X-RAY EMISSION ACCOMPANYING
THE CATHODE MICRODISCHARGE

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Abstract: Electrical discharge in vacuum is accompanied by X-Ray radiation. A good knowledge of the generation mechanism of radiation may lead to its practical use. The analysis of this phenomenon indicates that it is only at the discharge development phase until the moment of the anode plasma generation that the proper conditions for X-Ray generation are satisfied. The intensity of radiation is dependent upon the field current intensity on the cathode surface as well as upon the value of the electron current supplying the anode. The anode current at the vacuum discharge development phase has a pulse character, and the pulse amplitude is dependent on the cathode plasma density. The radiation intensity may be increased by increasing the current amplitude, e.g. by artificial plasma generation in the trigger system.

Introduction

It is well known that X-Ray emission accompanies the process of current discharge in vacuum [1]. The analysis of this process indicates that optimal conditions for generating X-Rays occur at the stage of the discharge development when there is a high current flowing in the presence of the high voltage [2]. As soon as the discharge is developed into the arc stage, the voltage in the electrode gap is considerably lowered with the simultaneous intensity of radiation. Thus, the analysis of the mechanism of electrical discharge in vacuum with special allowance made for pre-breakdown current is very important.

Development of Electrical Discharge in Vacuum

It follows from numerous publications on this subject that vacuum discharge can develop under the influence of field emission and microdischarges, or can be initiated by microparticles. Of particular interest to this research study is the mechanism of microdischarges [3,4]. Microdischarges occuring on one of the electrodes result in the formation of plasma which contributes largely to the further discharge development. There is no consensus about the mechanism giving rise to microdischarge. Taken here into consideration are explosive emission [5,6] or discharges in the adsorbed layer near the electrodes [7]. It follows from both these mechanisms that microdischarge is the generating of plasma on the cathode surface. Thus, this phenomenon is similar to that occuring in a trigatron, the difference being that the plasma neighbouring the electrode is produced artificially from an additional source. The formation of the cathode plasma is conditioned by the flow of the current being sufficient for the anode plasma to be generated, which results in the breakdown. Observations of this phenomenon by means of high speed photography provide interesting information on this subject. By way of example this is shown in the streak photograph Fig.1.

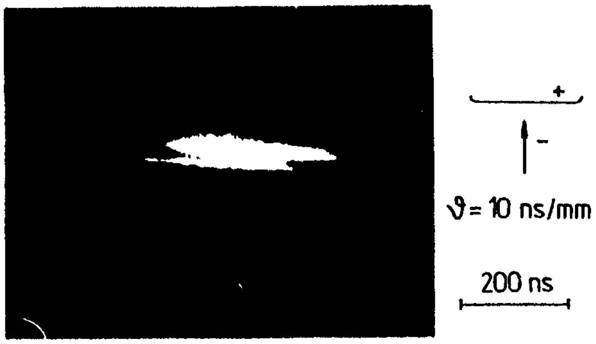

Figure 1. Streak photograph of the initial stage of electrical breakdown in vacuum.

These observations indicate that the discharge always starts as a light on the cathode surface. Then, after a period of time depending, among other things, on the distance between the electrodes, on the material and the anode temperature, an intense anode light appears in the interelectrode gap. The appearance of the anode plasma is equal in effect to the loss of the insulating properties of the vacuum gap and to the abrupt drop in the voltage on the electrodes. In this way the conditions for generating X-Rays will disappear. Thus, from this point of view, of much interest to us are only the phenomena accompanying the development of the discharge until the moment when the anode plasma appears. With the use of the appropriate recording speed of the camera it can be observed that the cathode light has a pulsating character, Fig.2.

Cathode pulses are also observed on the trigger cathode, Fig.3.

The above phenomenon is in both cases similar, the difference being that the artificially generated cathode plasma has a more intensive light and the frequency of pulses being much higher right after their generation, decreases at further development stages. It has been found that the brighter the pulses, the greater their frequency. This

Figure 2. A streak photograph showing oscillating light emission at the cathode.

