MEASUREMENT OF ELECTRIC CURRENT IN LIQUID JET

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Abstract

Electrospinning is very progressive method for nanofibrous layer's creation. Here is the exploitation of self-organisation of matter for formation of the nanofibers and the nanofiber's structures, having one dimension bellow 1 µm. Electric energy is necessary for creation of nanofibers and its quantity had been measured as a time dependence of quantity of the electric current in liquid jet, by the changing of the pulses of oscilloscopic measurement. Quantity of the charge, the velocity growth of the discharge channel and other parameters were characterized by the shape of these pulses. Electrospraying/electrospinning transition was studied by the oscilloscopic and speed camera record. It is possible to find length of the spinning and estimation of the quality of the fibers by the oscilloscopic measurement. The quantity of the energy measured by the oscilloscope can be helpful for understanding of the thermodynamics processes.These experimental data are very important for the theoretical description of electrospinning.

Keywords: electrospinning, electrospraying, nanofibers, current measurement.

1. INTRODUCTION

Electrospinning is a method of producing sub-micron fibers. In the electrospinning process, polymer solution or polymer melt is formed into thin fibers in electric field.

Various electrospinning techniques have been described in papers, namely needle and needleless process. In the needle electrospinning [1], a charged polymer solution is pumped through a hollow needle. Sub-micron fibers are formed between the tip of the needle and a grounded collector electrode creating a layer on the latter. In the needleless electrospinning [2], Taylor cones are created on the surface of polymer solution. Typically, the polymer solution is placed on the surface of a slowly rotating metal roller partly immersed in a reservoir (Fig. 1 a). Many Taylor cones are created on the surface of the roller (typically 5,000 – 50,000 per square meter) which gives a high spinning throughput and makes the process industrially interesting. In a laboratory scale, needleless electrospinning can be profitably studied using a metal rod as a spinning electrode (Fig. 1 b). If the diameter of the metal rod (and that of polymer solution droplet) is greater than 8 mm, 1 – 6 Taylor cones occur on its surface or circumference. Only one Taylor cone usually occurs if the rod diameter is 3 mm or less.

Measurement of electric current during electrospinning was suggested by Rutledge [3,4] as a method to study electrospinning mechanism. The authors measure voltage on a resistor 1.0 MΩ using a digital multimeter Fluke 85 III. The voltage is converted into current using Ohms law. Volume charge density in the polymer jet is expressed as I/Q, where I is measured current and Q is flow rate.

It is the aim of present work to measure electric current in polymer jets during needleless electrospinning process, to analyse it and to discuss relations between the current and the mechanism of electrospinning .

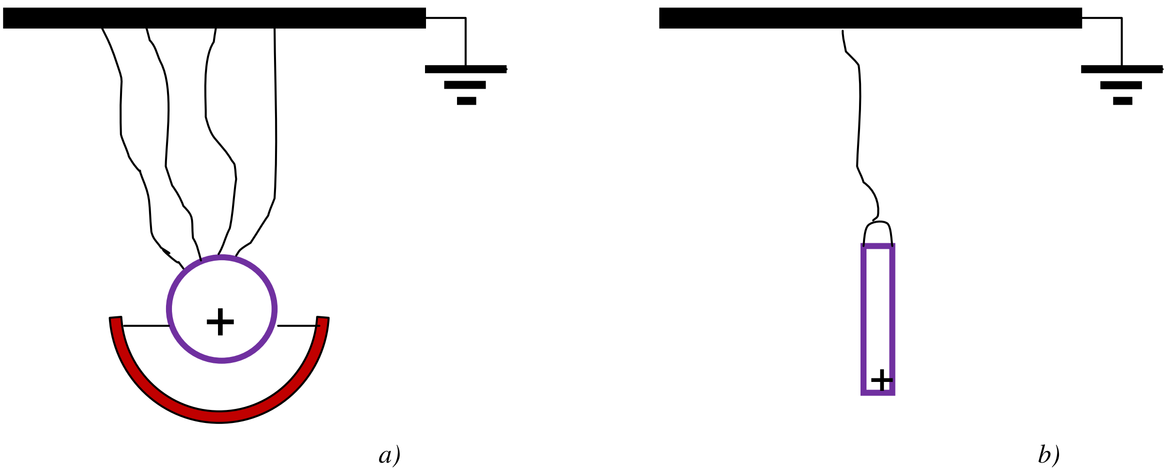

Fig. 1. Needleless electrostatic spinners. A roller spinner (a) and a rod spinner (b)

2. EXPERIMENTAL

Laboratory spinning device including the measuring circuit is shown in Fig. 2. It consists of a steel rod (1), diameter 3 mm, as a spinning electrode, and a steel collector electrode (2). Spinning electrode is linked with a source of high voltage (3). Collector electrode is grounded through a resistor adjustable to 10 – 100 kΩ (4). Voltage is measured on the resistor using a memory oscilloscope (5). Current is calculated using Ohms law (typically 10^{-6} Amps).

