

Effects of the Dynamics of Cathode Spot on Trichel Pulses

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Abstract—Negative corona discharge has been investigated in ambient air in the point-to-plane electrode configuration in Trichel pulse regime on copper, graphite and aluminum cathodes. Results of oscillography of Trichel pulses been presented in form of amplitude – pulse time separation diagrams demonstrated separately influence of the gap conditions and influence of the surface properties on Trichel pulses. It was found that topography of the cathode tip decisively affected the amplitude of the Trichel pulses, whereas the pulse frequency depended primarily on the discharge gap and voltage. Also effects of the surface properties on stability of Trichel pulses have been found.

Keywords—Trichel pulses, discharge wandering, surface conditions

I. INTRODUCTION

First extensive study of negative corona discharge with use of telemicroscopy and oscillography was performed by Loeb [1]. Typical for Trichel pulse corona wandering, flickering and jumping of discharge glow from one active spot to another on the cathode surface was attributed to change of secondary emission coefficients of the surface due to two opposite simultaneous actions – surface oxidation and erosion cleaning. Oscillographic study made by Trichel [2] with use of 100 kHz bandwidth oscilloscope revealed that appearance of the regular Trichel pulses with constant amplitude and impulse time separation always was associated with the concentration of the discharge at a single localized active spot which covered a small area.

The amplitude and interval between pulses in Trichel pulse corona are not generally constant. The statistical distributions of amplitude and pulse separation time of Trichel pulses were investigated in [3-7]. These dependencies are of certain technological interest because of commercial approaches of negative corona as well as because of the own rights for more comprehensive understanding of processes involved in negative corona phenomena.

However the physical explanation of observed distributions is still missing. In [4], [7] the irregularity of Trichel pulses was explained in terms of “memory effect” - space charge and metastables influence generated in previous pulses. Moreover there is not any conventional decision about the most probable mechanism of a single Trichel pulse regardless any statistical distribution [8-15].

In this work the correlation between cathode spot dynamics, surface properties and Trichel pulse amplitude and pulse separation time is investigated.

II. EXPERIMENTAL SETUP AND PROCEDURE

Negative corona discharge has been investigated in point-to-plane electrode configuration in atmospheric pressure air in Trichel pulse mode. Setup layout is presented in the Fig. 1.

As a cathode pointed graphite, copper and aluminum pins with diameter 20 - 500 μm were used. Pins were mechanically made and shaped by use of diamond abrasive. Copper cathodes were chemically polished with diluted FeCl_3 solution so that surface looked smoothly under optical microscope. Graphite cathodes were made from S-3 spectral graphite – polycrystalline graphite with typical grain size 1 μm . No performance was made to remove oxide film from the surface of aluminum cathode. Also no performance was made to shape precisely the pins tip before discharge because it was shaped and conditioned in few seconds due to erosion processes after the discharge was switched on. So at average current 100 μA metal cathodes with diameter 20 μm shortened in discharge with typical velocity 1 $\mu\text{m}/\text{min}$, and graphite ones - with velocity 10 $\mu\text{m}/\text{min}$. Hence any history of

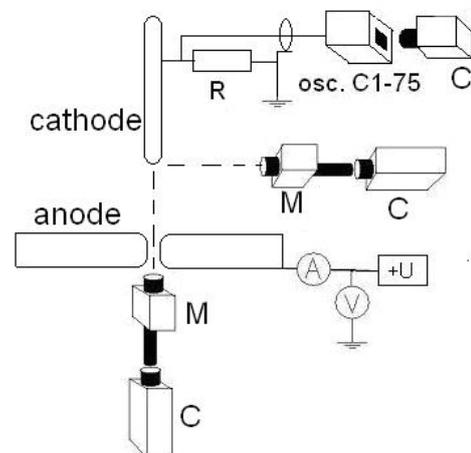


Fig. 1. Experimental setup layout.
M – microscope, C – camcorder.

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pre-discharge surface treatment disappeared soon after the discharge was switched on.

