power supply. Moreover, the market offers full gamma of various kinds of electrical devices powered DC, mainly various types of LED light sources. It is therefore recommended (especially in residential buildings) an implementation of additional, separate DC installation (Fig. 1) however, adapted in a case, for connection to an AC primary site as proposed, for example in [1]. However, the use of the DC power source is related to serious disadvantage resulted primarily with the inability of its transformation into different voltage levels, although dominated by standardizing 5 V for USB power supply. Hence, there is a need for transferring and switching currents of relatively

* Wrocław University of Science and Technology, Department of Electrical Power Engineering, Wybrzeże Wyspiańskiego, 27, 50-370 Wrocław, Poland, e-mail: grzegorz.wisniewski@pwr.edu.pl

higher values and energy. Effective switching of DC loads needs the use of both special semiconductor and/or hybrid devices with the overvoltage protection.

Fig. 1. Wall socket with dual USB interface and electrical outlet

In certain applications, however, particularly under small values of currents and where the breaking speed is not important the contact switches are equipped with damping resistors [2]. However, during breaking inductive loads the switching arc duration can be prolonged significantly and can lead, as result, to rapid damage of the switch and contacts. Studies of the arcing under low voltage DC showed that in a number of cases it can be found advantageous effect of spontaneous transition of the arc into glow discharge. This reduces the erosion of contacts surface and increases considerably, as a result, the electrical life of the switch at a very effective limitation (often to zero) the switching overvoltage values [3,4]. The duration of the glow discharge is of course dependent on the energy of the inductive circuit therefore in some cases, it is necessary to use its forced limitation. However, in most applications there is no such necessity. The problem, however, remains the practical implementation of the switch structure so that you could predictable control the transition of DC switching arc in glow discharge as fast as possible after the opening of the contacts. The question is tough because of the complexity of mutually interacting phenomena within the contact gap associated with the electrical discharge. It is thus found either a fast transformation of initial unstable electrical pre-arc in the glow discharge, or his initiation after a while of burning arc duration or at all lack of glow discharge. Thus the efficiency of the transformation process changes during switching, but fortunately there is a statistically predictable. This is primarily due to the difficulty in maintaining the same reproducible physical-chemical conditions as on the contact surfaces as well as within a relatively small gap area between the contacts. Some explanations of the conditions of instability provide a mathematical description of this effect based on the experimental results obtained [4]. The article presents and discusses the results of experimental studies of transition effect of switching DC arc in a glow discharge when interrupting a DC inductive current of low power (≤10 J) and low voltage (≤250 V). The study concerned the impact of such factors like, current and voltage value, inductive energy of switching circuit and selected parameters of the switch. Particular emphasis is placed on the selection of contact material. Based on the results of experimental study using, among other things, fast photography and spectroscopy for the implementation of the arc to glow transition effect in selected contact switches of a low power and low voltage DC.

2. THEORETICAL EVALUATION OF THE ARC TO GLOW TRANSITION

The study showed that a glow discharge appears under unstable burning of the arc and can be initiated or almost immediately after the start of the opening the contact and/or after some time of the arc existence. Approximate theoretical analysis of the arc transition in a glow discharge (for the electric circuit as shown in Fig. 2) is given in detail in [6].

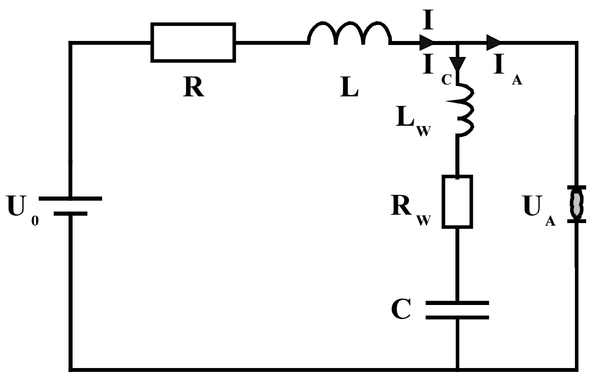

Fig. 2. Electrical circuit diagram of the test rig: U_0, I – supplied voltage and load current; U_A – arc voltage; R, L, C – load resistance, inductance and circuit capacity; L_W, R_W – wires inductance and resistance respectively

