DEVELOPMENT OF DEVICE FOR PARALLEL STRUCTURED NANOFIBERS YARNS PRODUCTION

SHYNKARENKO Andrii[1], KLÁPŠŤOVÁ Andrea[2], KROTOV Anton[1]

[1]*Technical University of Liberec, Faculty Of Mechanical Engineering, Department of manufacturing systems and automation, Liberec, Czech Republic, EU*
[2]*Technical University of Liberec, Textile Faculty, Department of textile materials, Liberec, Czech Republic, EU*

Abstract

Nowadays production of parallel structured nanofibers is widely evolving and is gaining popularity in various fields. This research is about the development of a modified device to produce nanofiber yarn with high quality oriented fibers. The main requirements of the device are to simplify the production of homogenous nanofibers and allow possibilities to change parameters of the experiment. This article describes the design process of the device in accordance with the technological requirements, its construction and prototyping. The article also includes an overview of the main disadvantages of existing device and the advantages of the modified device. The main feature of the developed device is the precise control of the rotational speed of the collecting element. This is done in order to make the collecting fibers process in precise parallel form. The modification of collecting element also allows changing the parameters of the nanofibers collection process. Using this device it will be able to test new materials for the production of nanofibers. The device tested with several materials and positive results are achieved.

Keywords: Nanofibers, oriented structure, electrospinning, prototyping, device design.

1. INTRODUCTION

Electrospinning is a technology to produce nanofibers. This technology allows the production of various nanofibers or microfibers. The electrostatic forces acting on the polymer solution causes the production of nano or micro fibers [1]. This article deals with the production of parallelized nanofibers by the electrospinning technology from the polymer solution. To achieve an oriented structure of the resulting layer, it is necessary to use special collector. Using the rotating carousel is very simple and recognized method [2]. Some researchers have previously worked on this device but performance tests in the laboratory have large amounts of disadvantages. Considering its disadvantages, it was necessary to construct a modified device which would allow for a greater range of materials spinnability and improved quality of oriented layers.

This device is only part of a huge project for the production of complex structures of nanofibers. One of the main objectives is to provide a parallel strand of nanofibers.

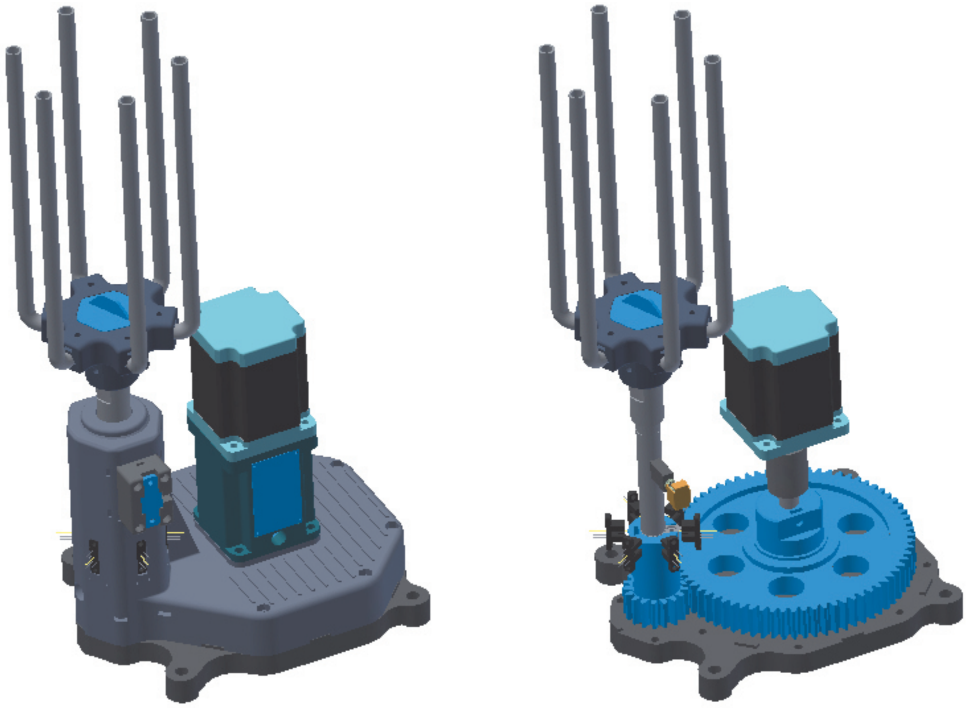
2. PREVIOUS RESEARCH

The first experiments with a rotating collective head were carried out using a device assembled from some improvised material. The main task was to transfer the voltage to the rotating bars. After successful experiments and the obtained nanofibers samples, it was decided to continue with the experiments in this direction. Nanofibers were produced from this device, but the device was not stable, the contact with bars was not permanent and the speed of rotation was not high enough for the necessary experiments. The distance between the bars on the head were fixed, but that's not enough for testing with a variety of polymers solutions. To change the speed it was necessary to change the gearbox or use a different engine. All these operations take up a tremendous amount of time and they require financial expenses, but even when a new device is made, it should be noted that the device could be used with fixed parameters for a specific polymer solution. Due to the instability of the device and the complexities of changes in the parameters of the experimentation it was pretty hard to conduct a series of experiments under the same conditions and to collect the necessary amount of data for statistical analysis.

