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Automation of a horizontal electrospinning system to obtain polymeric nanofibers at low cost

Automatización de un sistema de electrohilado horizontal para obtención de nanofibras poliméricas a bajo costo

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Abstract

The objective of this research is to automate the horizontal electrospinning system to obtain nanofibers with polymeric solutions. The open loop system was designed and implemented for the electromechanical system of the horizontal electrospinning machine to control the speed of injection, distribution and storage of the polymeric solution and the control of the distance between the capillary and collector, and the display of the temperature at through a human-machine interface. The control system is made up of the reference value, control, correction and process stages, in other words, in the reference value the desired values of each of the variables to be controlled are assigned, in the control stage decision making and send the signals to the correction stage to make the changes and maintain the desired value and the process is where the physical variables are controlled, it was carried out with the LabView software and the ATMega 2560 microcontroller. With the automation of the horizontal electrospinning system, they will determine the conditions of the process and environmental parameters for obtaining nanofibers from different polymer solutions for use in the area of catalysis and biomaterials.

Automation, Horizontal electrospinning, Variables

Resumen

El objetivo de esta investigación es automatizar el sistema de electrohilado horizontal, para la obtención de nanofibras con soluciones poliméricas. Se diseñó e implemento el sistema de lazo abierto para el sistema electromecánico de la electrohiladora horizontal, para controlar la velocidad de inyección, distribución y almacenamiento de la solución polimérica y el control de la distancia ente el capilar y colector, la visualización de la temperatura a través de una interfaz hombre máquina. El sistema de control está constituido por las etapas valor de referencia, control, corrección y el proceso; en otras palabras, el valor de referencia asigna los valores deseados de cada una de las variables a controlar, en la etapa de control se toma decisiones y envía las señales a la etapa de corrección para que realice los cambios, así se mantiene el valor deseado; en el proceso se controlan las variables físicas, se realizó con el software de LabView y microcontrolador ATMega 2560. Con la automatización del sistema de electrohilado horizontal se determinan las condiciones de los parámetros del proceso y ambientales para la obtención de las nanofibras a partir de diferentes soluciones poliméricas para su uso en el área de catálisis y biomateriales.

Automatización, Electrohilado horizontal, Variables

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Introduction

According to Arbones (Arbones, 2009) an automated system is a set of components that interact with each other, after receiving instructions provided by the operator, decides and acts, thus substituting man. Such substitution produces faster execution, better regulation of the results and avoids the man the painful and repetitive tasks.

In the field of industrial and process production, automation has become a necessary and indispensable working tool to optimize production processes and increase competitiveness. Therefore, automation has the mission to achieve added value in manufactured products, varying their characteristics and carrying out a transformation of materials or goods until reaching a finished product (Pardo, 2012).

Production involves repetitive tasks, where a set of magnitudes of physical variables (pressure, temperature, humidity, speed, voltage, current, etc.) must be maintained within pre-established margins (desired value or reference). The application of electromechanical and electronic systems in the industrial area allowed automating repetitive tasks, increasing production levels, and controlling the magnitudes of physical variables more precisely (Daneri, 2008).

Electrospinning is one of the most used and economic techniques, for obtaining nanofibers, where an electric field is generated between the two parallel plates with a high voltage source with positive or negative polarity, an injection or tubular pump to carry the solution from the plunger or pipette to the spinneret and a conductive aluminum collector (Fahimirad, Ajalloueian, & Ghorbanpour, 2019).

The diameters of nanofibers are in the submicron to nanometer range, it contains unique characteristics in which are: very large surface area relative to volume (Tong, Zhang, & Wang, 2012) and superior mechanical performance compared to other already known forms of the material, these characteristics make nanofibers, candidates for a variety of applications including: tissue engineering (Dersch, Steinhart, Boudriot, Greiner, & Wendorff, 2005) (Jayaraman, Kotaki, Zhang, Mo, & Ramakrishna, 2014); with nanofibers different materials are obtained with properties and characteristics that improve products or new ones are created, with applications in areas: medicine, environmental (Antúnez García, Maytorena Córdova, Petranovskii, & Raymond Herrera, 2000), textile (Jayaraman, Kotaki, Zhang, Mo, & Ramakrishna, 2014), (Srinivasan & Reneker , 1995) (Xue, Chen, Yin, Jia, & Ma, 2012), tissue engineering, biosensors, filtration, wound dressings, drug delivery and enzyme immobilization (Travis, 2008).