On the basis of the investigated results [3, 4, 6] the process of contact opening, associated with arc to glow discharge, can be presented in four stages representing different phenomena [4] as illustrated in Fig. 3. The stage I (pre-arcing) is related to the initial conditions for arc ignition in particular the values of current, voltage, density of evaporated metallic particles from contacts, length of contact gap, as well as electric field intensity that are important for further arc evaluation. According to different temperature value in the contact spot, one can distinguish here, three intervals as follows: first-from initial to softening temperature (elastic restitution); second-from softening to melting (plastic deformation) and third-from melting to boiling temperature (bridging) respectively. Since the first two parts are of a very short duration in our case (under consideration) thus, a liquid contact bridge is the most important factor for the further arc development. There are two existing mechanisms of the bridge formation and its dynamics strongly related to physical properties of contact material. The first one corresponds to a bridge formation due to melting of a micro-asperity on the contact surface, whereas the second is due to the extension of a liquid drop from the melted area in the constriction zone [4].

This drop extension mechanism of the bridge formation is typical for low-melting point metals with high thermal conductivity like silver and its compositions. Therefore, for such contact materials the length and duration of the ruptured bridge (t_b in Fig. 3) is large enough to provide thermal ionization of metal vapours needed for the arc ignition [5].

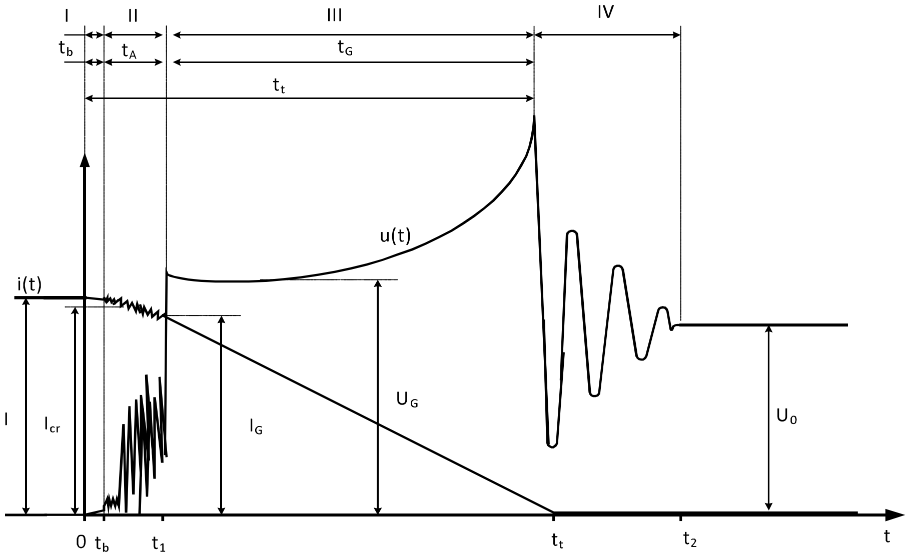

Fig. 3. Illustration of voltage current characteristics at contact opening:
t_t, t_G, t_A, t_b, t_{cr} – total, glowing, arc discharge, bridge and critical arc time, respectively;
U_0, U_g – supply and glow voltage; I_{cr}, I_G – critical arc and glow transition current, respectively

The further evaporation is also enough sufficient to maintain stable arc of a relatively long duration (extended stage II – Fig. 3). Therefore, silver and its compositions are not suitable for the arc to glow applications what was confirmed by experiment. On the contrary the micro-asperity genesis seems to be peculiar for more refractory metals such as nickel. The quantity of vapours of micro-asperity is not sufficient for stable arc ignition and its occurs because of field emission breakdown and/or air avalanches breakdown. The bridge is in such case significantly reduced or even invisible.

Sometimes it may be accompanied by showering phenomena and/or explosive electron emission (ecton process). As a result the arc duration at this mechanism of bridge formation is small and depends on the pressure according to Pashen's law [2]. When the decreasing current reaches the certain critical value I_{cr} at the critical time t_{cr} the arc becomes unstable therefore, even a very small perturbation of current or voltage may cause the arc collapse (see Fig. 3.).