Cathode axis was perpendicular to the anode plane and discharge gap was adjusted from 10 to 20 mm. Positive voltage in the range 5 - 15 kV was applied to the plane anode which was a 10 cm diameter silicon disc with a 3 mm diameter hole in the anode center with smooth edges in front of the cathode. According to observations no critical influence of the hole on any discharge parameters was found.

Trichel pulses were registered by C1-75 dial oscilloscope with 300 MHz bandwidth which was connected across a 50 Ohm resistor between the cathode and the ground. Video recording of oscilloscope display has been performed.

Average discharge current was measured by use of dial ammeter between the anode and power supply. Cathode surface was video recorded by means of telemicroscopes with spatial resolution 3 μm . Simultaneous side and frontal observation through the hole in the anode was performed. Frame frequency of Cannon MW750i camcorders was adjusted as 25 frames per second with frame exposition time 40 ms.

Topography of cathode surface after treatment in the discharge was analyzed with spatial resolution 40 nm by use of FEI Quanta 200 and Jeol JSM-840 scanning electron microscopes.

III. RESULTS AND DISCUSSIONS

It was found that fixation of cathode spot in certain position on the cathode surface during discharge was always accompanied by Trichel pulse train with constant amplitude and pulse separation time. Change of amplitude and pulse time separation of Trichel pulses during discharge at fixed gap conditions was always associated with change of discharge position on the cathode surface.

When discharge changes its position on the cathode surface amplitude and pulse separation time of Trichel pulses may change, if the amplitude increases the pulse separation time increases too, and conversely. If a new spot position is stable for a certain time, the pulse train with possibly changed but also stable amplitude and pulse separation time is realized.

The average discharge current which was measured by dial ammeter did not change upon the wandering of the discharge spot position over the cathode surface.

Fig. 2 shows the typical oscillogram of the Trichel pulses. This photograph includes about 104 oscilloscope sweeps following each other during 40 ms. Start of each oscilloscope sweep coincides with start of one of the Trichel pulses. Voltage, average discharge current and discharge gap are fixed. Three trains of current pulses denoted a, b, c can be separated on the photograph, so that each train is characterized by individual nearly stable amplitude and pulse time separation.

Frontal and side photographs of the tip presented in the Fig. 3 indicate three stable fixations of the cathode spot (three active spots). These photographs were made

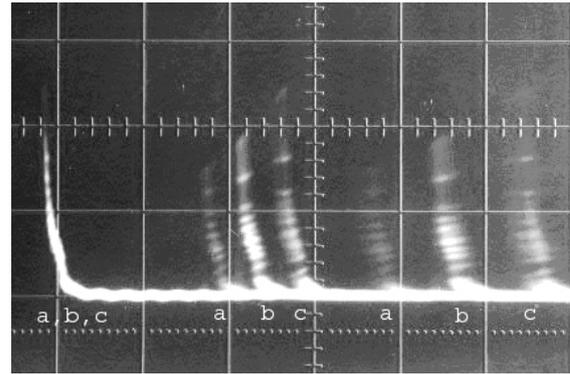


Fig. 2. The typical oscillogram of the discharge current.

Three pulse trains (a, b, c) may be distinguished
Frame exposition 40 ms. Scale 0,2 $\mu\text{s}/\text{div}$, 0,2 mA/div.



Fig. 3. Side photograph of the cathode during discharge.

On the insertion the frontal photograph which was made in the same time moment with outline of point dashed in.

Frame exposition is 40 ms. A 50- μm diameter graphite pin.

at the same moment as one presented in the Fig.2 with the same frame exposition 40 ms. So the conclusion is that every spot position is responsible for corresponding Trichel pulse train with certain amplitude and pulse time separation.

The observation shows that the amplitude of the Trichel pulses depends on local topography of cathode in the spot localization region. The smaller is the curvature of the surface region on which the spot is localized the higher is the Trichel pulse amplitude. In the same way the Trichel pulse amplitude depends on the average tip curvature [2].

Change of discharge position on the cathode surface is not sufficient condition for alteration of Trichel pulse parameters. If properties of cathode surface in a region of new spot position are the same as in previous one the Trichel pulse parameters do not change.