Figure 1 shows the electrospinning system, which consists of a capillary injector through which the polymer solution is expelled; a high voltage source containing two positive and negative electrodes are connected to the capillary and to the collector (Ju, Laurencin, Caterson, Tuan, & Ko, 2002), where the fibers are deposited after evaporation.

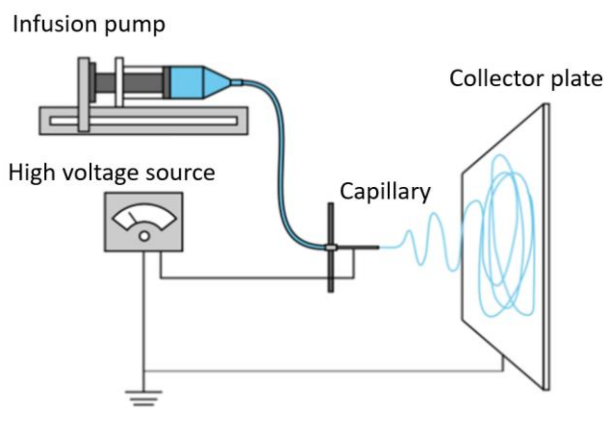

Figure 1 Assembly of the electrospinning system
Source: (Duque, Rodríguez, & López, 2012)

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There are several variables that are related to the properties and characteristics of the electrospun fibers; therefore, their control during the execution of the process is necessary. It is important to consider the parameters of the solution, such as: concentration, surface tension, conductivity, dielectric effect of the solvent, process parameters: voltage, output flow, distance between the needle tip and the collector plate (Ju, Laurencin, Caterson, Tuan, & Ko, 2002) and environmental parameters: humidity and temperature.

Voltage is one of the most important parameters within the electrospinning process; i.e., applying high voltages decreases the diameter of nanofibers (Sencadas, et al., 2012), or increasing the voltage decreases the diameter of nanofibers (Lee, et al., 2004), increases the probability of obtaining defective fibers (Deitzel, Kleinmeyer, Harris, & Tan B., 2001) (Sencadas, et al., 2012); a lower outflow the solvent would have more time to evaporate avoiding the formation of defects in the fibers (Yuan, Zhang, Dong, & Sheng, 2004), when the outflow increases the diameter of the fibers and possibly in the size of the defects (Zong, et al., 2002) (Ribeiro, Sencadas, Gomez, & Lanceros, 2010); the distance between the needle tip and the collector plate depends on the properties of the solution. It can have an effect on the morphology of the fibers, with very large distances the electrospun fibers may break under their own weight, especially if the fibers are small in diameter (Li, Wang, & Xia, 2003), a minimum distance is required to give the fibers enough time for the solvent to evaporate before it reaches the collector, with very large or too small distances the appearance of beads has been observed (Ki, et al., 2005).

Aligned or oriented nanofibers have been obtained with rotating or parallel collectors (Jayaraman, Kotaki, Zhang, Mo, & Ramakrishna, 2014) and random ones with lamellar collectors inside the membrane that configure the movement according to each collector; i.e., without movement. The development of the collectors, influence by the membranes that can be obtained, by the control of the process, in other words, the magnitudes of the variables that converge for an optimal preparation of nanofibers (Suárez, Goméz, & Muñoz , 2015).

Therefore, this work explains the automation of the electromechanical system of the horizontal electrospinning, implementing an open loop system, for the control of injection (injection speed of the polymeric solution), distribution (horizontal distribution speed of the polymeric solution) and collector (storage speed of the polymeric solution); It also controls the positioning of the platform (distance between the capillary and the collector) and temperature monitoring, i.e., the desired value for each of the process parameters is assigned through the human machine interface (HMI) to obtain nanofibers, which can be used as biomaterials or in catalysis for the removal of organic dyes in effluents.

Methodology to be developed

The mechanical system of horizontal electrospinning was automated to obtain nanofibers; that is, an open loop system was implemented to control the magnitudes of the physical variables of the horizontal electrospinning process (injection speed, distribution and storage of nanofibers); manipulate the separation between the capillary and the collector, monitor the temperature in the process and finally test the operation of the equipment.

