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Original Article

Possibility of Control of Transition of Switching Arc Dc into Glowing

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Abstract: This paper presents and discusses results of 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, gas quenching medium and its pressure. The transition phenomenon is analysed by means of fast photography and emission spectroscopy. On the basis of investigated results the conclusions about the possibility of control of the arc to glow transformation for practical use in electrical control switching devices are formulated.

1. INTRODUCTION

Arc to glow transformation is found to appear also at contact opening for specified load conditions, particularly under heavy inductive loads of low power (≤ 10 J) and low voltage (≤ 250 V) dc, which is the most onerous category of utilization (DC-13) [1]. This phenomenon appears to be a real advantage for reliable operation of a switch device due to significant reduction of contact surface erosion. Moreover, switching in circuits can be over-voltages suppressed. The transformation from glow to arc discharge is a well-known phenomenon [2-6].

However, the inverse transformation from arc to glow discharge is a little-studied and recognized process. At present, no theory exists, which can explain the physically based and mathematically described mechanism of arc-to-glow transformation. This results from a complexity of the problem due to the fact that in a given arc, a number of mechanisms co-exist with one more prominent than the others, but where a dynamic change in contact environment can lead to a shift in their relative magnitudes so that a different mechanism becomes dominant.

The essential problem before mathematical modelling is to find conditions, criteria and optimal choice of interdependent parameters (material and gas properties, current, voltage, circuit time constant, pressure, opening velocity etc) providing arc instability and controlled arc-to-glow transformation. Therefore, respective investigations were carried out both at atmospheric conditions as well as in a hermetic chamber filled with pure argon or with N_2 + H_2 (5%) mixture at normal and decreased pressure (from 100 kP up to about 10 kPa). On the basis of the measuring results conclusions about possibility of control of the switching arc to glowing are formulated.

2. EXPERIMENTAL INVESTIGATIONS

2.1. Testing Procedure

Investigations were carried out in a special testing system controlled by a PC and equipped with a

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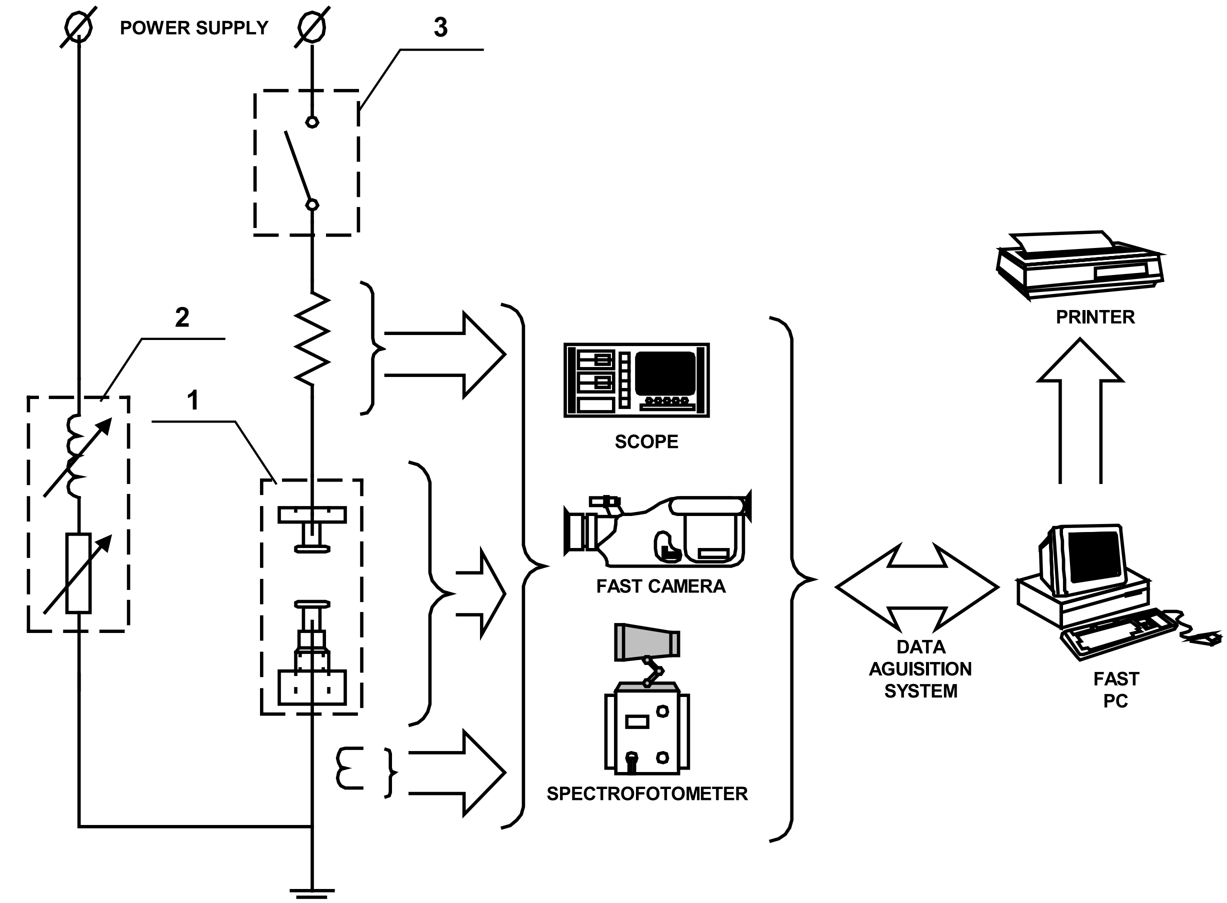