On the tip of 20 μm diameter copper pin the surface properties tend to equal all over the surface. Fragment of such surface after treatment in the discharge is demonstrated in the Fig. 4. Oscillographic study of Trichel pulses on this surface revealed stable Trichel pulse regime with constant amplitude and pulse time separation in spite of discharge spot wandering, traces of

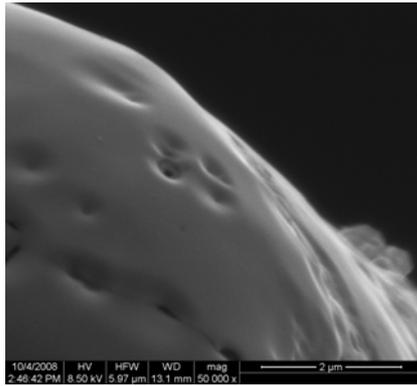


Fig. 4. Fragment of a 20 μm diameter copper cathode after treatment in corona.

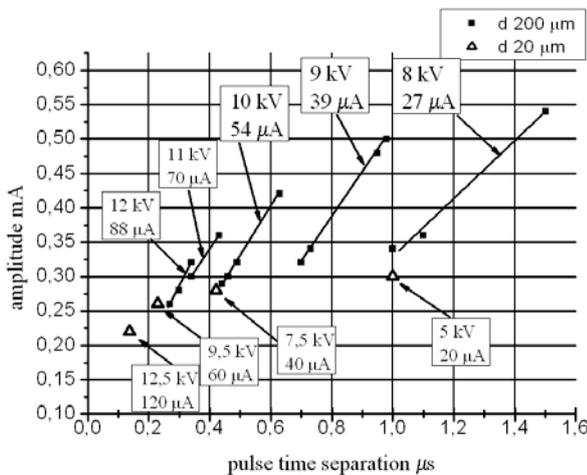


Fig. 5. Amplitude - pulse separation time diagram of Trichel pulses for 200 μm diameter copper cathode. Parameters of Trichel pulses in stable regime on 20 μm diameter copper cathode are also plotted.

wandering are apparent as erosion craters over the surface. Note that before discharge this surface was 15 μm deep inside the cathode. The aim of use of 20 μm diameter cathodes was to separate zones of discharge localization and erosion material redeposition [16] to avoid influence of the deposited oxide on the discharge.

Using oscillograms presented in the Fig. 2 one can draw the amplitude - pulse separation time characteristics of Trichel pulses for a given cathode. An example of such dependence for 200 μm - diameter copper cathode is demonstrated in the Fig. 5.

The experimental points in the Fig. 5 that are connected by line correspond to various cathode spot positions on the tip surface at fixed gap, voltage, and average discharge current. Change of a point position inside a certain line corresponds to change of cathode spot position on cathode surface. An increase of voltage increases the average discharge current and shifts a line left (the same action would effected by decrease of discharge gap or pressure). Actually during discharge Trichel pulse parameters tend to take on the all values inside the certain line and in the Fig. 5 only these experimental points are plotted which were registered during 40 ms frame time exposition.

So the results of oscillography of Trichel pulses been presented in form of amplitude - pulse time separation diagrams let demonstrate influence of gap conditions separately from influence of surface properties on Trichel pulses (movement inside of line or shift of line as a whole). Results of oscillography of Trichel pulses in stable regime on 20 μm copper cathode which is demonstrated in the Fig.4 are also presented on the plot in the Fig. 5.

Change of Trichel pulse amplitude and pulse separation time with constant gap properties is caused by change of local surface properties in the region of cathode spot localization during spot wandering. Oxidation, erosion, ions absorption, dust speck deposition in the spot localization region change secondary emission and field emission coefficients as well as local field strength which are responsible for initiation and replenishment discharge conditions and shift spot. Oxide layer formation may also initiate Malter effect which drastically influences electron emission on the surface.

Note that slight alteration of Trichel pulse parameters inside certain train in the Fig. 2 is also observed. This alteration occurs when cathode spot position is generally fixed and hence may be attributed to both erosion change of local cathode properties and space charge influence. Also indistinguishable for optical observations movement of cathode spot in the region of its localization take place, small shift of cathode spot may result in small change of Trichel pulse parameters.