Results

Control system

An open loop control system was implemented, because the magnitudes of the reference values are not compared with the magnitudes of controlled variables, these systems are only calibrated to obtain a precision, the block diagram of the control system for horizontal electrospinning, is shown in Figure 2.

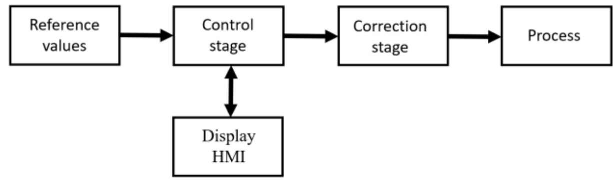

Figure 2 Block diagram of the control system for the electromechanical horizontal electrospinning system
Source: Own elaboration

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Reference values: The magnitudes of the physical variables that are controlled are: injection speed, distribution and storage of the polymeric solution; the distance between the needle and the roller is manually manipulated, and the temperature is monitored.

The control of injection speed, distribution and storage of the polymeric solution and the separation between the capillary and the collector were implemented direct current motors manipulated by pulse width modulator (PWM) at a frequency range of 0 to 970 Hertz (Hz) and the ATMega 2560 microcontroller.

Control stage

Manual and autonomous control of the injection system: The direction of rotation of the motor is manipulated with the digital outputs 11 and 12 of the ATMega 2560 microcontroller; i.e., it is controlled manually by enabling the "Close" button actuates the electromechanical system with which a force is applied to the syringe plunger that injects the solution and the "Open" button releases the syringe plunger and autonomous control of the injection system sets the injection time then sets the speed of the DC motor in the range of 0 to 255 related to the frequency of 0 to 1. 942 KHz with the knob "injection motor control" and finally the buttons "intermittent" and "close" are activated and the electric actuator rotates clockwise and with the buttons "intermittent" and "open" the rotation of the direct current motor is inverted, in other words the electromechanical system will return to its initial state; meter 3" is an indicator instrument that shows the percentage of the duty cycle of the pulse width modulator that controls the speed of the DC motor and the indicator light if deactivated indicates that the electromechanical system is in manual mode.

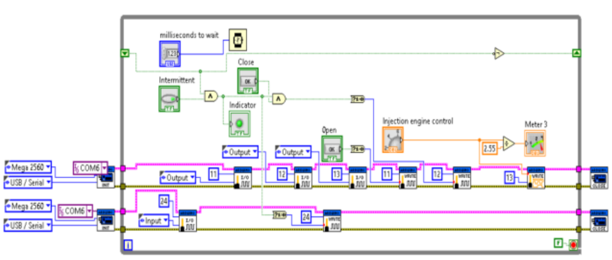

Figure 3 Injection control system for the mechanical horizontal electrospinning system
Source: Own elaboration

Oscillation speed control: The speed of the oscillation system is set with the slider "oscillation motor control" with values from 0 to 255, duty cycle of the pulse width modulator from 0 to 100% is displayed on the indicator instrument "meter 2" and the frequency range is 0 to 970 Hz (pin 7); The DC motor rotation control of the electromechanical oscillation or distribution system uses pins 5 and 6 to reverse the rotation of the electric actuator automatically in conjunction with two slot sensors (pins 24 and 26) placed at the ends of the mechanical system; that is to say, if the light beam of the slot sensor emitter is not interrupted in the receiver a logical 1 is obtained and therefore the mechanical system moves to the left or right otherwise when it reaches the limit the slot sensor changes state from 1 to 0 and therefore, the rotation of the motor changes direction and also with two indicator lamps shows at which end is the mechanism, shown in Figure 4.

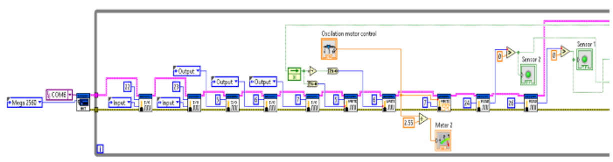

Figure 4 Horizontal electrospinning distribution system control system
Source: Own elaboration

Speed control of the collector (roller): The direction of rotation of the direct current motor of the electromechanical system of the fiber collector is manipulated; In other words, clockwise direction of rotation of the electric actuator is used pin 9, which is assigned a Boolean value equal to one, a voltage is supplied and otherwise a voltage is provided to the direct current motor and with pin 8 the counterclockwise direction of rotation is inverted, the Boolean value is set equal to zero, therefore, a potential differential is applied to it, a potential differential is applied and otherwise no voltage is applied to the direct current motor and the speed is controlled with pin 10, with the pulse width modulator (PWM) technique at a frequency from 0 to 487 Hz, the values are from -100 to 100, for positive values a high pulse is sent to pin 9 and a low pulse to pin 8 and negative values a logic zero is sent to pin 9 and a logic one to pin 8, as shown in Figure 5.