3. EXPERYMENTAL INVESTIGATIONS

3.1. TESTING PROCEDURE

In order to conduct research a special testing system equipped with a dismountable hermetic chamber with the contact system inside, controlled by a PC was designed and assembled as in Fig.4.

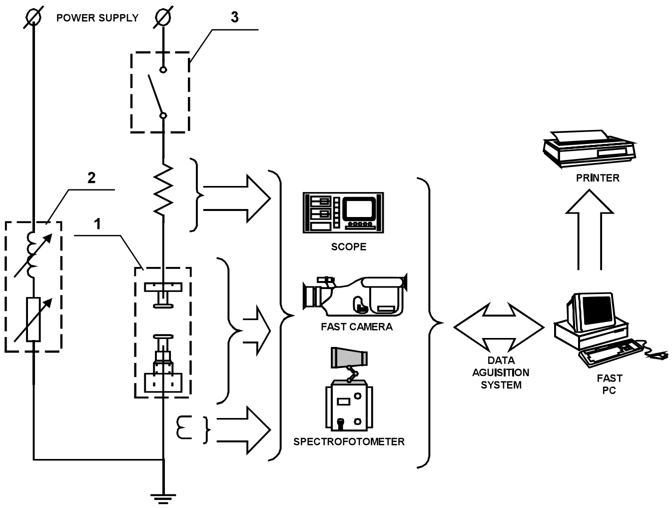

Fig. 4. Schematic set-up of the test apparatus: 1 – dismountable chamber stand, 2 – load to be adjusted, 3 – auxiliary protection switch

Plain, round contacts (5 mm in diameter and 1 mm of thickness) operated in gaseous medium under normal pressure. As a contact material were used different both refractory and non-refractory fine metals (like W, Mo, Ni, Ti, and Ta), selected fine powder tungsten-copper sinters (with some additives like Co 2%) and vapour deposited copper molybdenum and copper chromium compositions. Contacts opening velocity was ranged from 0.04 m/s up to about 0.4 m/s at contact force from 0.6 N up to around 40 N. During the study with the use of fast photography (2200 frames per second) and radiation spectra measurements the length of contact gap was enlarged up to about 7 mm (from 2.5 mm). Due to the limitation of performance in transient of the selected fiber-optics spectrometer (time spectrum analysis about 200 ms) the research of emission spectrum (in visible light range from 300 nm to 750 nm) was carried out for separately generated arc and glow discharges produced under the DC inductive load breaking. The investigations were performed for currents in the range of 0.5–3.0 A at voltage from 48 V to 250 V and at a circuit time constant varied from 10 ms up to 40 ms (discharge energy less than 10 J). The voltage, current, discharge power and the contact gap length variation were respectively recorded. To reduce the influence of surface contaminations, the contacts were preliminary mechanically and chemically cleaned and subjected to preliminary operation before testing. Ten samples for each contact material were selected and mean values and predicted ranges with 95% level of confidence were calculated after completed testing.

3.2. CONTACT MATERIAL EFFECT

The study showed that effect of transition of the arc discharge in a glowing is primarily dependent on contact material applied. However, it is noticeable for both refractory as well as non-refractory different materials under specified conditions of operation no less for materials such as silver and its alloys it is unattainable. It has been also found, that for consecutive switching under identical conditions, the transition is not identical but similar. It reveals that, some of the mechanisms depend on the probability of various events and therefore, the arc to glow transformation is not completely determined, but is subject to the lows of probability. The glow discharge at contact opening is found to arise most easily when fine nickel is applied. It can be attainable

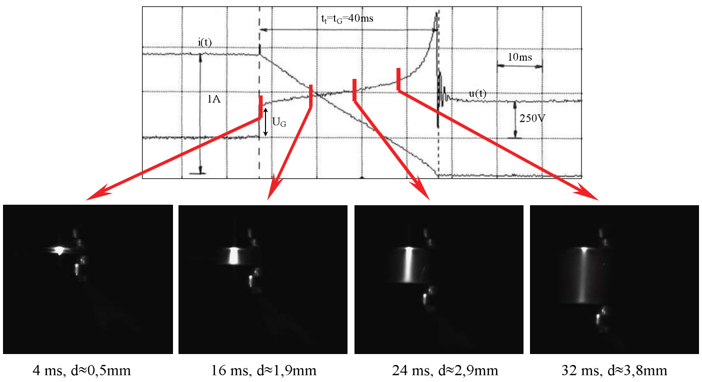

Fig. 5. Glow discharge triggered at the beginning of the contact separation when breake inductive load DC (250 V, 1 A, 40 ms) in air (~100 kPa) with contacts made of fine nickel: t_t, t_G – total and glowing time respectively, U_G – glow voltage