Fig. 1. Schematic set-up of the test apparatus (1-dismountable chamber stand, 2-load to be adjusted, 3-auxiliary protection switch).

dismountable hermetic chamber with a contact system inside as in Fig. 1 [7]. As a gaseous medium, both air, pure argon and N_2 + H_2 (5%) mixture were used. Plain round contacts (of 5 mm in diameter and 1 mm in thickness) made of both refractory and non-refractory fine material (W, Mo, Ni, Ti, Ta), selected fine power tungsten-copper sinters (with some additives like Co 2%, TiAl 1%) and vapour deposited copper molybdenum compositions were tested with a medium opening velocity, ranging from 0.04 m/s up to about 0.4 m/s, at contact force up to 40 N. To complete the study of the arc to glow transformation by fast photography (2200 frames per second) and radiation spectra measurements, the contact gap value is enlarged up to 7 mm. The contact set is located vertically with movable cathode at the bottom [8]. Due to the principle of the operation of the fiber-optics spectrometer applied, which is able to analyze the spectrum only as a resultant radiation within 200 ms, the inductive load to be switched is selected to produce the DC arc discharge and/or the glowing as an independent phenomena. The spectrum detected is limited to a visible range, from 300 nm up to about 750 nm due to the transparency of a fibre waveguide. The investigations are performed for currents in the range of 0.5-3 A at voltage from 48V to 250V and at a circuit time constant varied from 10 ms up to 40 ms (discharge energy ≤ 10 J). The current, voltage, discharge power and the contact gap length variation were recorded. To reduce the influence of surface contaminations as much as possible, the contacts were preliminary, mechanically and chemically cleaned and subjected to operation under load before testing. Mean values and predicted ranges with a 95 percent level of confidence are calculated for ten samples of each contact material.

3. RESULTS AND DISCUSSION

3.1. Contact Material Effect

The investigated results have indicated that contact material is a key factor. However, the arc-glow transition may occur for both refractory and non-refractory different materials, under specified conditions of operation but some materials like silver and its compositions are useless here, since the glow transition is almost unattainable. The observation of consecutive switching under identical conditions shows some variation in general appearance. For identical conditions arc to glow transformations are never exactly the same, but they are similar. The reason for this is 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 laws of probability.