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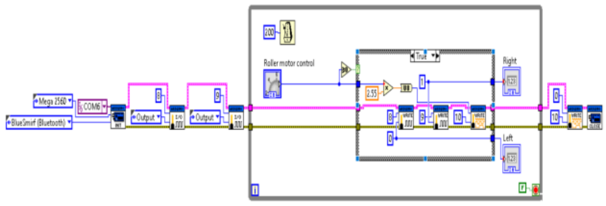

Figure 5 Horizontal electrospinning roller control system
Source: Own elaboration

Platform control: To control the separation distance between the capillary and the collector is used an electromechanical system that is manipulated with a direct current motor, for the displacement of the platform forward is manipulated with pin 3 if it is assigned the Boolean value of 1 with an event of a click of the button "forward" and backward is done with the push button "back" and the displacement speed with manipulated with the knob "platform control", The "meter" display instrument shows the duty cycle of the rotating machine or 100% is controlled by the pulse width modulator technique, see figure 6.

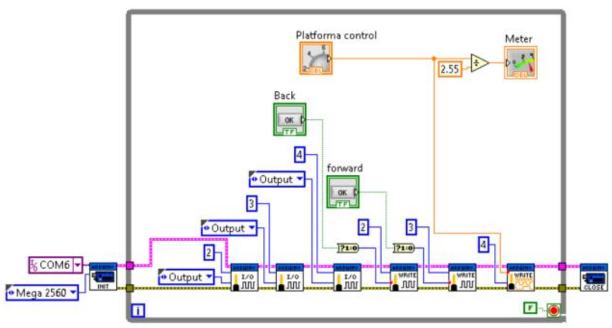

Figure 6 Horizontal electrospinning platform control system
Source: Own elaboration

Temperature: the temperature reading is made by means of a thermocouple, which sends an analog signal to pin A0 of the ATmega 2560 Microcontroller. This signal is processed passing first through a difference, then the result to a division by 0.0255 and the magnitude of the temperature of the process is obtained, as shown in Figure 7.

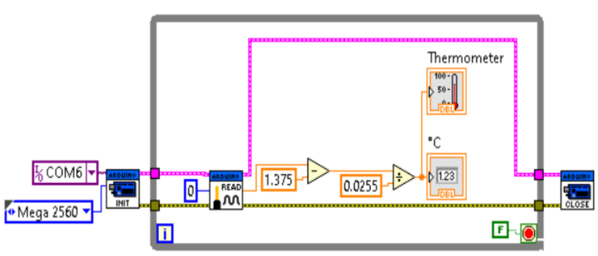

Figure 7 Horizontal electrospinning platform control system
Source: Own elaboration

Conclusions

The control system of the variables of distribution, injection of the polymeric solution and storage of the nanofibers, the speed was manipulated with a pulse width modulator, and the control of the separation between the capillary and the collector and the temperature of the process was visualized, and the operation was checked by performing tests with a polymeric solution under different reference values of voltage, injection speed, distribution and storage, with the man-machine interface (see figure 8).

With the automation of the electrospinning system, the feasibility conditions of polymeric solutions for obtaining fibers are being sought.

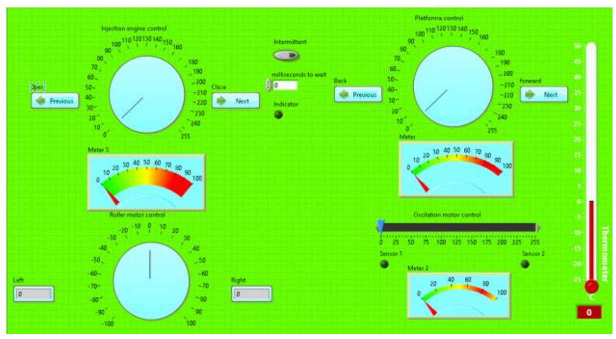

Figure 8 Man-machine interface of the horizontal electrospinning system
Source: Own authorship

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