

# Generation of Non-Thermal Transient Gasdischarges at Atmospheric Pressure for Pollution Control

Rüdiger Kutzner      Jürgen G. H. Salge  
Institut für Hochspannungstechnik, TU Braunschweig  
Postfach 3329, D-38023 Braunschweig

## Abstract

An advanced reactor system is presented suitable for the treatment of exhaust gases by non-thermal transient gasdischarges. The electrode arrangement allows a gas treatment by bursts of streamer discharges restricted to parts of the reactor. The power is supplied by a resonant circuit which has the potential to recover certain amounts of energy not required directly for the generation of streamer discharges. Experimental results obtained so far are discussed.

## 1. Introduction

Although non-thermal transient gasdischarges are very attractive to reduce the pollution of exhaust gases a number of problems remain to be solved before a broader application is possible. A major one is the reduction of power consumption. For instance a Japanese study committee has pointed out that the level of power consumption of existing systems has to be reduced down to one half to one third /1/.

Mainly two types of reactors are investigated so far. The first type uses corona discharges. The electrodes form an inhomogeneous electric field. The reactor is powered by steep voltage pulses generated repetitively by the discharge of capacitors. Spark gaps or other gasdischarge switches are used. Only parts of the energy delivered into the reactor can be transferred into streamer discharges. A significant amount is absorbed by pulse forming elements in particular by the switches /1/,/2/.

The second type uses barrier discharges. In this case the discharges are generated in gas gaps of some mm between electrodes which form nearly a uniform electric field and where at least one electrode is covered with a dielectric barrier. The electric field and the discharges in the gap are generated by alternating voltages at frequencies in the range of up to some 100 kHz. Also in this case small parts of the energy delivered in each period into the reactor can be transferred to the microdischarges which are distributed statistically in the reactor volume. A major part oscillates between the capacitance of the reactor and the power supply system and parts of this energy can be recovered in principle. But powered continuously the discharges are

not well matched to the gas flow to be treated. Another drawback of barrier discharge reactors are small gas gaps which cause additional pressure losses.

Common to both reactor types is that the generation of excited molecules and radicals by streamer respectively microdischarges and the conversion of contaminants into harmless species takes place in the same volume. Having in mind these facts and analyzing the possibilities to reduce the power consumption for an improvement two major options exist:

1. The reactor should be divided into active and passive zones. Thus the radicals generated by the discharges which have a long lifetime compared to the ionization processes can attack the pollutants undisturbed.

2. The reactor should be powered by resonant circuits which allow to generate bursts of discharges well matched to the gas flow. A recovery of energy not needed directly for the discharge generation should be possible.

The reactor system presented in this paper takes into account both options.

## 2. Advanced reactor system

Figure 1 shows the design of an experimental reactor of this type. A coaxial electrode configuration is equipped with sharp-edged ring electrodes forming an inhomogeneous electric field. The gap width can be kept in the range of some cm. The gas flows in through slotted holes, passes the area of transversal plasma treatment at the edge electrodes and is guided out through radially distributed pipes.

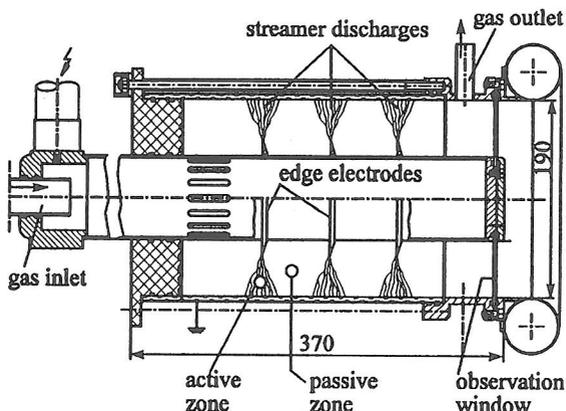


Fig. 1: Experimental reactor with coaxial electrode configuration

The discharge volume of the device is concentrated around the edge electrodes. Thus the volume of exhaust gas treatment is divided into active and passive zones. A volume element of the gas flow moving through the reactor is treated sequentially by the discharges. In conventional precipitators using wires the passive phase of radical reactions is restricted to the intervals between the voltage pulses  $/3/$ . The electrode configuration of the new reactor system allows to extend the passive phase

independent from the repetition rate of the voltage pulses.