The glow discharge at contact opening is found to arise most easily when fine nickel is applied. It can be attainable even at the beginning of contact

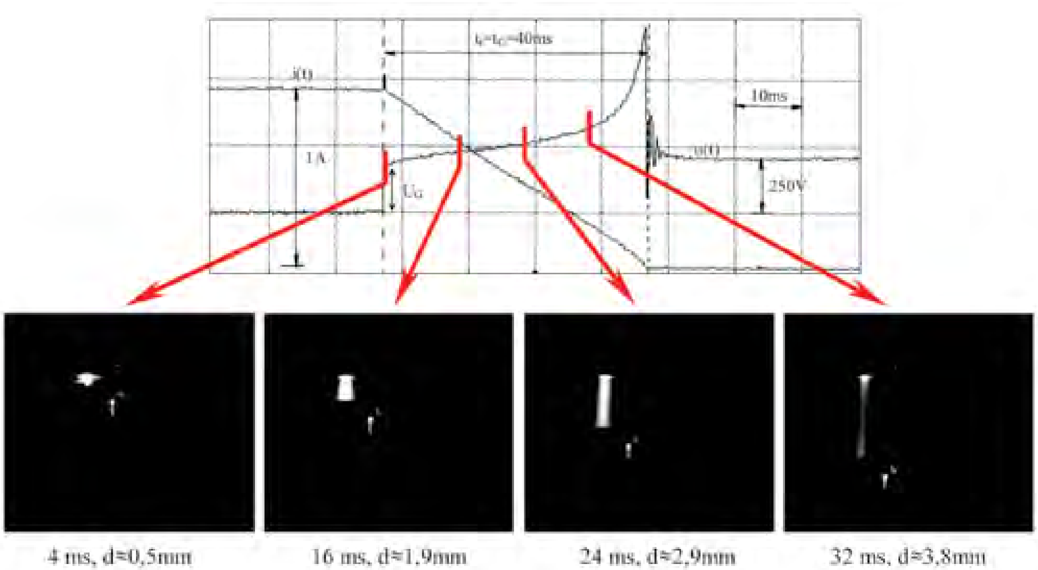


Fig. 2. Glow discharge triggered at the beginning of the contact separation when brake inductive load DC (250 V, 1 A, 40 ms) in air (~ 100 kPa) with contacts made of fine nickel. (t_t, t_G – total and glowing time respectively, U_G – glow voltage).