Based on the above, it was decided to develop a working prototype of the device, which would take into account the shortcomings of the previous model, namely to ensure a stable contact with the bars, have a stable and controlled rotational speed of the collective head, provide the possibility of changing the distance between the bars, as well as to position this head in the space so as to ensure further operation to collect nanofibers from bars.

3. HARDWARE

First of all, a 3D model of the future product (**Fig. 1 (a) (b)**) is created. As the main goal at this stage is to create a working prototype, it was decided to make most of the details on the 3D printer.



(a) (b)

Fig. 1 (a) 3D model of developed device, (b) Inside view

To manufacture the majority of spare parts 3D printer Dimension SST 768 was used. The ABS plastic is used as printing material. 3D printing technology has been selected because it is relatively fast and high quality way to manufacture parts of complex shape.

Design feature of the new model of the device is that the majority of units are easily replaceable, upgrading and changes of construction is possible to produce quickly and without making big design changes. This is due to the reason that it is a first prototype and during the experimentation may break or may need upgrading for a particular function. For example, if we want to change the engine and a new motor has a different mount from the previous one - we can print only a small converter, not a whole body where our engine fixed.

To transfer voltage brushes are used which are pressured by a spring to a rotating shaft and attached to the rotating collective head. Even though they rub out with the passage of time, but provide a stable contact. This brush can be easily changed. If a method of transferring the voltage to the shaft for any reason ceases to satisfy us, the modular design of the device makes it possible to replace one part without redoing the entire device.

Based on the knowledge from previous experiments, an important parameter is the speed of rotation of the head with bars. There have been many experiments at low speed (one rotation per minute), but there is no research for the higher speed. To maintain the stability and positioning accuracy of the rotation a stepper motor SH1603-5240 is used, working together with the driver HY-DIV168N. This combination allows obtaining 6400 steps per 360 degrees. As the controller at the present stage Arduino Mega 2560 r3 board is used. Based on technical description it is capable of speeds 3.3 rpm. But to increase the speed it was decided to add a gear assembly. Transfer ratio was 1: 4. This greatly increased the speed of rotation without any loss in the positional accuracy of the head. The next step involves the automatic collection of the resulting nanofibers from the rotating head. It was necessary to do this to ensure accurate positioning of the bars relative to the collective unit. This problem was solved by the establishment of optical sensors in the lower part of the device (**Fig. 2**).

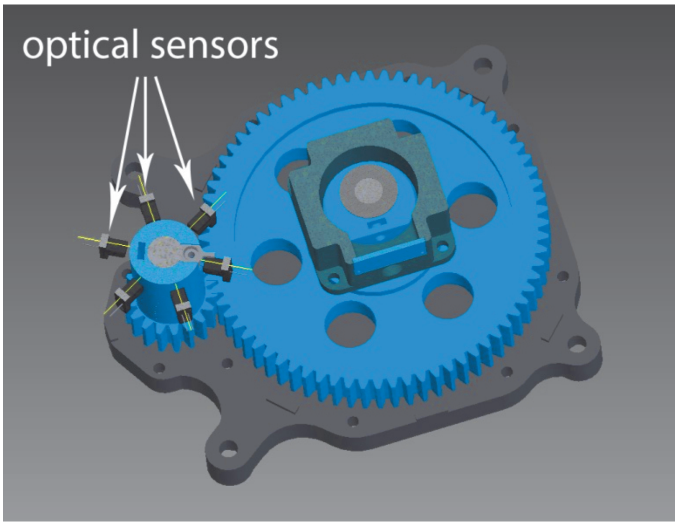


Fig. 2 Position of optical sensors

An important feature of this new model is a quick change heads with different distances between the bars. Replacing the head takes less than one minute. This increases the number of various experiments and using different types of polymer solutions. During the development of the rotary head, special attention is given for the aerodynamic of the bars, that can occurs the high speed airflow. As sometimes this flow can destroy the resulting nanofibers. Previously, flat bars were used, which are replaced in the new device with cylindrical bars.

4. SOFTWARE

The main idea for the manufacturing of the device is that any possible parameters for experimentation can be changed. This will increase the number and variety of tests with different parameters, on the same device with minimal downtime. Currently this devise is programmed for working in test-mode to debug and fix all possible problems [3].

5. EXPERIMENTAL PART

Functional prototype was tested in the laboratory and its performance was compared with the existing device. Oriented structures were obtained from two polymers solutions.

5.1. Material

The first experiment: Polyvinylidene fluoride (PVDF; Kynar 720) was obtained from Arkema. Polyethylene oxide (PEO; Mw 900 000) was obtained from Sigma Aldrich. Dimethylacetamide (DMAC) from Penta. Polymer solution was prepared from PVDF and PEO (at ratio 10:1) dissolved in DMAC at 60°C. Concentration of solution was 16,7% by weight. The second material: Polyvinyl alcohol (PVA; Mw 60 000) was obtained from Sigma Aldrich. Polymer solution was prepared from PVA dissolved in distilled water (concentration was 12%).