The reactor is powered by systems which allow the recovery of energy not needed directly for the discharge generation. The block diagram of such a system is given in fig. 2. It is similar to those used for the generation of barrier discharges [4]. The system is based on the principle of a single-ended push-pull converter driven in resonant mode using semiconductor switches and a pulse transformer. The capacitor  $C_1$  is charged via a control transformer and a rectifier up to voltages of some 100 V. Power-MOSFETs can be used as switching elements which are triggered by a control unit. Rectangular voltage pulses are formed at the primary winding of the pulse transformer. The pulse width of the MOSFET-units can be matched to the resonance frequency mainly given by the pulse transformer and the capacitance of the electrode system of the reactor. The switching operation of the MOSFET-units can be kept close to times when the current is zero. This causes low switching losses. The control unit allows to generate single voltage pulses repetitively. When the pulse transformer

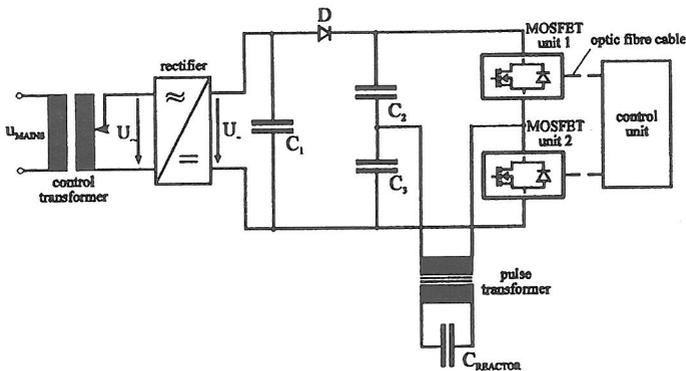


Fig. 2: Block diagram of a pulsed power supply system

is excited, the capacitance of the reactor is charged to voltages that streamer discharges are ignited. If it is guaranteed that the streamer discharges extinguish arriving at the counter-electrode, the energy remained in the electric field of the reactor oscillates back into the charging capacitors  $C_2$  respectively  $C_3$  via the pulse transformer and the diodes of the MOSFET-units. Thus parts of the energy can be recovered. Compared to power supply systems operated with spark gaps, the steepness of the voltage pulses is much smaller. Therefore one key question for a successful operation of the system is that a sufficient number of streamer discharges can be generated not passing over into spark discharges.

### 3. Generation of streamer discharges with slow rising voltage pulses

Figure 3 shows the block diagram of the experimental setup. For the generation of high voltage pulses a power supply described previously was used. The main dimensions of the reactor are given in fig. 1. The voltage was measured by a voltage divider in combination with a voltage probe (Tektronix P6015A). The current was

measured by a coaxial 2- $\Omega$ -shunt of low inductance. Photographs of the light emitted by the discharges could be taken by a sensitive CCD-camera. The trigger delay and the exposure time could be varied between some ns and 1 ms.

The results of a characteristic experiment obtained with a single voltage pulse is presented in figure 4. The experimental reactor was equipped with one sharp-edged ring electrode. The gap width between ring and outer electrode was 40 mm. The gas flow through the reactor was ambient air and had a velocity of about 900 l/min. The relative humidity was 40 %, the temperature 23 °C.

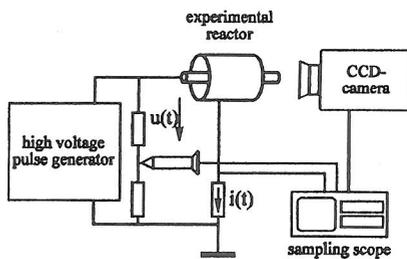


Fig. 3: Block diagram of the experimental setup

Figure 4a shows the voltage and current waveforms. The voltage pulse has a steepness of about 2.5 kV/ $\mu$ s. The time to crest is about 25  $\mu$ s. At  $t_0$  the voltage starts to oscillate up to about 56 kV. At  $t_1$  a current pulse with an amplitude of 15 A and a duration of about 300 ns occurs. After that the current remains zero.

The rapid decrease of the current pulse indicates that the discharge quenches although the voltage remains at a level of 40 kV for some additional  $\mu$ s. In accordance with investigations performed by Sigmond