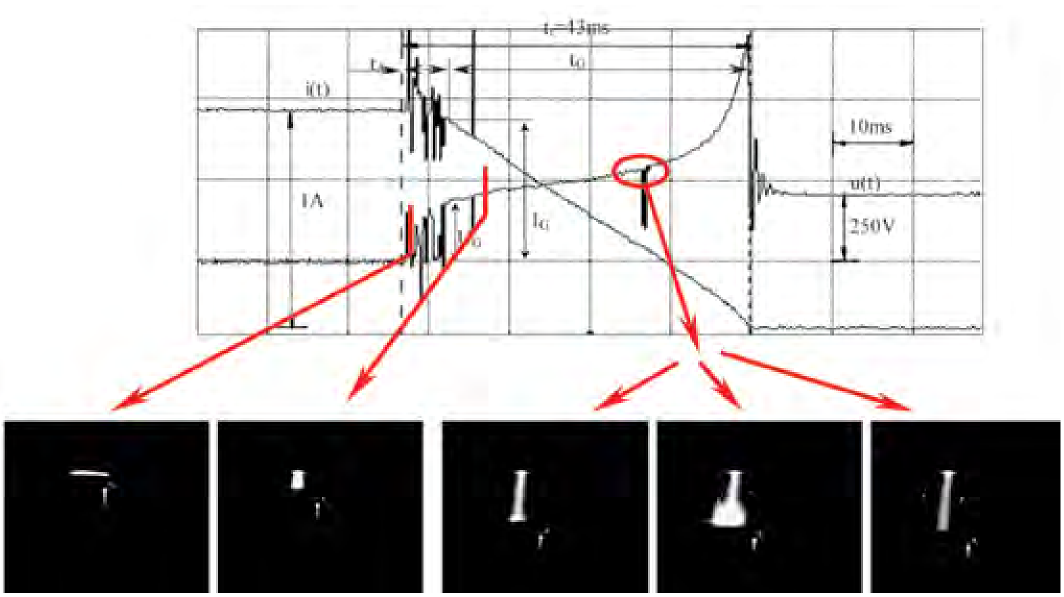


Fig. 3. The unstable arc to glow transition when use the nickel contacts (250 V, 1 A, 40 ms, air ~ 100 kPa) (t_t t_{ARC}, t_G – total, arcing and glow discharge time respectively, U_g – glow voltage, I_G – arc to glow transformation current value).

displacement (at the moment of bridge evaporation or protrusions explosion) as illustrated in Fig. 2. As a result, the discharge energy within the contact area is dissipated at a much higher voltage level (U_g about 300V) 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 Fig. 3 and Fig. 4. 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. 3). This is related to a sudden change of the cathode surface conditions and associated reinforced emission, which confirm 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. 4. Since the arc appearance for tungsten and molybdenum contacts does not vary significantly in pure argon (as a quenching medium), the increased oxidation of the contact surface in air at an elevated temperature does not

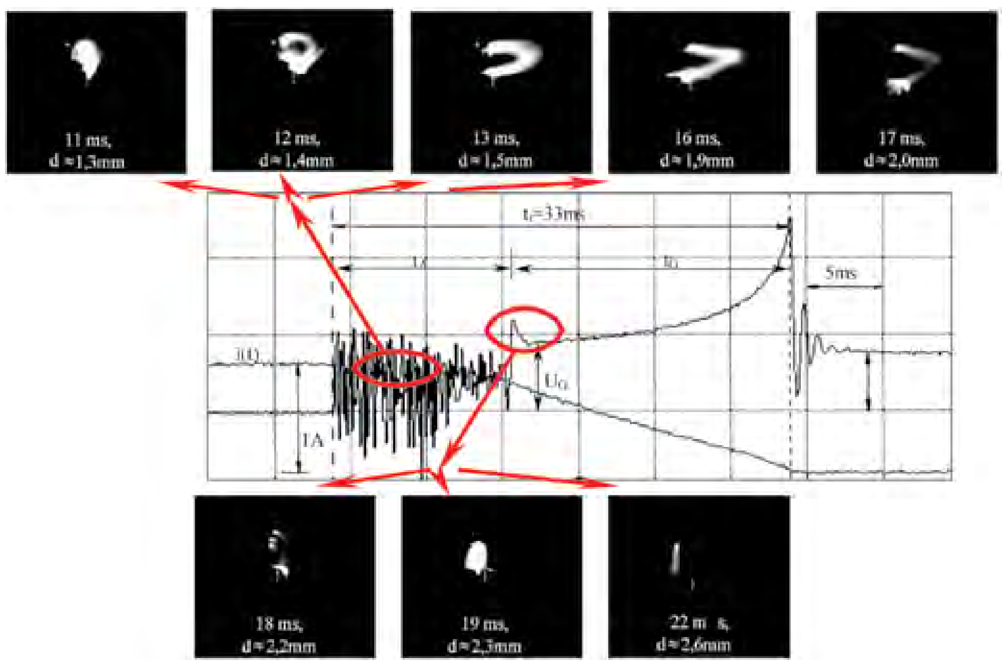


Fig. 4. Development of the electrical discharge when use contacts made of fine molybdenum (250, 0.5 A, 40 ms, in air under 100 kPa).

