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Journal Innovative Design

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Presentation of the content

In the first article we present, *Polyvinyl alcohol and fluorescein electrospun fibers* by CUAHUIZO-HUITZIL, Guadalupe, SANTACRUZ-VÁZQUEZ, Claudia, TOXQUI-LOPEZ, Santa and SANTACRUZ-VÁZQUEZ, Verónica, with adscription in the Benemérita Universidad Autónoma de Puebla, in the next article we present, *System for inspection of fuel level sensor* by DUARTE-LOERA, Jorge, REYNOSO-JARDÓN, Elva Lilia, DÍAZ-RIVERA, Abelardo and ARÁMBULA-LEDEZMA, David Daniel, with adscription in the Universidad Tecnológica de Chihuahua, in the next article we present, *Design of a mechanism for applying sensitive films to gas sensors based on quartz crystal resonators* by LEBONNOIS-RODRIGUEZ, Ian Denis, MUÑOZ-MATA, José Lorenzo, ROJAS-GARNICA, Juan Carlos and JIMÉNEZ-ARELLANO, Juan Jesús, with adscription in the Universidad Tecnológica de Puebla and Benemérita Universidad Autónoma de Puebla, in the last article we present, *Development of a blueberry sorting machine* by CASTILLO-QUIROZ, Gregorio, LIMON-DIAZ, Miguel Ángel, CRUZ-GARRIDO, Arnulfo and VERGARA-REYES, Ángel Vidal, with adscription in the Instituto Tecnológico Superior de Huauchinango.

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Polyvinyl alcohol and fluorescein electrospun fibers

Fibras electrohiladas de alcohol polivinílico y fluoresceína

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Abstract

Electrospinning is a technique that allows obtaining new fibrous structures from synthetic or natural polymers for the development of materials used in the pharmaceutical and biomedical industries, among others. However, the low production rate of electrospinning has limited its industrial application, forcing the development of new injectors that allow higher productivity. In this work, a coaxial injector was designed to develop products encapsulated in polymeric fibers. For the demonstration of the encapsulation of one fiber included in another, fluorescein was used as internal compound in a polyvinyl alcohol solution, and polyvinyl alcohol was used as external fiber. It was obtained that the encapsulation process is possible by using this coaxial injector.

Nanofibers, Coaxial electrospinning, Coaxial injector

Resumen

El electrospinning es una técnica que permite obtener nuevas estructuras fibrosas a partir de polímeros sintéticos o naturales para el desarrollo de materiales utilizados en la industria farmacéutica y biomédica, entre otros. Sin embargo, la baja tasa de producción del electrospinning ha limitado su aplicación industrial, forzando al desarrollo de nuevos inyectores que permitan una mayor productividad. En este trabajo se diseño un inyector coaxial con el cual se desarrolló productos encapsulados en fibras poliméricas. Para la demostración de la encapsulación de una fibra incluida en otra se empleó la fluoresceína como compuesto interno en una solución de alcohol polivinílico, y como fibra externa se empleó el alcohol polivinílico. Se logró obtener que el proceso de encapsulación es posible mediante el uso de este inyector coaxial.

Nanofibras, Electrohilado coaxial, Inyector coaxial

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Introduction

Currently, there are different methods for the manufacture of fibers and microfibers, including electrospinning or electrospinning. This technique was observed by Rayleigh in 1897, who evaluated the effect of inducing electrical charges in water jets, as well as the asymmetric instability of the jet flow. The electrospinning process allows the formation of fibers at micro and nanometer scales in a simple way, generating important advantages over other fiber production methods. However, there are several configurations of electrospinners, horizontal and vertical, with injector, simple, carousel or coaxial injection. The latter configuration has been of great interest in recent years.

This interest is not accidental, since the quality of the fiber or microfiber will depend to a large extent on the proper functioning of this system, which in turn will determine such important parameters as the encapsulation and release of an active substance, especially in view of the ever-increasing requirements in the pharmaceutical field. But this requires a thorough understanding of all the phenomena involved in the coaxial injection process itself.

Undoubtedly, one of the most critical parts in this process is the composition of the solution, and more specifically, the diameter of the internal and external capillary tubes used in the coaxial injection system. From the geometry of these will depend the characteristics of the fibers that can be obtained, and from the flow conditions just at the exit of the orifice will depend the behavior of the Taylor cone. Therefore, the objective of this work was to obtain electrospun fibers of polyvinyl alcohol and fluorescein using a coaxial injector.

Only until a few years ago due to the demand for materials with nanometer scale dimensions, the electrospinning technique has become a more attractive process thanks to the ability to transform a wide range of materials in the form of nanofibers at low cost and with relative simplicity.

The electrospinning equipment consists of a capillary through which the polymer solution is expelled; a high voltage source that has two electrodes, which must be connected one to the outlet of the solution and the other directly to the collector plate, conductive metal sheet or rotating mandrel, among others. To start the process, the polymer must be diluted in the solvent or solvents that allow dilution to obtain homogeneous fibers.