On the tip of a 140 μm diameter graphite pin in the Fig.6 erosion traces are irregular. Surface curvature is different over the tip surface and erosion craters with strongly different shapes present on it. Oscillographic study of Trichel pulses on this cathode revealed Trichel pulse irregularity like is demonstrated in Fig. 2.

The same Trichel pulse instability is observed on copper cathodes with diameter more than 30 μm. A 100 μm diameter copper pin is demonstrated in the Fig. 7. On this pin erosion cleaning does not prevail over oxidation - copper oxide is formed as result of cathode material redeposition in the same region where discharge is localized. Contrary on the pin of 20 μm cathode copper oxide is deposited on the side of cathode [16] apart from region of cathode top where discharge is mostly localized.

So Trichel pulse irregularity is caused both by oxide

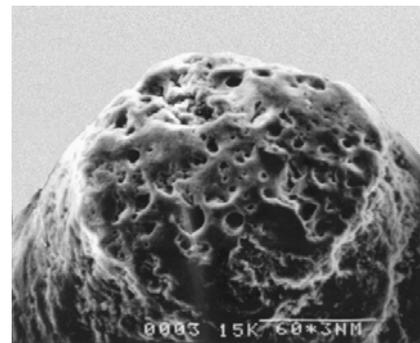


Fig. 6. Tip of 140 μm diameter graphite pin. Irregular erosion pattern is observed.

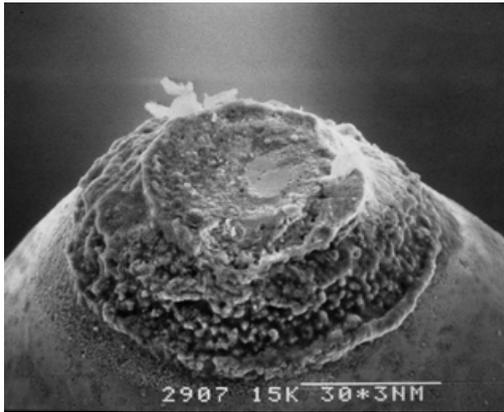


Fig.7. Tip of 100 μm diameter copper cathode. Copper oxide in erosion zone is observed.

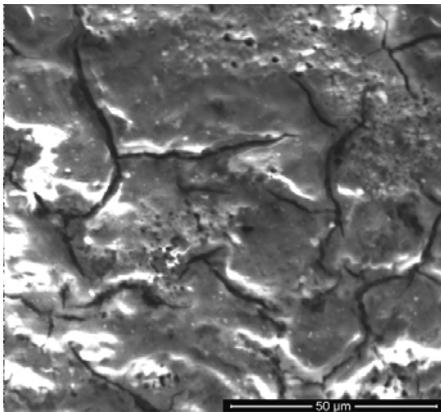


Fig.8. Fragment of tip of 500 μm diameter aluminum pin. Numerous holes and fissures in the oxide layer are observed.

formation and by irregularity of erosion pattern of the surface.

Oscillography and visual observations in the case of aluminum cathodes revealed that Trichel pulses appeared independently one from another without any simple correlation in amplitude and pulse separation time between consequent pulses. Also the discharge was found to change the point of its localization on the cathode surface at least 1000 times during 40 ms frame time exposition. Peculiarities of erosion and discharge dynamics on Al were explained by Weissler [2] in terms of alteration of the oxide-coated surface film by the impact of positive ions. Erosion holes and fissures in the oxide film on the aluminum tip are demonstrated in the Fig. 8.

IV. CONCLUSION

Correlation between erosion pattern, cathode spot dynamics and Trichel pulse parameters was found. It is found that change of Trichel pulse amplitude and pulse time separation at fixed gap conditions is caused by discharge wandering over the surface. Cathode surface oxidation and irregularity of erosion pattern lead to irregularity of Trichel pulse parameters. Fixation of

cathode spot or equalization of cathode properties over the surface result in regularity of Trichel pulse parameters. Amplitude – pulse time separation diagrams of Trichel pulses let demonstrate separately influence of cathode spot wandering and influence of gap conditions on Trichel pulses.

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