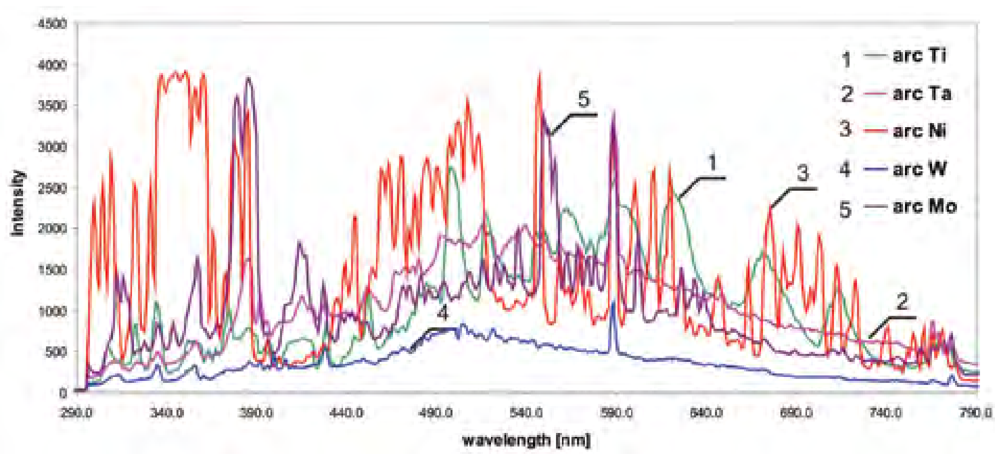


Fig. 5. Radiation spectrum of breaking arc in air under normal pressure for contacts made of different fine materials (Ti, Ta, Ni, W, Mo).

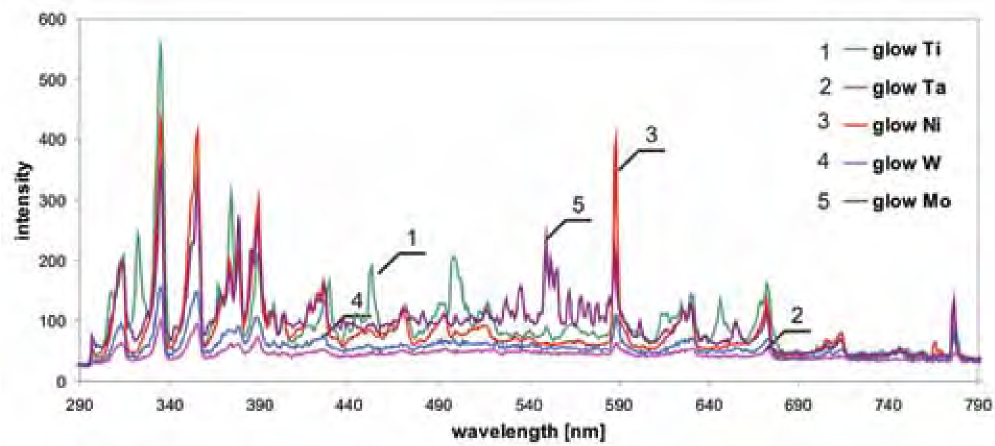


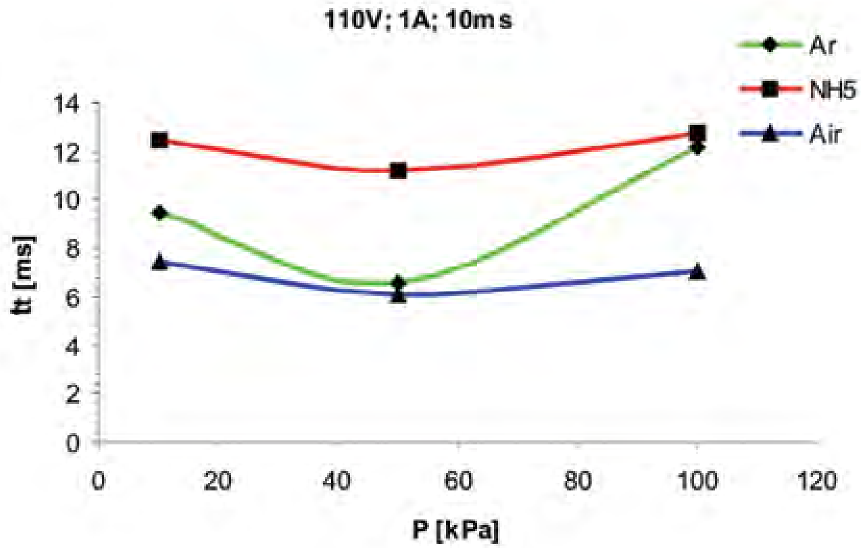
Fig. 6. Radiation spectrum for glowing discharge at contact opening in air for different fine contact materials (Ti, Ta, Ni, W, Mo).