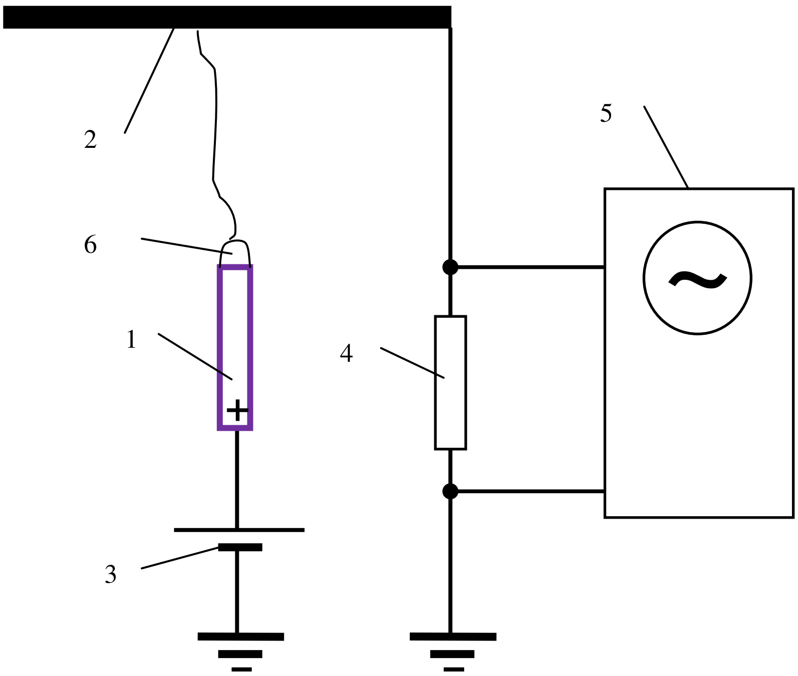

Fig. 2. Experimental setup

Measurement consists of following steps: A droplet of a polymer solution (6) is placed on the spinning electrode. High voltage is switched on. In the initial stage, only the current is measured corresponding to conductivity of ionized air. After a Taylor cone is developed on the surface of the droplet, the current increases and a trigger automatically initiates its recording. The development of the Taylor cone needs the time between several hundreds of second to several seconds. A typical record of the electrospinning of a spinnable polymer solution is shown in Fig. 3. In this picture is shown many waveformes. Firstly, peaks of corona discharges. A typical rise time about these peaks is about 10^{-7} – 10^{-8} seconds. The peaks represent recording of the course of the electric current during the discharge construction. Secondly, the elevation of oscillogramme baseline up to zero line represent the electric current going through the liquid jet. Thirdly, the area under the line of oscillogramme represent the used energy of electrospinning.

Very important is comparation of the current record to the optical record of the spinning. The time dependent current is compared with the Taylor cone development and than with the jet development using high-speed camera in (**Fig. 4**).

