Effect of a microwave field on the cascade arc light emission

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EFFECT OF A MICROWAVE FIELD ON THE CASCADE ARC LIGHT EMISSION

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Abstract. The effect of a pulsed microwave field on the integral light emission from the argon plasma of a dc atmospheric-pressure cascade arc is investigated experimentally. An intensive light pulse and oscillations of light emission at frequences of the order of 10 kHz are observed. The shape and the amplitude of the light pulse as well as the frequency and the amplitude of the oscillations depend on the arc current and on the microwave power in the pulse. A possible mechanism of these phenomena is outlined.

Introduction. The state of the plasma of an atmospheric-pressure argon arc can be well described by the PLTE model. The particle densities can be calculated when the temperature and pressure are known. The ground level atom density forms an exception being slightly overpopulated as compared to LTE. Electron density n_e and electron temperature T_e measured in the cascade arc used in our experiments proved to have a fixed relationship which deviates slightly from the LTE predictions /1/. In view of these results it is of importance to know which effects determine the establishment of the equilibrium state in our plasma. For this purpose in this work the equilibrium state is disturbed by means of a pulsed microwave field and the subsequent relaxation to the original equilibrium state is investigated.

Experiment. A schematic view of the experimental device is shown in fig.1. The disks are 1.5 mm thick, their separation is 0.3 mm Inside the interaction chamber, the plates are 1 mm thick their separation being also 1 mm. The chamber is both a part of the arc device and a X-band waveguide. The arc channel has diameter 5 mm and total length 70 mm, 10 mm of the latter being inside the chamber. The gas, argon, flows at rates 5 to 10 l/h at atmospheric pressure. The experimental device allows optical measurements along the arc axis and in the perpendicular direction throgh small holes in the walls of the waveguide bends. A photodiode serves as a light detector. A 100 kW 9.4 GHz magnetron supplies single 4 μs pulses. The incident wave power can be varied between a few kW and 50 kW. The basic mode wave propagates in the microwave system. The microwave electric field vector is parallel to the arc axis.

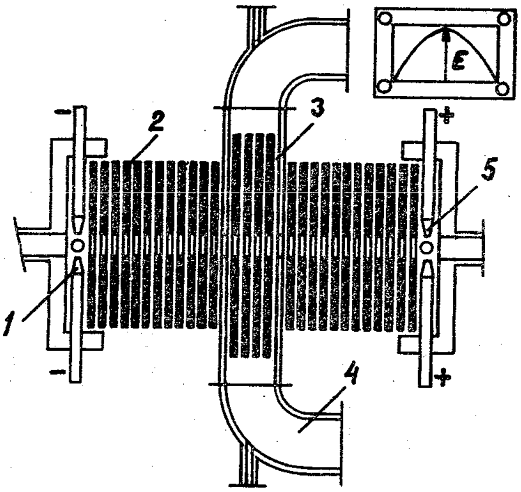

Fig.1. Experimental device.
1 - Cathode:four tungsten tips transverselly at 90°; 2 - Cascade disk; 3 - Interaction chamber; 4 - X-band waveguide; 5 - Anode: four tungsten tips transverselly at 90°.

Results. The electron density of the arc plasma is far beyond the cut off density determined by the microwave field frequency used. Therefore an intensive reflected wave appears and the energy absorbtion estimation requires accurate, time-resolved measurements of the incident, reflected and transmitted powers. The reflected power oscillograms indicate definite absorbtion in the system during the first μs of the pulse. Within the same time interval microwave arcing in a layer surrounding the main arc takes place and results in a short light emission pulse with considerable intensity /short time-scale phenomenon/. This pulse can only be observed side-on. The shape of the light pulse strongly depends on the arc current as illustrated in fig.2. The negative modulation of the light pulse apears at current about 60 A. The e-folding times for the positive and negative modulations are shown in fig.3 their amplitudes /relative to the dc light level (DCL)/ being shown in fig.4. The energy absorbtion during the microwave pulse leads, later on, to regular dumping oscilations of the integral light

