Production of yarns composed of oriented nanofibers for ophthalmological implants

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Abstract. Parallelized nanofibrous structures are commonly used in medical sector, especially for the ophthalmological implants. In this research self-fabricated device is tested for improved collection and twisting of the parallel nanofibers. Previously manual techniques are used to collect the nanofibers and then twist is given, where as in our device different parameters can be optimized to obtained parallel nanofibers and further twisting can be given. The device is used to bring automation to the technique of achieving parallel fibrous structures for medical applications.

1. Introduction
Glaucoma diseases is the worldwide problem in ophthalmology. The progression of this disease leads to permanent blindness. Statistics show that more than 60 million people worldwide suffer from this disease[1,2].These problem can be eliminated by nanofibrous tubular shape for drain of fluid [3]. The main goal of the produced yarn is to ensure the incompressibility of the structure and safe drainage of fluid from the patient's eye due to this oriented structure.

In this article the parameters of self-fabricated device that allows the fabrication of a nanofibrous yarn are described. The main idea of this device is full automation of the process of manufacturing a nanofiber thread. And also to improve the accuracy of the manufacturing by avoiding the operation that was previously done manually.

2. Previous experience
Device for production of nanofibres parallelized structures has been previously constructed in cooperation with Clemson University in South Carolina, USA [4]. This device was modified at Technical University of Liberec and enables the production of nanofibres yarns with the different rotating collectors and the electrostatic forces. The improved device enables the production of higher quality oriented structures from multiple materials. Results of the work were presented in the articles [5,6]. But that device was a first step in production of a nanofiber yarn.
3. Implementation

To obtain such yarns it is needed to collect the produced parallel oriented nanofiber layer and then twist it. This process previously held only by manual way. This process has been automated using a prototype device specially designed for the collection and twisting fibers.

The device model is shown in figure 1: 1) disks that come into contact with the nanofiber; 2) a platform that provides movement up and down; 3) a rotating platform. The device rotates 270 degrees. This allows you to approach the device from three sides; 4) a platform that allows the anticipation of the whole device along the work surface. The revolving structure around the axis provides easy access to the manufactured samples for the user and also provides a field for further modifications of the device. The movement along the axis provides a safe distance during the electrospinning on the rotating manifold. Also, movement along the axis is necessary when using different collector diameters.

Figure 1. Model of collecting device.

Each motor is driven by individual drives. Therefore, it is possible to change the speed of rotation and the direction of rotation. To maintain smooth and precise movements for collecting rings a stepper motor 42HS03 is used, working together with the driver DM422C. Both of elements are from Leadshine company. This combination allows obtaining 6400 steps per 360 degrees. To move up and down, a more powerful combination of the motor of the controller was used: 57HS22-A stepper motor with Leadshine M752 driver. As the controller at the present stage Arduino Mega 2560 r3 board is used. With the help of this microcontroller, communication with the computer was provided via a serial port, pulses were generated at a certain frequency in order to drive a particular motor, set the direction of moving, and read data from the end stops. To manufacture the majority of spare parts 3D printer Dimension SST 768 was used. The ABS plastic is used as printing material.

For positioning the device is equipped with optical sensors and mechanical end stops, which breaks the supply of voltage to the motors in the event of an unforeseen situation.

The nanofibrous layer is collected by means of two rotating disks from top to bottom. On the contour of the disk, the designer has provided a special track that can be filled with various materials for contact with nanofibres or the disk can be equipped with brushes for rigid sampling of the nanofibers.
And also, depending on the diameter of the discs and the physical properties of the nanomaterial, when twisting, it is necessary to shorten the distance between the disks in order to control the tension of the thread and avoid a rupture. The assembly of the rotary collector and the collecting device is shown on a figure 2.

![Figure 2. The assembly of the rotary collector and the collecting device.](image)

There are a lot of parameters to change in the device. Therefore, the microcontrollers have been programmed in such a way as to receive and transmit the variables responsible for the speed of rotation of the collecting discs, the speed of movement of the device along the axes, the direction of movement, and the like on the serial port to a computer on which the user can easily operate with these parameters.

4. Experiment

Functional prototype was tested in the laboratory using the following materials. Polyvinylidenfluorid (PVDF; Mw: 180 000 g/mol) and polyethyleneoxide (PEO; Mw: 900 000 g/mol) obtained from Sigma Aldrich. Dimethylacetamide (DMAC; purity ≥99%), was obtained from Penta Chemicals. Polymer solution was prepared as follows: PEO 1wt.% and PVDF 16,7wt.% were dissolved in DMAC at 60°C. This material was chosen for the reason that it has very good elastic mechanical properties. The polymer solution was magnetically stirred for 4 hours at 60°C to allow complete dissolution before electrospinning. Electrospinning was carried out also at 60°C. The polymer solution was heated using a special device for heating the solution in the syringe. Solution was pushed from syringe to an opposite charge rotation collector for ca. 20 minutes. The voltage on the tip of needle was 15kV positive and on the collector was 4kV negative. The distance between needle and collector was 15 cm and the distance between arms of the collector was 10 cm. The speed of rotation of the collector was 50 rev./min. Collector was powered by DC Regulated Power Supply (model RXN-302D-3). All experiments were carried out at 21°C and relative humidity of 60%.

The collection of nanofibers from a rotating collector can occur in two ways. The difference is in the impact of collective discs on the collector and their rotation speed. Two types of collection are presented in the scheme shown on figure 3. In the first case (figure 3a), prefabricated disks barely
touch the canvas with nanofibers and move along the crooked arrow downward. The speed of rotation of the disks corresponds to the rate of descent downward. Thus, the circumference of the disk as if passes through the surface of the nanofibrous canvas. In the second case, the assembly discs run to the collector as much as possible, as depicted on Figure 3b. The direction of rotation of the assembly discs remains the same (clockwise), but the rotation speed decreases. This is done in order to increase the density of the material that is collected, as there is an assumption that the resulting material after such a collection method has a higher percentage of parallel fibers in its structure.

Figure 3. Two ways of collecting nanofibers. 1. Rotating collector; 2. Collecting disks.

In our experiment, the first method of collection was used. All the obtained samples are prepared for liquid transport testing.

5. Results

Figure 4 shows the results of operation of the device.

Figure 4. Results of operation of the device: a) gathered nanofibrous from rotating collector; b) twisted nanofibrous

The topology of collected nanofibrous yarns was studied by scanning electron microscopy (SEM; Tescan Vega 3SB Easy Probe). Fibers were sputter coated by 7 nm of gold. Fiber morphology evaluation was carried out by software program NIS Elements AR 3.2. Images of nanofibrous layers are shown in figure 5. Fiber diameter of produced yarn was 980±120 nm.
6. Conclusions
The functional prototype showed very promising results for future research in nanofiber yarns production from parallelized nanofiber structures. Yarns are made from combination of PEO and PVDF polymer solution showed good mechanical properties. They are elastic and have required form. One of the main benefit of the devise is the possibility to change parameters of gathering and twisting the fibrous. This option will be useful for further experiments. Also a lot of different polymer solutions will be tested in future.

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