Pulsed corona investigations with a wide parameter range

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An experimental set-up for pulsed corona discharges is presented that offers a much wider parameter range than usual. The discharge is created in a large stainless steel vessel that allows point-plane gaps to vary from 10 to 160 mm. The gas pressure in the vessel can be the standard 1 bar, but it can also be decreased down to 13 mbar. The operating gas is usually ambient air, but pure N_2 from cylinders is also available. Two pulsed power supplies are constructed that permit pulse amplitudes between 2 and 90 kV, voltage rise times between 15 and 180 ns and pulse durations from 100 ns up to many microseconds. Furthermore, both supplies operate with both pulse polarities. Examples of photographs with an intensified CCD camera are shown.

1. Introduction

The research on corona discharges already has a considerable history [1]. It is, however, a complicated matter as is shown in a recent review paper [2]. Practical applications receive more and more interest in recent years, mostly for environmental applications such as gas and water cleaning [3-6].

Large-scale applications necessitate the use of pulsed corona discharges. In order to be competitive in the large market of cleaning systems the pulsed power supplies must be very efficient, reliable and compact [4]. It has been demonstrated recently that pulsed power supplies of 10 kW average power can be made with very high wall-plug efficiencies of more than 90%. Under the conditions of such a supply, the corona discharge appears to match itself to the impedance of the pulsed power source [7]. This behaviour is unexplained up to now.

Recent research on pulsed corona discharges focuses on streamer diameters and velocities [8-11] also for the sake of comparison with numerical models [9, 12-16]. Most of these measurements are performed in short point-plane gaps (10-40 mm) and at pressures between 0.1 and 1 bar. However, the size of the corona discharge increases when the pressure is lowered; therefore, a larger gap allows us to explore the scaling of streamer properties with pressure.

In small gaps at 1 bar the streamer diameter usually is around 0.2 mm [8-10]. In contrast, diameters of up to 10 mm are found in gaps larger than 100 mm at voltages higher than 100 kV [17, 18]. Recently it has been shown that there is a gradual change from one regime of diameters to the other [11]. These measurements are, however, far from complete.

This paper describes an experimental setup and two pulsed power supplies that are designed to obtain a comprehensive set of data of pulsed corona discharges. The aim is to vary parameters to a much larger extend than has been reported up to now. Inside the reactor, the gap size is adjustable from 10 to 160 mm without noticeable effects of the sidewalls. The pressure can be varied from 1 bar down to 13 mbar while maintaining a preset flow. The gases to be used are ambient air and mixtures of N_2 and O_2 from bottles with high purity gases. The high voltage pulses can reach amplitudes of up to 90 kV while voltage rise times can become as short as 15 ns.

2. Experiments

The vacuum vessel, in which the pulsed corona discharges are created, is shown in Fig. 1. It is made of stainless steel; it has an inner diameter of 500 mm and an inner height of 300 mm. It has three large viewing ports at the side and a high voltage feed through on top. The vessel is inside a Faraday cage to shield neighbouring equipment from the high voltage pulses. The CCD-camera can look through a window covered with ITO that is transparent from 300 to 800 nm and electrically conductive. The anode is a tungsten pin of 1 mm with a grinded tip having a radius of ~15 µm.

Fig. 1 also incorporates the pulsed power supply as described in [11]. It is a spark gap (SG) switched capacitor (CC) charged negatively through R_1. The rise time of the pulse can be adapted with R_2 and its decay time with R_3. This circuit produces positive pulses but their polarity can easily be inverted.

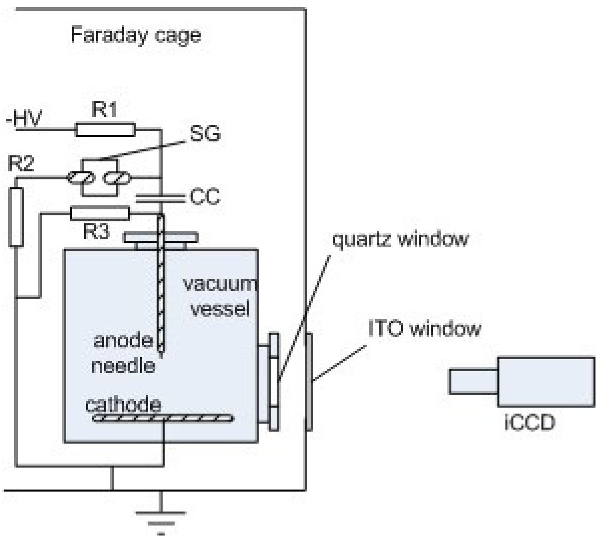

Fig. 1: The corona reactor inside the Faraday cage with on its top the spark gap switched capacitor