5.2. Electrospinning

Electrospinning was carried out from a polymer solution, heated at60°C. The solution is pushed from the syringe to a opposite charge rotation collector for 10 minutes. The voltage on the needle was set at 20 kV negative and on the collector as4 kV positive. The speed of rotation of the collector was 200 rev./min, collector was powered by DC Regulated Power Supply (model RXN-302D-3). The distance between the end of the needle and the collector was 20 cm. All experiments were carried out at 23°C and relative humidity of 60%.

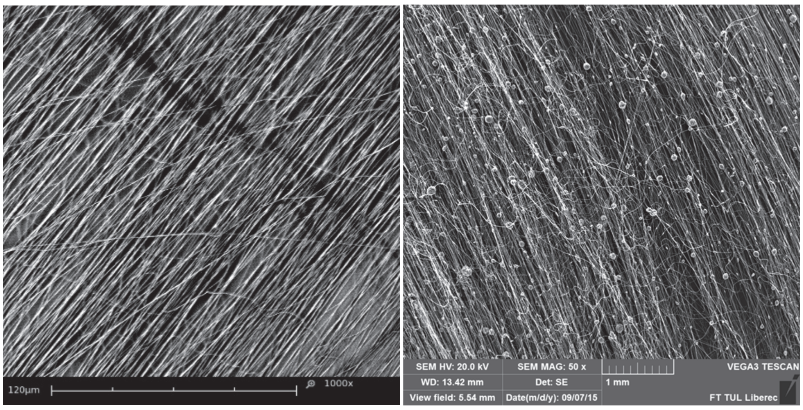
For PVA electrospinning the voltage on the needle was set as 15kV negative and on the collector as4kV positive. Other conditions were kept similar same as for the PVDF/PEO solution.

5.3. Characterization

Oriented electrospun fibers were coated with gold using sputter coating and their morphology including fiber diameter was observed under scanning electron microscopy (SEM; TescanVega 3SB Easy Probe).

6. RESULTS

In this research, two experiments are conducted using this new device. The morphology characteristics of result oriented structures obtained from PVDF/PEO and PVA solutions were studied by SEM. Image analysis are shown in **Fig. 3**.



(a) (b)

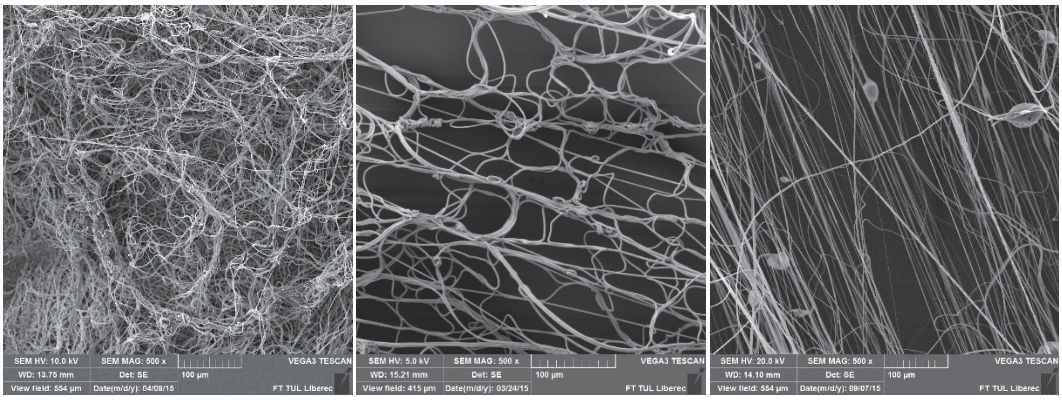
Fig. 3 Image analysis: (a) PVA layer, (b) PVDF layer

The averages electrospun fibers diameters and parallelized percent age of fibers are summarized in **Table 1**.

Table 1 The averages electrospun fibers diameters and parallelized percent age of fibers

Sample	Fiber diameter [nm]	% of parallelized fibers
PVA	280±68	92
PVDF/PEO	3185±260	75

The diameters of fibers this novel device are compared with the production of two different technologies. The first layer was made by classical method for producing nanofibers by roller electrospinning **-** Nanospider. The second was from the previous device and the third was from the modified device. As we can see on the **Fig. 4**, the novel method is the able to produce highly parallelized structure. All experiments were carried out from a solution of PVDF/PEO under the conditions described in the previous experiment.



(a) (b) (c)

Fig. 4 Image analysis: (a) PVDF/PEO Nanospider layer, (b) PVDF/PEO layer from original device (c) PVDF/PEO from the novel device

7. CONCLUSIONS

The new device showed very promising results for future research related to parallelized nanofiber production. Both the polymer solutions showed high degree of parallel fibers as compared to older techniques. The possibilities to change parameters in this novel device could be very beneficial for the researchers working with different solution to test on laboratory scales. The device is a great improvement to the older versions for production the parallel nanofiber webs. The device will be further tested with different solution of polymers in future.

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