seem to be a major stimulating factor. Besides, it is worth noting that just at the transition moment, the anodic spot may split into a few separate parts (see three spots delete at 18 ms in Fig. 4). 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 [3]. This is particularly visible for fine nickel where ratio I_G/I_{cr} value can reach up to about 2.5. The fine copper, likewise silver and its compositions are found useless as a contact material under DC heavy inductive loads, since the electric discharge within the contact gap area is usually dominated by a stable electric arc. 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 measuring results of the radiation spectra during electrical discharges at contact opening confirm the arc to glow transition phenomenon. 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 (Fig. 5). 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. 6. 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.

3.2. Velocity and Contact Gap Effect

The arc to glow transition, which occurs under inductive load DC in a gaseous medium does not exhibit a strong dependence neither on contact opening velocity (under the range investigated) or on gap length. Note that maximum velocity up to about 0.4 m/s is selected due to the compliance and damping of bellows anticipated for use in a real model of hermetic compact auxiliary switch operating, according to DC-13 category of utilization. The glow discharge can be reached almost immediately after contact separation (contact gap ≤ 0.1 mm) or after short arcing (contact gap ≤ 2.5 mm) so the discharge phenomena are greatly affected by the electrodes and their neighbouring contraction regions. Therefore, the arc to glow transformation seems little dependent on contact gap length. However, it is interesting to note that the rate of voltage at glow stage for AgCdO contacts is found positive in the range of opening velocity up to about 0.4 m/s, while in the range from 0.5 m/s to 0.75 m/s it becomes negative [9]. For higher (> 0.5 m/s) opening velocity it is also observed that both velocity at contact separation as well as variation of acceleration can be important for the control of arc-to-glow transition.



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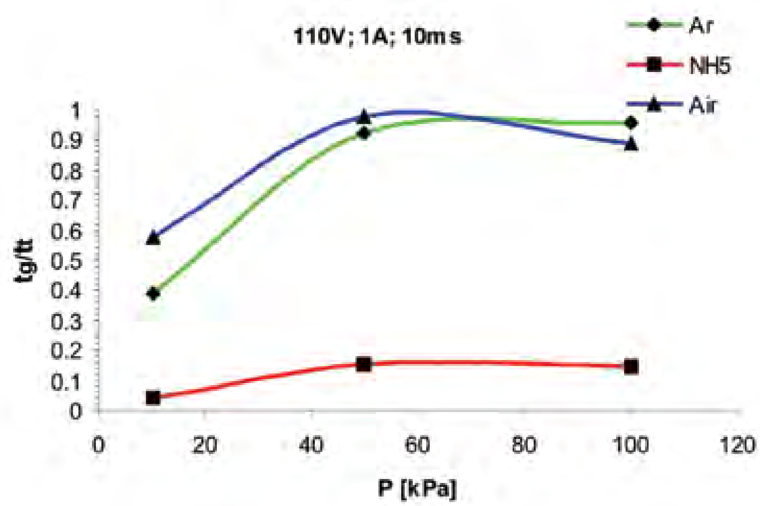

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Fig. 7. Variation of the discharge time (t_t) and the portion of the glow duration (t_G/t_t) versus pressure (P) when interrupt inductive load DC (110 V, 1A, 10 ms) in selected gaseous mediums (air, argon, nitrogen-hydrogen 5% mixture) with contacts made of the fine nickel.