A second power supply, called power modulator, is shown schematically in Fig.2, more details can be found in [6-7]. This power modulator is also able to generate pulses of both polarities. Two coaxial cables in parallel are used as the energy storage capacitor. Two cables are used in order to obtain a line-impedance of 25Ω, equal to the impedance of the rest of the pulse-forming network. The main advantage of discharging a cable, instead of a lumped capacitor, is that the generated pulses are rectangular. The pulse-width is determined by the length of the cables. If a pulse-width of 100 ns is required, the cables should be 10 meter long. The cables are discharged using a heavy-duty spark-gap switch. The LCR-circuit is used for triggering of this switch. The energy stored in the coaxial cables is discharged into another set of coaxial cables. These cables act as a 2-stage transmission line transformer (TLT). The main purpose of the TLT in this circuit is to double the voltage amplitude. The magnetic cores around the upper stage of the TLT are added to ensure that the losses of the TLT are minimized.

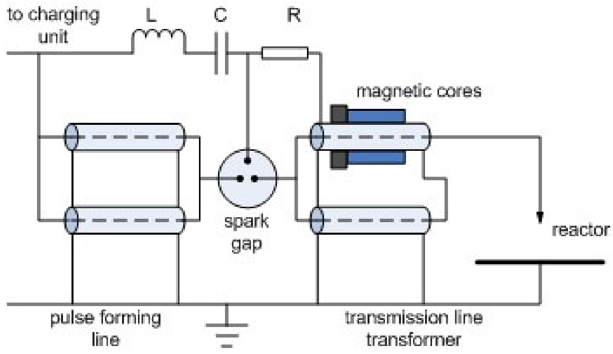

Fig. 2: Schematic diagram of the power modulator for making pulses with a rise time of 15 ns and a duration of 100 ns.

The camera used for the discharge photos in this paper is a Stanford Computer Optics 4QuickE. This camera has a minimum optical gate of 2 ns, the intensifier has a spatial resolution of 40 line pairs per mm and the CCD has 1024 x 1360 pixels of 8x8 μm. It is mounted with a 105 mm Nikon quartz lens.

3. Results

Results obtained in gaps of 40 and 80 mm are extensively described in a recent paper [11]. It is shown that the diameter of the streamers of positive corona strongly depends on the voltage. At voltages not much above onset, the diameter is about 0.2 mm in ambient air. If the voltage pulses are sufficiently short, their amplitude can be taken above the static breakdown voltage, i.e., in the "overvolted" regime; the streamer diameter then becomes much larger. In the set-up shown here, the largest diameter is ~5 mm in a 40 mm gap with a voltage amplitude of 60 kV.

In a gap of 150 mm with a 120 kV pulse, a streamer diameter of 10 mm was reported in [18]; this diameter is 50 times larger than the minimal diameter of 0.2 mm [11]. Another interesting observation is that thin streamers branch quite frequently, while the thickest streamers branch hardly in these gaps.

New photographs were taken in a 40 mm gap with moderate voltage amplitude. Fig. 3 shows an example of such a discharge in air at 35 kV. Here the streamers are thin – except close to the anode at the top – and they branch frequently, but the distance between branches increases when they approach the cathode. Streamers also start from the anode from positions higher than the tip. In [11] it was found that these streamers start after the other streamers have reached the cathode.