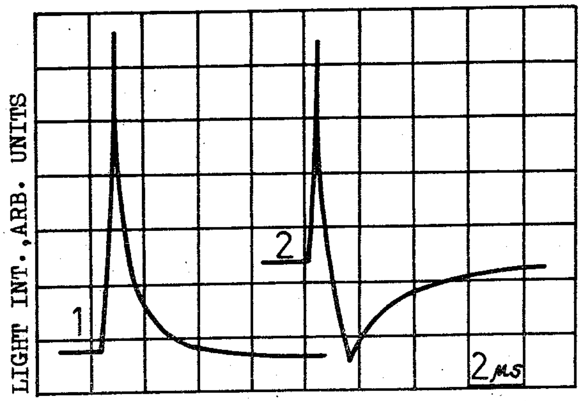

Fig.2. Short time-scale relaxation. Microwave power 38 kW. 1 - 40 A; 2 -160 A

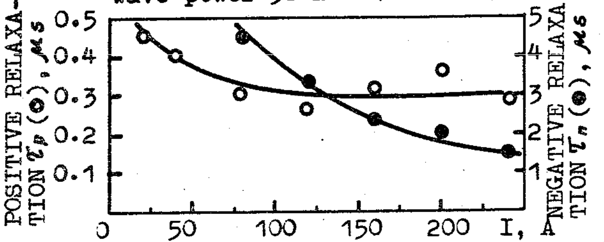

Fig.3. The e-folding width of the short time-scale relaxation vs arc current.

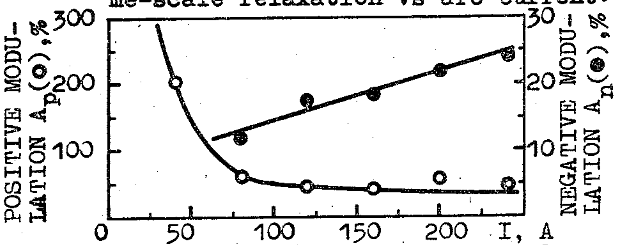

Fig.4. Relative amplitude of the modulations vs arc current.

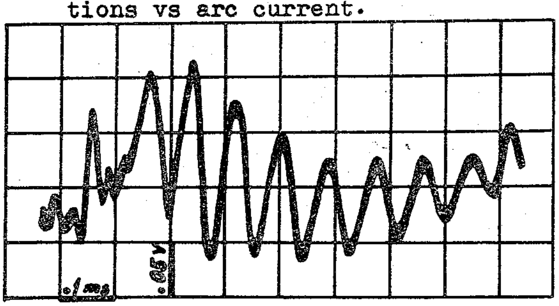

Fig.5. Long time-scale oscillations. Arc current 40 A, power 43 kW, DCL 6 V.

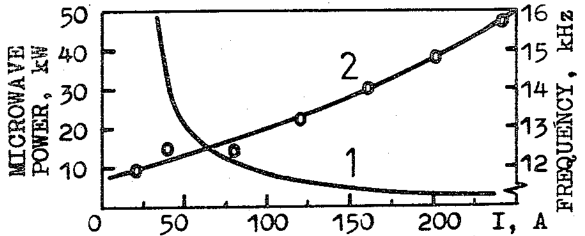

Fig.6. Critical power vs current /curve 1/ and frequency vs current /curve 2/.

emission /long time-scale phenomenon/. An example is given in fig.5. The oscillogram is obtained from end-on observation of the central part of the arc. At the very beginning the frequency is about 30 kHz and later on 12.3 kHz. The excitation of the higher frequency takes place only when the arc current and the microwave power exceed certain values. This corresponds to the region above curve 1 in fig.6. The lower frequency is a function of the arc current as shown by curve 2 in fig.6 being almost independent of the power. The amplitude of the oscillations depends on the power in the pulse. In general it is a few percent of the DCL at maximal amplitude. The profile of the amplitude across the arc coincides with the profile of the DCL.

Discussion. The short time-scale fenomenon can be interpreted as a sum of positive and negative relaxation. If we assume that the microwave energy causes an initial rise of T_e in a thin layer at the periphery of the plasma column, the sharp increase in light intensity can be attributed to the resulting extra excitation and ionization. The positive relaxation would then be caused by the subsequent equalization of T_e and T_i. The time constant associated with this effect is of the order of tenths of µs. Equalization /i.e. rise/ of the temperature across the arc column follows. The main part of the light output at higher currents - continuum radiation /2/ proportional to $n_e^2 T_e^{-1/2}$/1 - exp(-hν/kT_e)/ - is now reduced thus accounting for the negative modulation. The characteristic time for this process, determined by heat conduction, is about 1µs. Further we assume that the long time-scale oscillations are connected with periodical contraction of the plasma cross-section, mainly in the interaction chamber where the wall stabilization is less efficient than in the remainder of the arc.

Conclusion. We conclude that it proves possible to disturb the equilibrium state of an atmospheric-pressure arc plasma using the described method. The subsequent relaxation to the original equilibrium conditions is studied. We plan to apply alternative heating methods with known absorbtion in the plasma, and, possibly, resulting in less oscillations. Still, the described method offers an efficient way to apply short, powerful disturbance to a plasma.

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