The polymers used are dielectric, and in the presence of an electric field can be considered as an arrangement of microscopic electric dipoles composed of positive and negative charges whose centers do not coincide perfectly (Dekker, 1959), remaining in place by the action of atomic and molecular forces, and can only change their position slightly in response to strong external electric fields, which explains why the stretching of the solution occurs in the process (Fano, 1987). Sometimes to increase the dielectric properties of the solution, some solvents with high dielectric constants are added (Lee, Kim, Khil & Ra, 2003), this favors the formation of fibers with less defective "droplet" structures and reduced diameters (Son, Youk, Lee, & Park, 2004).

Once the solution is in the injector, the application of high voltage is initiated, the charges accumulate promoting the formation of a droplet at the tip of the capillary and as the electric field strength increases, the droplet elongates to create a conical shape known as a Taylor cone. The electric field strength overcomes the cohesive forces of the solution, in most cases dominated by surface tension, as a jet of polymer solution begins a journey from the tip of the capillary to the collector plate; on its journey, the polymer solution jet is elongated due to electrostatic interactions between charges near segments of the same jet, meanwhile, the solvent evaporates, finally, the fibers solidify upon arrival at the collector plate (Chandran, Ravichandran, Chandran, Chemmanda, & Chandarshekar, 2016). There are several operational parameters that are intimately related to the properties and characteristics of the electrospun fibers so their control is indispensable.

Among the most important variables in the electrospinning process are:

Concentration of the solution, surface tension, conductivity of the solution, dielectric properties of the solvent, while the external variables of the electrospinning process are voltage, output flow and distance between the needle tip and the collector, to mention the most important ones (Moreno-Cortez et al., 2015).

Types of injector

There are several configurations for the electrospinning process, and they are the horizontal and vertical configuration; referring to the position of the injector and collector that can be horizontal and vertical respectively. Similarly of the injectors present modifications in their configuration, among it is the single injector, needle injector or also called capillary, coaxial injector and multi-injector (Yao, Chang, Ahmad, & Li, 2016).

The needle injector is the most commonly used configuration according to the literature and was the first injector designed for the electrospinning process (Huang, Zhang, Kotaki, & Ramakrishna, 2003). It consists of an embolus or syringe with an electrically charged capillary attached, which serves as a duct for feeding the fluid to be electrospun. Unfortunately it presents disadvantages such as: low feed flow, impossibility to obtain fibers from immiscible materials, low encapsulation capacity (Moreno-Cortez et al., 2016; Tang et al., 2016; Vyslouzilova et al., 2017).

The coaxial injector is a modification of the conventional electrospinning process that involves the arrangement of multiple feed systems for simultaneous electrospinning. Generally, a matrix arrangement of needle injectors is employed (Figure 1), allowing the injection of an internal solution into an external one, this to produce continuous coated or hollow nanofibers.

The coaxial electrospinning configuration involves a core-shell nozzle attached to a dual-compartment syringe (Yarin, 2011) that consists of coupling an inner needle or capillary into the concentric outer needle, which is connected to the core and shell solvent reservoirs, respectively. Figure 1 presents the schematic for Taylor cone formation in a coaxial injector, noting that the conductivity and properties of the outer or shell polymer are important for fiber formation.

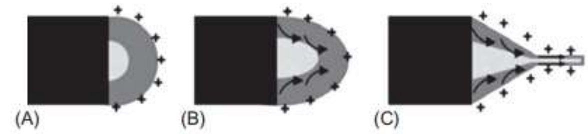

Figure 1 Schematic illustrating Taylor cone formation in the coaxial injector. A) Surface charges b) Shell formation in the droplet c) Taylor cone for shell formation
(Derived from Hao R, Yuan JY, Peng Q, 2006)

The application of an electrostatic field in the coaxial injector results in the formation of the composite Taylor cone consisting of the core solvent surrounded by an envelope solvent, as the inner fluid is pushed inward and embedded within the envelope fluid to give an outer fluid.

Since the pioneering work on this topic was published in the early 21st century (Sun et al., 2003, Loscertales et al., 2002, Zhang et al., 2004), modification of the original injector has been achieved for better feasibility and applicability. The importance of this injector lies in the possibility of producing biphasic fibers from fluids with different physical and chemical properties, allowing the formation of fibers of electrospinnable materials without mixing, in the form of polymer: polymer/organic compound and polymer/inorganic compound. This technique allows obtaining sophisticated conduits for drug delivery, energy storage and sensors (Zhang et al., 2015); It optimizes processes as is the case of nanotube fabrication, in which the vapor deposition phase is eliminated.

This coaxial injector allows obtaining materials with innovative nanoscale architecture (branched, thread-in-tube, multichannel, porous) and corresponding hybrids (Wu et al., 2013), focused for the design of technological applications in sensors, engineered fabrics, drug delivery systems and nanoelectronics (Greiner and Wendorff, 2007; Bandyopadhyay-Ghosh et al., 2015). Some materials such as metal salts and enzymes possess unique properties at the nanoscale level; However, their capabilities to form nanofibers are limited by a number of factors including molecular weight, solubility, low solvent conductivity and high surface tension and thus the use of coaxial injector allows forming a protective coating that encapsulates the desired compound in the core.