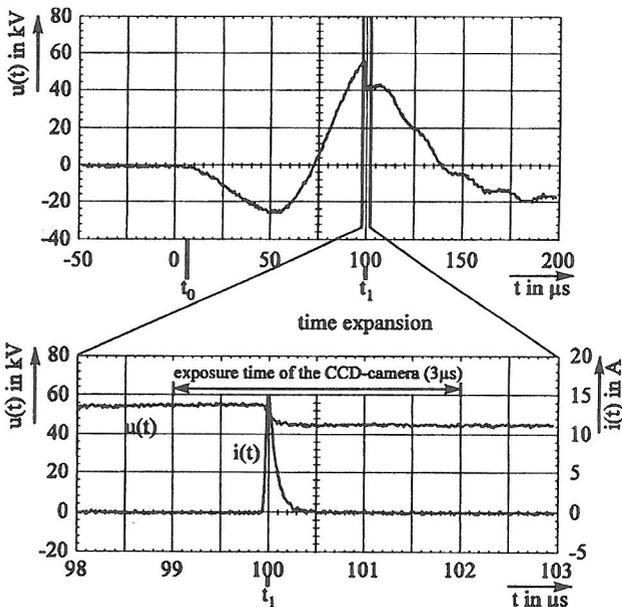


Fig. 4a: Voltage and current waveforms at the experimental reactor

/5/ it indicates that only streamer discharges are obtained. Sigmond has pointed out that between point to plane electrodes such a quench can occur when the sharp-edged electrode has a positive polarity. The discharge development starts when the breakdown strength at the anode is exceeded. Streamer heads are formed and fast ionization waves move towards the cathode. During the movement of the streamer heads weakly conductive residual channels remain in the gap. When the streamer heads reach the cathode a current peak occurs. Now the local field strength across the

gap distance is redistributed. The electric field strength is equalized and remains for a while at a level so that an arc formation is prevented. Experiments performed by the authors of this paper with a point to plane gap and slow rising voltage pulses have shown that even a certain increase of the voltage across the gas is tolerable during the quenching period /6/. Photos taken side on confirm these considerations. A photo belonging to fig. 4a is shown in fig. 4b. At the total circumference of the edge electrode discharges are obtained. The discharges have a fine and wide spreading which offers good conditions for a transversal treatment of the gas flow.

For a continuous treatment of a gas flow the reactor has to be driven repetitively and the pulse repetition rate has to be matched to the gas flow. For example an estimation of the reaction volume at one edge electrode at a gas flow rate through the reactor of 900 l/min results in a pulse repetition rate of about 70 Hz, if each volume element of the gas flow should be treated once.

Additional basic experiments have shown an interdependence between pulse repetition rate, discharge distribution, steepness of the voltage pulses and prestressing of the discharge gap.

At repetitions rates of more than 100 Hz and slow rising voltage pulses ( $2,5 \text{ kV}/\mu\text{s}$ ) the ring electrode is only partly covered with discharges. This behavior can be prevented if the pulse voltage steepness is increased. For instance at 150 Hz the steepness has to be about  $150 \text{ kV}/\mu\text{s}$  in order to attain a discharge covering at the whole circumference of the edge electrode. On the other hand the steepness of the voltage pulses can be decreased if a positive dc-voltage is superposed. At repetition rates of 100 Hz and steepnesses of  $10 \text{ kV}/\mu\text{s}$  discharges covering the whole circumference of three edge electrodes have been achieved. Obviously a prestress of the discharge gap by a dc-voltage influences the space charge distribution in the gap. The charges remained from the preceding discharge are removed more rapidly and the conditions for a uniform streamer formation are improved.

For practical applications of the system it has to be aspired to increase the voltage steepness as much as possible. This means that the resonant frequency determined mainly by the capacitance of the reactor and the leakage inductance of the pulse transformer has to be high. Both the capacitance and the leakage inductance have to be kept as small as possible.

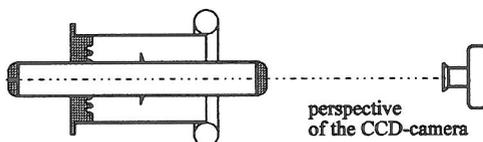
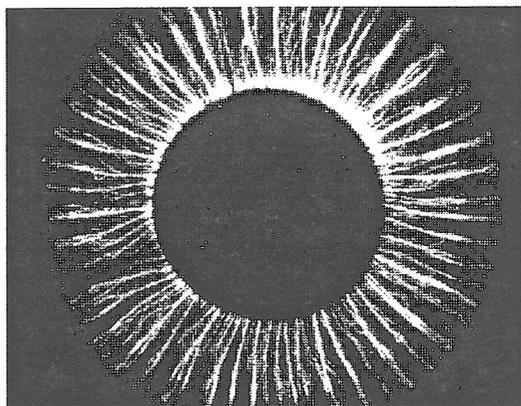


Fig. 4b: Discharges and experimental arrangement

#### 4. Summary and conclusions

An advanced reactor system is presented which allows a gas treatment by bursts of streamer discharges which are restricted to parts of the reactor. A coaxial electrode configurations allows the generation of streamer discharges repetitively with slow rising voltage pulses generated by power supply systems which make use of resonant circuits. A major advantage of these systems is that parts of the energy not needed directly for the discharge generation can be recovered and the possibility is opened to reduce the overall power consumption. Experiments have demonstrated that bursts of streamer discharges covering the complete circumference of ring electrodes can be generated with voltage pulses having a steepness of only 2,5 kV/ $\mu$ s. The system makes use of discharge quenching. There exist interdependencies between pulse repetition rate, discharge distribution, steepness of voltage pulses and prestress of the discharge gap. The capacitance of the reactor and the inductance of the resonant circuit should be kept small.

#### Acknowledgement

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