3.3. Load and Environment Effect

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 particularly for air and nitrogen-hydrogen (5%) mixture. However, when pure argon is applied it is reduced visibly at about 50 kPa when use contacts made of the fine nickel. (see Fig. 7a). With point of view of the effective arc to glow transformation the reduction of the pressure below 50kPa is not desirable what for investigated mediums can be compared from Fig. 7b. It is also worth to note that in argon the glow duration is extending due to a much lower glowing voltage (U_G) value [9]. On the contrary, when the air is replaced with N_2+H_2 (5%) gaseous mixture, the results under both normal and decreased pressure appear unsatisfactory due to the generation of high stability arc discharge [9]. 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. 8.

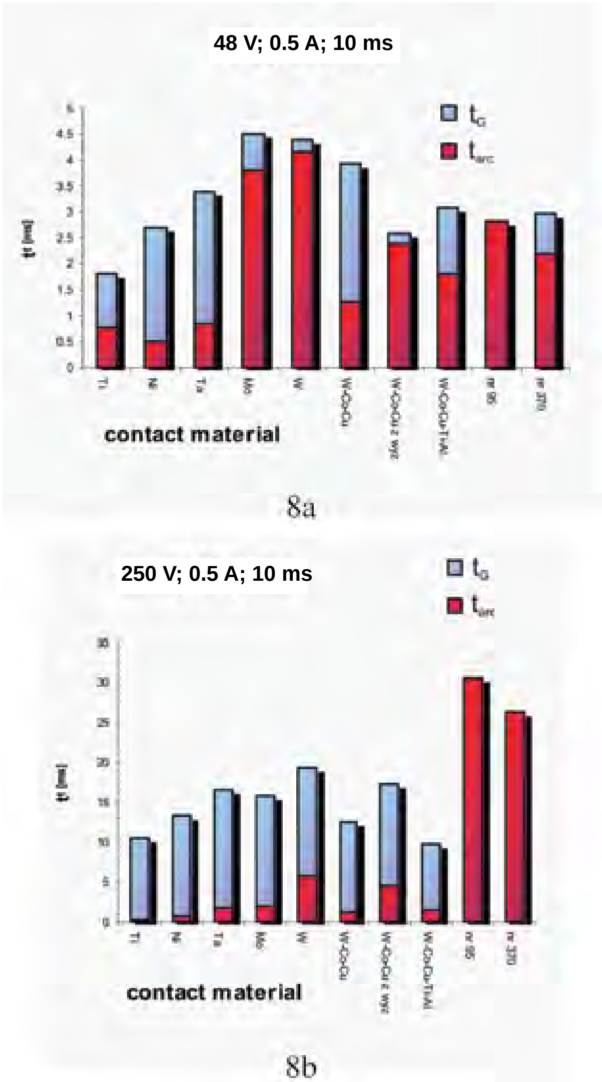

Fig. 8. Comparison of total discharge time (t_t) and portion of the glow duration (t_G) for tested contact materials when interrupt inductive load DC (0.5A, 10 ms) at different voltage value (48 V and 250 V) in air under normal pressure (~100 kPa).

It is found that for almost each material applied there is a certain value of gas pressure under which the arc is easily transformed. The best results are obtained for the fine nickel contacts when use either pure argon or with air (as a quenching medium) under pressures around 50-100 kPa. However, titanium seems to be promising as well particularly as dopant for fine powder sinters (Fig. 8) [10-11]. The superiority of fine nickel as a contact material over tungsten concerning the arc to glow transition, particularly for increasing current is visible in Fig. 9.