even at the beginning of contact displacement (at the moment of bridge evaporation or protrusions explosion) as illustrated in Fig. 5. As a result, the discharge energy within the contact area is dissipated at a much higher voltage level (U_G about 300 V) and for current decreasing almost linearly with time.

Therefore, both contact erosion and switching over-voltage values are reduced significantly. However, the glowing is usually generated due to transition from very unstable arc discharge (short arc, showering arc) which can be compared from Figs. 6 and 7.

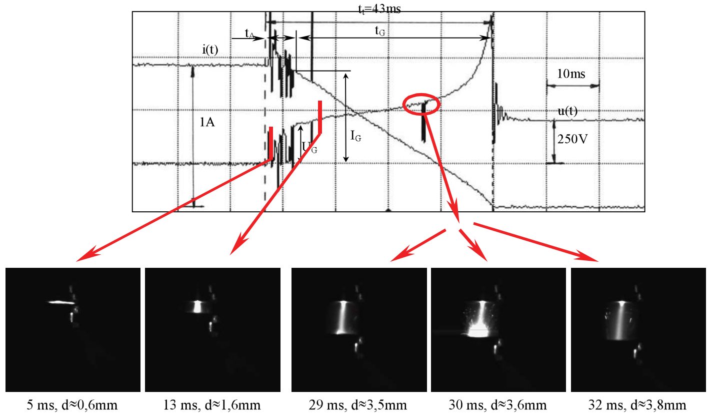

Fig. 6. The unstable arc to glow transition when use the nickel contacts (250 V, 1 A, 40 ms, air ~100 kPa):
t_t, t_A, t_G – total, arcing and glow discharge time, respectively;
U_G – glow voltage, I_G – arc to glow transformation current value

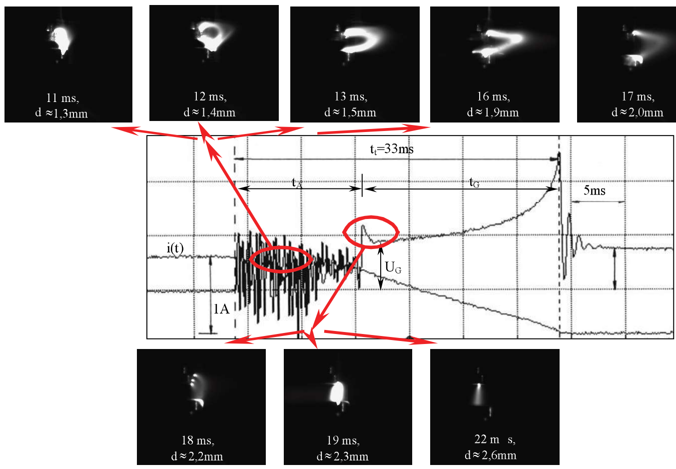

Fig. 7. Development of the electrical discharge when use contacts made of fine molybdenum
(250, 0.5 A, 40 ms, in air under 100 kPa)