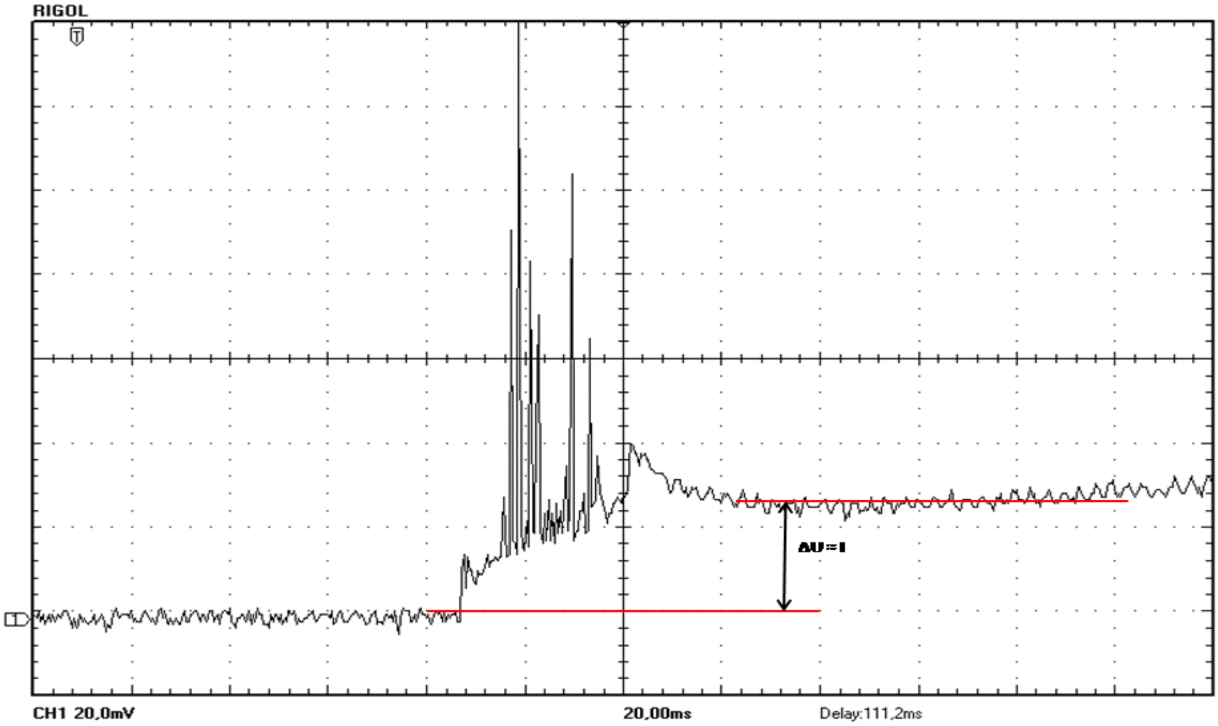

Fig. 3. A typical record of the current during electrospinning of a spinnable polymer solution

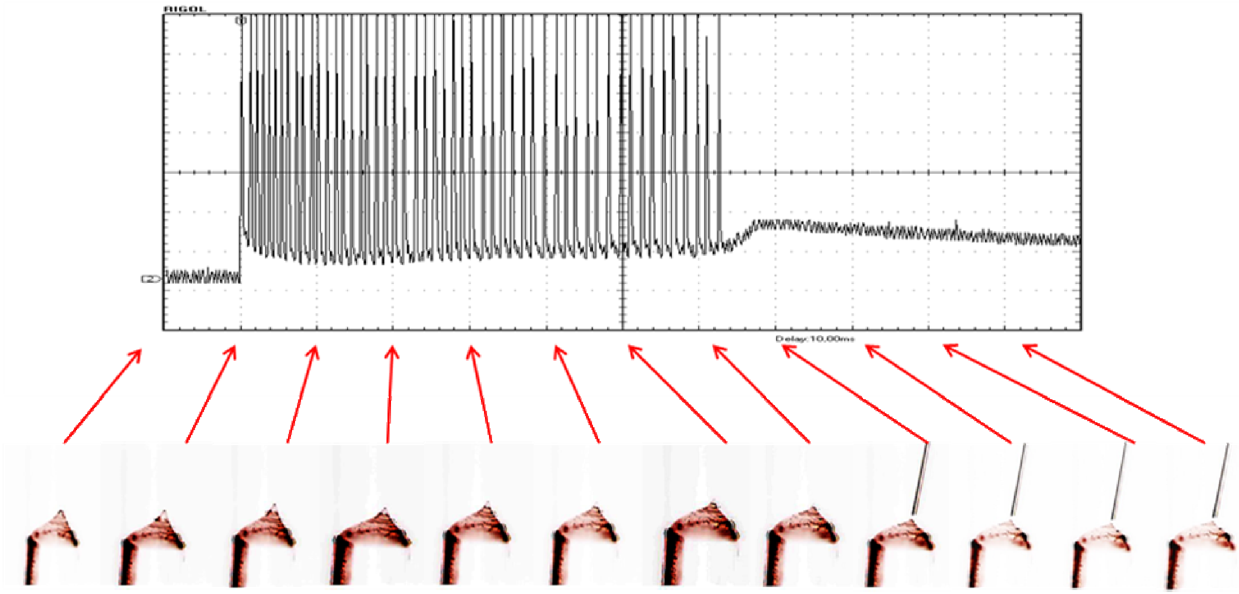

Fig.4. The time dependent current is compared with the Taylor cone development and the jet development using high-speed camera.