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

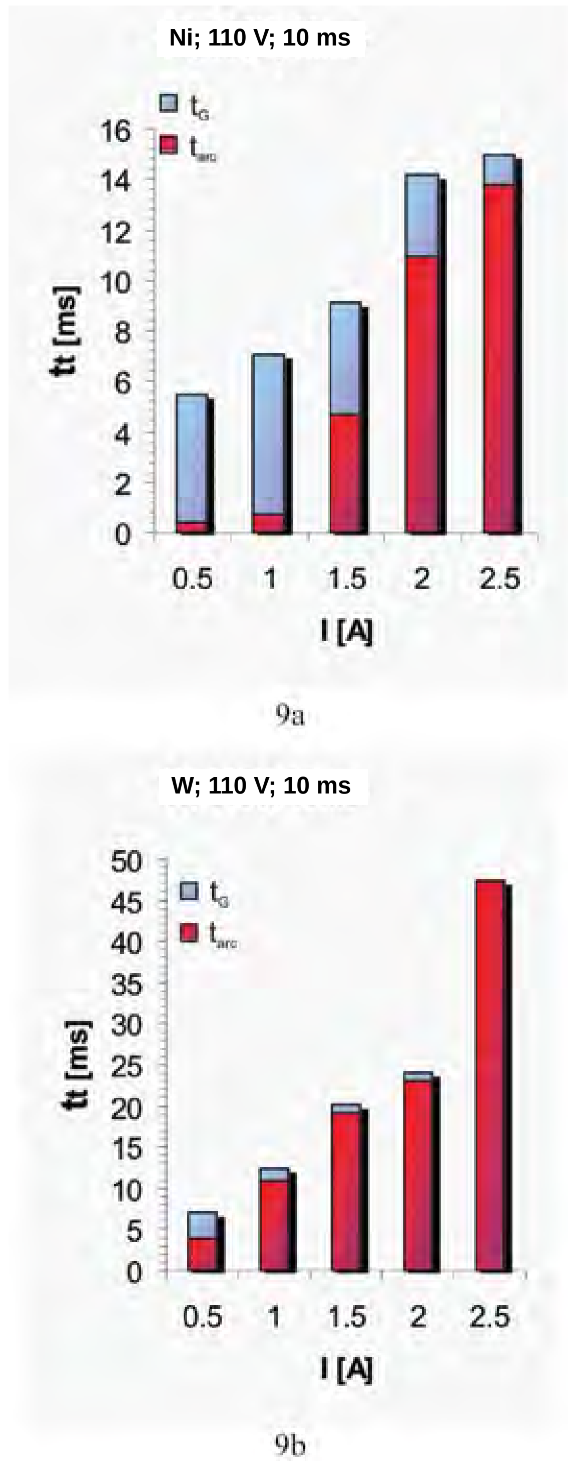

Fig. 9. Comparison of total discharge time (t_t) and portion of the glow duration (t_G) for nickel and tungsten as contact materials when interrupt inductive load DC (110 V, 10 ms) at different current value in air under normal pressure (~100 kPa).

analysis, indicates that in a case when the arc-glow transition occurs easily the erosion is less extensive.

4. CONCLUSION

Arc to glow transition appears at contact opening for specified conditions of operation and is an advantageous phenomenon resulting in the decrease of contact surface erosion and switching over-voltages.

- Neither materials of the highest melting and boiling points (like tungsten) or of the lowest (like fine copper, silver and their compositions) are found to be useful. The best results were obtained for fine nickel in air or in pure argon under pressures around 50-100 kPa.
- The duration of the glow stage increased with increasing supplied voltage and circuit time constant and became maximum at a certain value of the ambient pressure, depending on gas and contact material.
- Opening velocity and acceleration are important for the control of arc to glow transition. However, at low velocity it seems to be little dependent on contact gap length. The rate of glow voltage was positive for low opening velocity and negative for high opening velocity.
- However, the arc to glow transition can be obtained for any low voltage, and low power switch, operating even in air, but it is particularly recommended for auxiliary hermetic switches of compact structure, in which effects such as oxidation, contamination etc can be neglected.

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