In these cases the discharge tends to lead to occasional arcing due to explosive erosion from the cathode (see 30 ms for gap ≈3.6 mm in Fig. 6). This is related to a sudden change of the cathode surface conditions and associated reinforced emission, which confirms the major role of this electrode. For the contacts made of refractory materials like tungsten or molybdenum the arc to glow transformation can also be obtained. However, the extensive unstable arcing can be seen even for relatively low current values being broken as demonstrated in Fig. 7. Oxidation of the contact surface in air at an elevated temperature does not seem to be a major stimulating factor. Besides, it is worth noting that just at the transition moment, the anodic spot may be split into a few separate parts (see three spots at 18 ms in Fig. 7). It appears that the diffused anodic arc or multi-spot glowing confirms the importance of the anode as well and complexity of the problem. It should also be noted that the arc to glow transition can be initiated at a current (I_G) higher than so called "minimum arcing" current values (I_{cr}) for the applied contact materials [2]. This is particularly visible for fine nickel where ratio I_G/I_{cr} value can reach up to about 2.5. For example, the materials commonly used like fine copper and derivatives (brass), likewise silver and its compositions are found useless as a contact material to make USB connectors, since the electric discharge within the contact gap area is usually dominated by a stable electric arc [7, 8]. However, for copper-molybdenum condensed materials, with the increase of the molybdenum content (under the test up to about 14%) the arc to glow transition is visible, but with a small portion of glow duration. The contribution of gaseous elements (when operated in air) in arc radiation intensity is about 60% which indicates the existence of both metallic and gaseous arc phases (see Fig. 8).

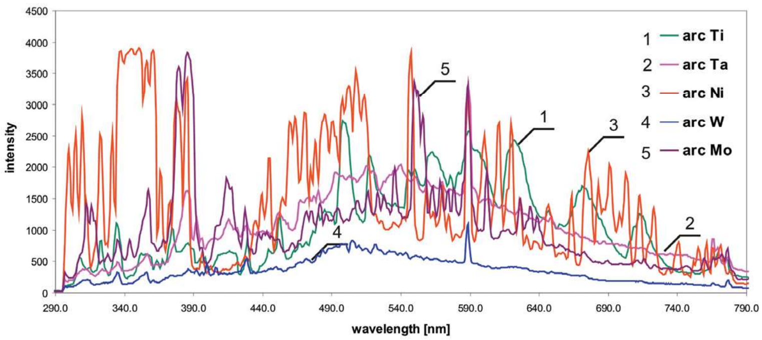

Fig. 8. Radiation spectrum of breaking arc in air under normal pressure for contacts made of different fine materials (Ti, Ta, Ni, W, Mo)

Intensity of the glowing radiation is about 10-times lower and exhibits an identical picture, independently of the contact material what can be compared from Fig. 9. The contribution of the electrodes elements under glowing, which is about 14%, results most probably from the fact that the metallic vapours inject into the gap area at the moment of bridge or protrusion explosion. For the given stored circuit inductive energy (circuit time constant) the total discharge time (t_t) was found to be almost independent on the quenching medium pressure.

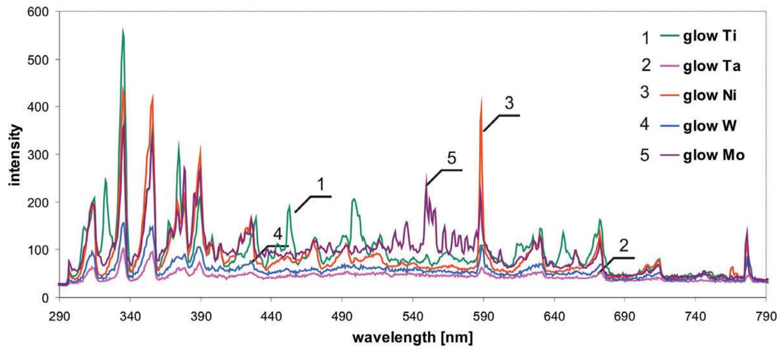

Fig. 9. Radiation spectrum for glowing discharge at contact opening in air
for different fine contact materials (Ti, Ta, Ni, W, Mo)

The total discharge time t_t as well as the portion of the glow duration is also enhanced by the increased supply voltage what for different contact material is illustrated in Fig 10.