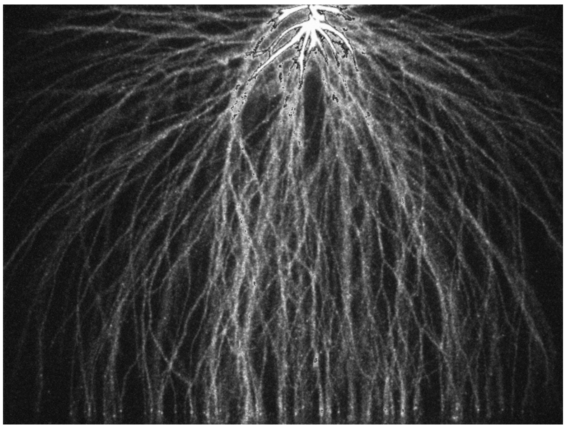

Fig. 3: Pulsed positive corona in a gap of 40 mm in ambient air, voltage amplitude 35kV, rise time 180 ns.

Other interesting features show up when the pressure is reduced. Fig. 4 shows a photograph of a pulsed corona in a 40 mm gap at a pressure of 100 mbar. The voltage amplitude used here is 8.5 kV and the pulse rise time is 130 ns. The overall structure resembles Fig. 6b of [11] quite well; that figure was taken in the same gap, but at 1 bar and a voltage pulse of 54 kV. (However, in the present picture, there is no branching at all and the "cloud" at the anode tip is larger.) This shows that streamers at high pressures and high voltages can be very similar to streamers at low pressures and low voltages, without any rescaling of lengths.

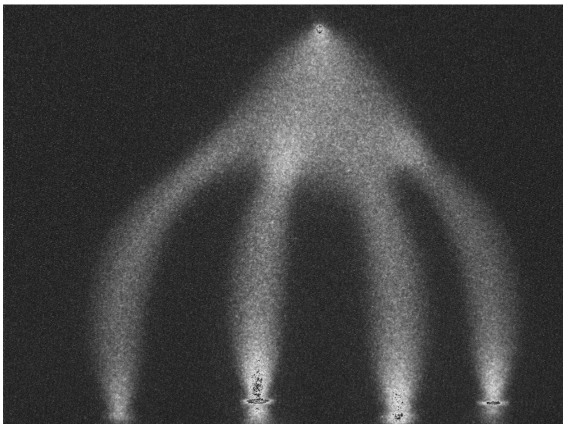

Fig. 4: Pulsed positive corona in a 40 mm gap in air at 100 mbar, voltage amplitude 8.5 kV, rise time 130 ns

4. Discussion and conclusions

Corona streamers at pressures below one bar have been investigated recently [9, 10]. First, density variation is a natural extension of the range of measurements. Second, lengths and fields are expected to approximately scale with particle density, N, [2], therefore lower densities create larger and slower streamers with characteristic lengths and times proportional to 1/N, therefore structures and evolutions are easier to measure at lower values of the density N. Third, streamer concepts are also applied to so-called sprite discharges [2, 19-22] that occur at heights of 40 to 90 km in the atmosphere; the pressure at 70 km height is about 10^{-5} bar. Here the verification of similarity laws is vital for predictions.

In older investigations of the similarity laws in a gap of 17 mm [10], there was not enough space for the evolution of the full structure at low pressure. Fig. 4 of the present paper shows that at a pressure of 100 mbar and a gap of only 17 mm, the cloud at the electrode tip would fill the complete gap. With the new set-up illustrated in Fig. 1, discharges can be tested in gaps of up to 160 mm. In this case, pressures down to 13 mbar were explored, and the experimental results will be presented at the conference.

The similarities and differences of positive and negative coronas is a long standing but unresolved issue. In the past, it was mostly found that positive coronas are more efficient in ozone production and cleaning processes [3, 4]. Recent investigations show almost no difference between the ozone yield for positive or negative corona [23]. CCD images of pulsed corona discharges will be taken for both polarities in a pulse amplitude range of 2 to 90 kV with the power supplies shown in Figs. 1 and 2. These results will be presented at the conference as well.

The experimental set-up for pulsed corona discharges described in this paper offers possibilities to perform measurements under a wide range of conditions that have not been reported up to now. These conditions include gap size, pulse parameters, polarity and gas pressure and composition. The results will be compared with theory [9-16] with the final goal to understand and optimize the streamer discharges.

5. Acknowledgement

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