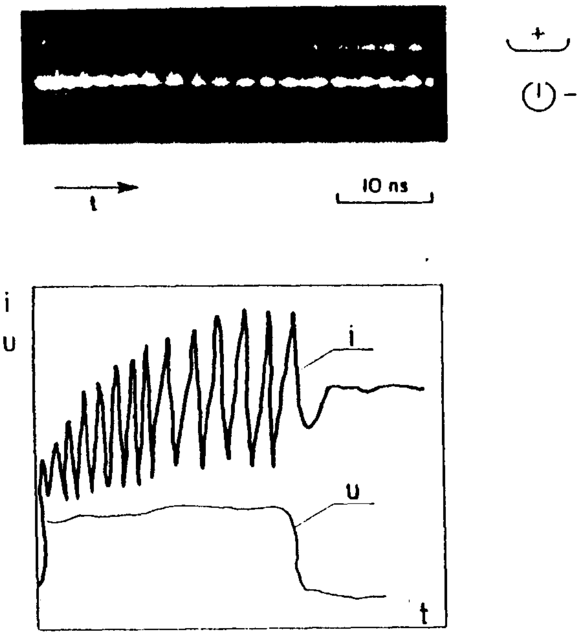

Figure 3. A streak photograph of cathode light emission for triggered D.C. breakdown and predicted current and voltage transients.

allows the frequency of the observed impulses to be associated with the density of the plasma generated. Such an image of the development of the vacuum discharge implies that the anode is bombarded by a stream of electrons accelerated from the cathode area. The source of electrons, besides the field emission, is mainly the cathode plasma. Corresponding to the presented light picture should be the predicted voltage and current transients shown in Fig.3. This is evidence that corresponding with each light pulse on the cathode should be the pulse of the electron current bombarding the anode. It follows from the photographic observation that the duration of such a current impulse is much shorter than 1 ns, the impulse repetition being 4 - 5 ns. At the 1 ns time the electromagnetic wave may cover under optimal conditions the distance of about 30 cm, which makes the recording of such oscillations very difficult. Additional disturbances introduce inductance of the connecting leads and of the shunt. The above mentioned considerations may account for the negative attempts to carry out such measurements [8]. Attempts to clarify cathode pulses by means of the cavity resonance mechanism have not been experimentally confirmed [8]. The impulse frequency does not change with the changes of the cave dimensions [9]. Apart from the measurment diffficulties discussed above the essential thing is that during the development of the vacuum discharge there are conditions for generating intense X-radiation. This radiation should be relevant to the current with the constant voltage assumed, while the current value can be influenced by the cathode plasma density and through appropriate technological procedures affecting the local field intensity on the cathode.

Experimental Procedure and Results

Studies into X-Ray radiation accompanying electrical discharges in vacuum were carried out for two and three electrode (trigatron) systems, Fig.4. Electrodes made of stainless steel were used and the interelectrode gap was being changed from 0.5 to 4.0 mm.

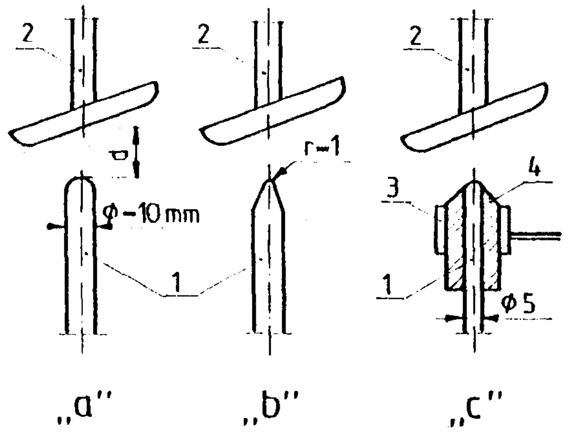

Figure 4. A schematic diagram of the electrode systems examined: 1-cathode, 2-anode, 3-trigger, 4-ceramic pipe $BaTiO_3$.

In the system being examined, the anode was 40 mm in diameter and its inclination angle was 10^o in relation to the plate being vertical to the axis of electrodes. Trigger electrodes were insulated by a $BaTiO_3$ ceramic pipe. The electrodes were put into the metal chamber with glass observation windows. The testing was carried out under a pressure of $7*10^{-3}$ Pa at the D.C. voltage after the system was conditioned.

The trigger electrodes were supplied by the impulse voltage obtained from the discharge 990 pF capacitor at the voltage of 17-18 kV. The initial radiation intensity measurements by means of PIN diodes have shown that the response time of the accessible diodes is too low, which made it impossible to record the radiation impulses accompanying the cathode impulses. This was the reason why further studies were carried out by means of a much cheaper photographic method recording the total radiation dose on Fotopan HL photographic plates with the ASA 400 sensitivity. They were being placed at the observation window of the testing chamber. The plates were calibrated by means of the reference standard radiation source. Fig.5. shows the dependence between the radiation dose as the function of the electrode gap for "a" and "b" electrode systems presented in Fig.4.