There is shown a growth of one Taylor cone and its decrease in the **Fig.4.**. The frequency of corona discharges is decreased too, as the consequence of an increase of the polymer solution viscosity. It is clear, that the electric discharges are related with any small droplets of the solvent. We present the hypothesis, that every peak of electric discharge reflects the very small moving liguid droplet. Consequently, the polymer solution is inspissated during the process. The liquid jet may arise only when the polymer solution has the right viscosity,

The other way of the documentation of this process is shown in the **Fig. 5.** There is an area of initial waveformes and after that is obvious the elevation of the oscillogramme baseline. This elevation corresponds to the presence of the liquid jet (see **Fig. 3.** and **Fig. 4.**).

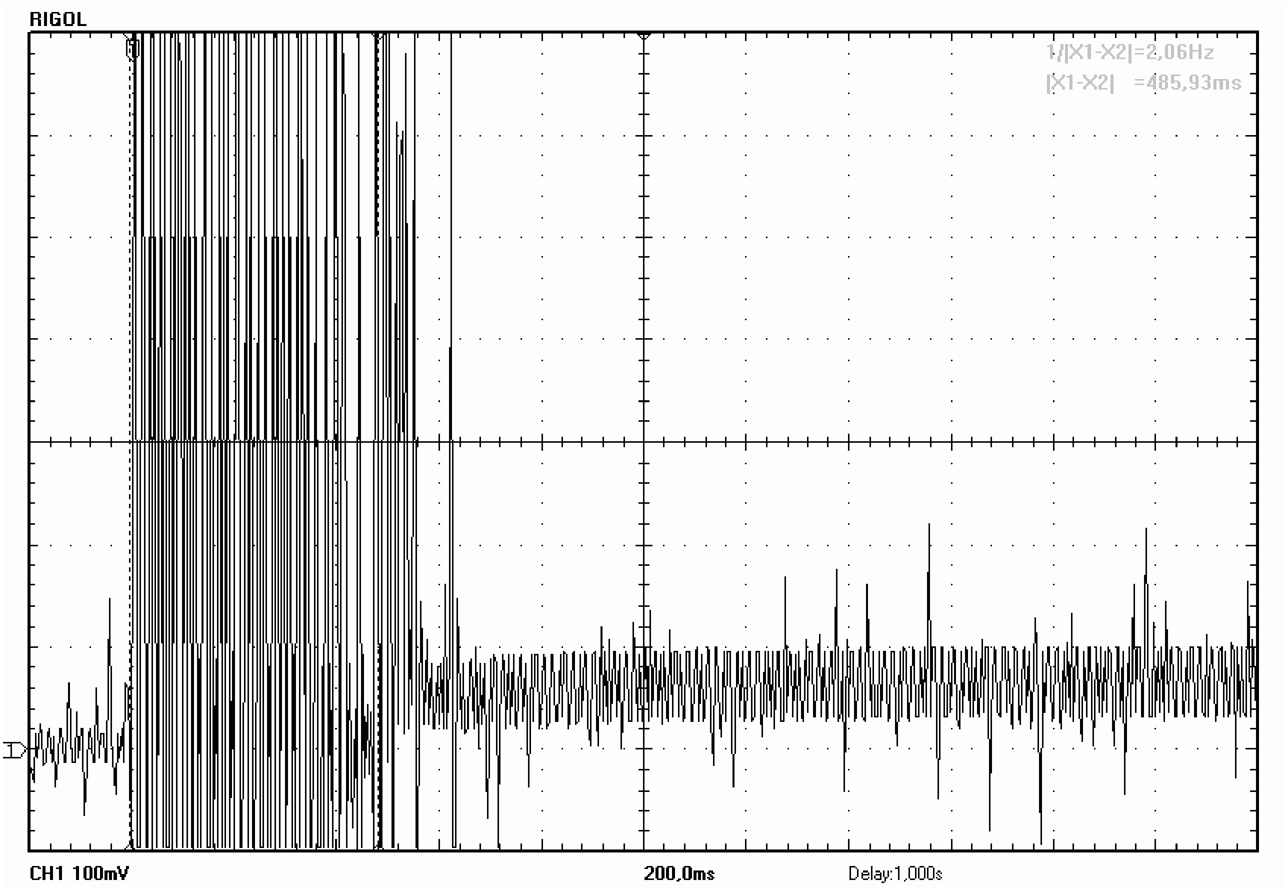

Fig. 5. Record of electric current during the electrospinning.