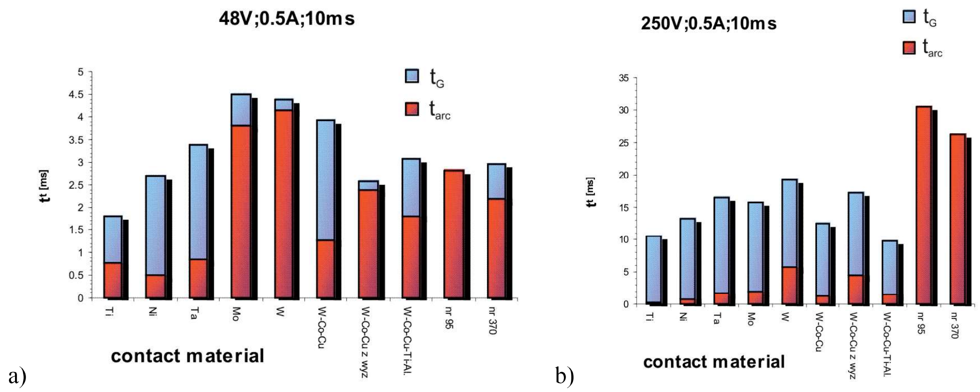

Fig. 10. Comparison of total discharge time (t_t) and portion of the glow duration *(*t_G*)*
for tested contact materials when interrupt inductive load DC (0.5 A, 10 ms)
at different voltage value (48 V and 250 V) in air under normal pressure (~100 kPa)

The best results are obtained for the fine nickel contacts. However, titanium seems to be promising as well particularly as dopant for fine powder sinters [6]. The portion of the glow duration here, is the highest under the same conditions of operation which reduces surface erosion significantly. The surface topography inspection, as well as a microstructure analysis, indicate that in a case when the arc-glow transition occurs easily the erosion is less extensive. For example, for pure nickel the eroded area of the contact surface (particularly the anode) after about 300 switching was found to be significantly smaller than after 40 switches with predominant arcing [3, 6]. This is equivalent to an increase in electrical life of the switch.

4. CONCLUSION

The occurrence of glow discharge and/or transition of the switching arc in a glowing observed in inductive circuits of low voltage and low power is an advantages because it decreases significantly erosion of the contact surfaces, thus extending the switch life, reducing simultaneously the voltage surge values.

Thus, although repeatability of as current as well as switching voltage waveforms at each successive cycle is not satisfied but, statistically the transition of arc in a glow discharge will be achieved. However, the transition can be obtained for any low voltage and low power contact switch, operating even in open air, but it is particularly recommended for auxiliary encapsulated (hermetic) switches of a compact structure, in which many interfering effects such as oxidation, contamination etc. can be reduced or even eliminated.

REFERENCES

[1] MECKLER J.P., GERDINAND F., WEISS R., BOEKE U., MAUER A., *Hybrid switches in protective devices for low-voltage DC grids at commercial used buildings*, Proc. of 27th Int. Conf. on Electric Contacts, June 22–26, 2014, Dresden, Germany, 2014, pp. 120–125.

[2] HOLM R., *Electric contacts. Theory and applications*, M. Dekker (Ed.), Basel, Switzerland, 1999.

[3] MIEDZINSKI B., SZYMANSKI A., WISNIEWSKI G., GRODZINSKI A., *Transformation of low power arc to glowing under inductive load DC*, Proc. Int. Conf. SAP 2001, Łódź, Poland, 17–20.09.2001, pp. 117–120.

[4] KHARIN S.N., NOURI H., MIEDZINSKI B., WISNIEWSKI G., *Transient phenomena of arc to glow discharge transformation at contact opening*, Proc. of 21st Int. Conf. on Electric Contacts, Zurich, Switzerland, 9–12.09.2002, pp. 425–431.

[5] KHARIN S.N., *Mathematical model of the arc evaluation from metallic phase to gaseous phase*, Proc. 20th Int. Conf. on Electric Contacts, Stockholm, Sweden, 2000, pp. 155–160.

[6] NOURI H., MIEDZINSKI B., KHARIN S.N., WISNIEWSKI G., *Analysis and investigations of arc to glow discharge transformation under DC inductive load*, Mechanizacja i Automatyzacja Górnictwa MIAG, No. 8/439, 2007, pp. 7–22.

[7] MIEDZINSKI B., WISNIEWSKI G., SHOFFA V.N., GRECHANYUK N.I., *Performance of copper-molybdenum contacts when used for inductive DC load*, Electrical Contacts and Electrodes, Institute of Material Science, 2004, pp. 19–23.

[8] KHARIN S.N., NOURI H., DAVIES T., *Influence of Inductance on the Arc Evolution in AgMeO Electrical Contacts*, Proc. 48th IEEE Holm Conf. on Electrical Contacts, Orlando, USA, 2002, pp. 108–119.