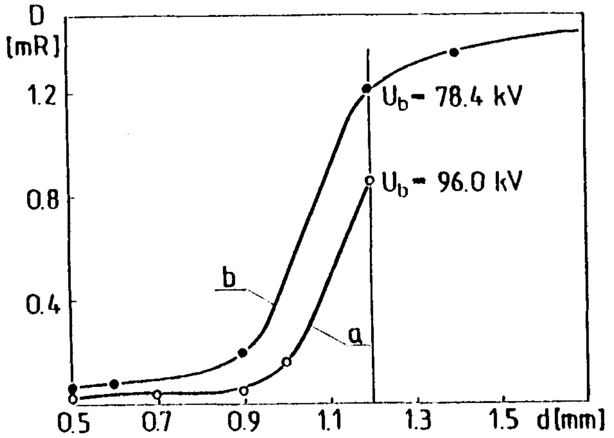

Figure 5. Dependence of X-Ray radiation dose on the interelectrode gap. U_b - breakdown voltage.

It has been shown that the system with a more non-uniform electrical field gives a higher radiation dose despite the lower cathode potential. This is evidence that the electron current pulse reaching the anode is dependent not only upon the voltage on the electrodes but also upon the local electric field. The increase in the electric field can be obtained by producing microprotrusions. X-Ray radiation intensity has a characteristic angle distribution for each particular electrode system, Fig.6.

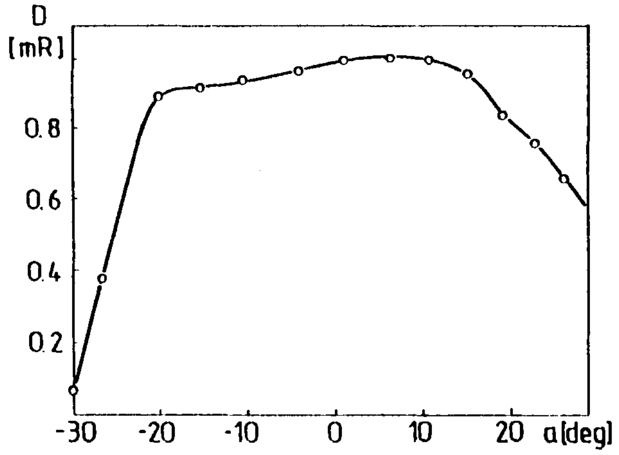

Figure 6. Distribution angle of radiation in the electrode system "a"

A further increase in the anode current can be expected by increasing the cathode plasma density. One of the possible solutions could be the plasma generation in the trigger system. The results obtained in the "c" system with trigger are presented in Table 1.

Table 1. Radiation dose in the "c" electrode system. U_b=75 kV - breakdown voltage for d=4 mm.

% U_b	74	63	53	37
U [kV]	55.7	47.7	39.8	27.8
X [mR]	5.7	1.61	0.28	0.11

Comparison of the radiation intensity in the "c" electrode system for the 4 mm electrode gap with the trigger on and off is presented in Table 2.

Table 2. Radiation intensity in "c" electrode system with the trigger impulse on and off.

Trigger	U [kV]	X [mR]
"off"	75.5	0.31
"on"	55.7	5.7

As can be seen from the results presented above the system with a trigger has made it possible to increase the exposure dose 20 times even though the voltage was decreased by about 25%.

Conclusions

The results obtained have confirmed the initial assumptions.
It has been found that:

- radiation intensity is dependent upon the electric field on the cathode surface as well as upon the density of plasma generated on the cathode. The field intensity on the cathode can be increased by increasing the voltage on the electrodes as well as by changing the cathode surface geometry,
- cathode plasma may be produced in the natural way by means of microdischarges accompanying the development of the vacuum discharge. This method, however, has limited possibilities of increasing the current amplitude as well as the radiation intensity. Much more promising results can be obtained in the trigger system . In this

system, by changing the energy of the trigger discharge, it is possible to change the cathode plasma density which involves an increase in the current amplitude and X-Ray intensity.

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