The area of initial waveformes is enlarged in the **Fig. 6.** In the small pictures a) to f) is shown the progressive enlargement of the distance among peaks. In picture **f)** is recorded the „strange“ waveform. The basic waveform is the record of the attenuated oscillations. A time constant RC of this waveform (14ms) is similar as the time constant of the spinner circuit. The capacitance of spinner is cca $1,5^{-12}$ F and resistance of the liquid jet is cca 10^{9} Ω. That „strange“ waveform is probably the response of the system to a unit jump after switch-on of the high voltage source. This process occurs every time, when the electrodes are connected because of the corona discharge.

On the background of the „strange“ waveform are obviously shown another sharp peaks as probably other corona discharges. This corona discharges reflect probably other very small droplets of solvent.

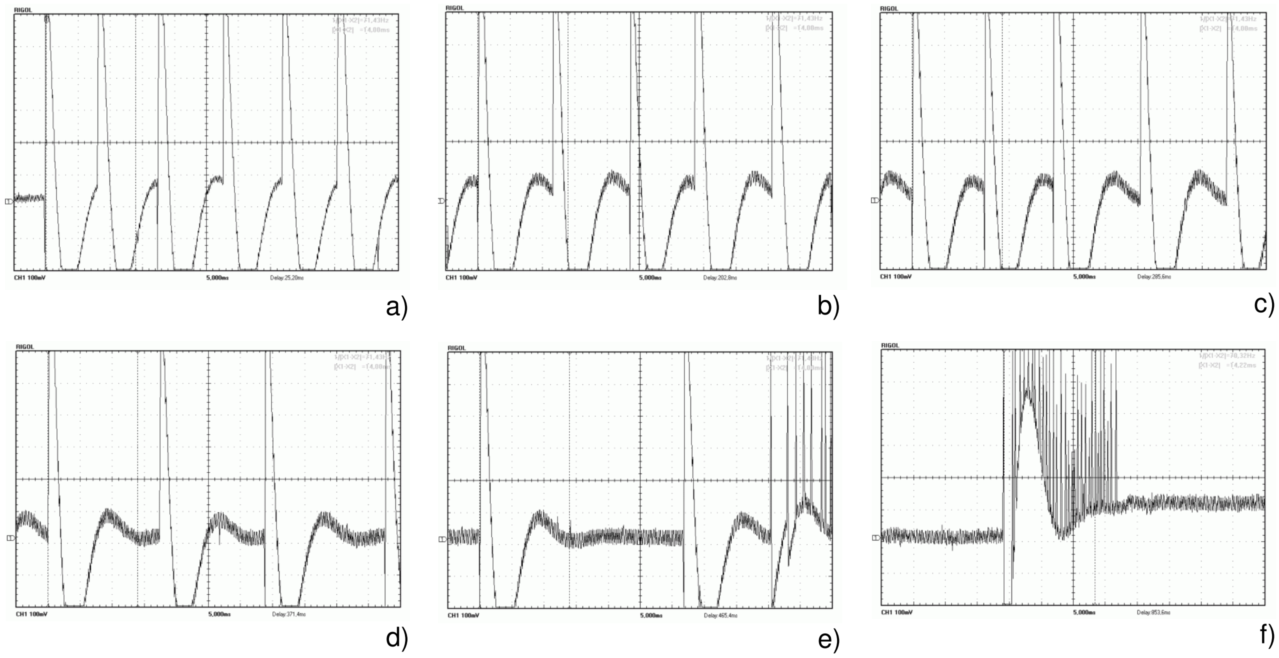

Fig. 6. Enlarged initial area of waveforms of **Fig. 5.**

3. CONCLUSION

Movement of charged substance is shown as an image of electric current on oscilloscope. This record shows the motion of substance in time. The peaks on the start of record are the same as those of corona discharge. The rise time of the start edge is about 10^{-7} seconds in corona discharge as well as in electrospinning. The electric current in liquid jet corresponds to the work needed to create nanofibers and their transport towards the collector.

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