For example, Teflon cannot be electrospun due to a low dielectric constant that prevents sufficient charging of the polymer, but it possesses hydrophobic properties necessary for the textile, construction and automotive industries, among others. Therefore, coaxial electrospinning was employed to take advantage of these properties of the polymer, and its encapsulation in poly (ε-caprolactone) (PCL) (Wu et al., 2013).

Chen et al. (2010) fabricated a nanotube structure from two fully miscible solvents through a set of three coaxial capillaries employing a chemically inert fluid between them as a separator.

As for the biomedical area, the application of coaxial electrospinning has made possible the safe fabrication of nanocomponents and microstructures of highly unstable materials, such as enzymes, that would otherwise decompose in reactive environments (Gu et al., 2013; Davis and Leach, 2011). It has been reported that this device allows an increase in the encapsulation process of active compound (Garcia-Moreno et al., 2016) and uniformity in the fibers, greater protection of the encapsulated actives (Yao, Chang, Ahmad, & Li, 2016), however this injector is a challenge for the materials designer since this configuration presents a different problematic and depends on several parameters such as viscosity, miscibility, surface tension of the solutions to be injected.

Encapsulation

Encapsulation is a process used for the preservation or protection of numerous commercial ingredients, not only food, but also pharmaceuticals, chemicals and cosmetics. The pharmaceutical and food industry applies encapsulation for several reasons: to stabilize the active agent, to control the release of the encapsulated material (rate and form of release), and to separate reactive or incompatible components. Encapsulation processes have been developed as a response to the loss of viability of those active components present and consist of the protection of these materials by covering them with a carrier or encapsulating agent.

Whose objective is to protect the active component from environmental conditions such as temperature, light, oxygen, pH, enzymes, presence of other nutrients (Chen, 2007), which diminish the beneficial effect of the active component for which it is intended (Pszezola, 2005). The quality of the encapsulates, i.e. their efficiency in protection and controlled release, depends on several factors, including: the operating conditions during production (temperature, pH, pressure and humidity) and the handling of these particles, as well as the composition and structure of the materials used (Fuchs et al., 2006).

Flavor retention is determined by factors related to the chemical nature of the active agent, including its molecular weight, chemical functionality, polarity and relative volatility, the properties and nature of the encapsulating material or carrier agent, as well as the parameters of the encapsulation process. Currently there is a wide variety of encapsulating materials and active agents including waxes and lipids, proteins such as gelatins, whey proteins, zein, soy proteins, gluten, among others, carbohydrates such as starches, maltodextrins, chitosan and biopolymers such as polypropylene, polyvinyl acetate, polystyrene, polybutadiene and polyvinyl alcohol.

The following is brief information on polyvinyl alcohol, since it is a polymer used as an encapsulant, but it is also reported in a number of studies with application in electrospinning. PVA is obtained by hydrolysis of polyvinyl acetate and its commercial presentations have between 80 and 100% hydrolysis and molecular weight ranging from 13,000-200,000.

The degree of hydrolysis of PVA affects its physical properties such as interfacial tension, biocompatibility, rheological properties of solution and water solubility (Abd El-aziz, El-Maghraby, & Taha, 2016). In the pharmaceutical industry it is widely used to coat tablets and capsules while in the cosmetology industry it is used to bind product components. In toxicological studies it has been found that the degree of absorption of this substance by the body is minimal so its oral consumption is approved.

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According to the background presented, the objective of this project is the development of novel materials using the electrospinning technique and coaxial injector to obtain coaxial fibers using polyvinyl alcohol (PVA) and fluorescein.

Methodology

Obtaining fibers using the single injector

The polyvinyl alcohol and fluorescein solutions to obtain the fibers were worked with voltages of 5 and 15 KV in each source, with a rotation speed of 100 RPM. Obtaining fibers of 90 - 110 nm based on what is reported in the literature.

Obtaining fibers using coaxial injector

The polyvinyl alcohol and fluorescein solutions were fed independently into the coaxial injector ducts for electrospinning, initially they were tested with the conditions shown in Table 1.

Injector type	Injector-collector distance (cm)	Voltage (kV)	Fluorescein feed flow (mL/hr)	PVA feed flow rate (mL/hr)
Single injector	15	5-15	0.5	1
Coaxial injector	15	5-15	0.5	1

Table 1 Electrospinning conditions for coaxial injector

Solution preparation and electrospinning

For the encapsulation tests, a solution of 87% hydrolyzed technical grade high-density polyvinyl alcohol (Meyer, USA, Cat. 5425) was used. For the encapsulation tests, an 8% solution of PVA with fluorescein (Aldrich, USA, Cat. 2456) was used as the active compound.

The characterization of the PVA and fluorescein solutions was carried out with the aid of Conductronic model PC18® equipment at room temperature, determining the following values of conductivity (mS) and hydrogen potential (pH).

The evaluation of the FTIR spectra made it possible to identify the main reflections of the spectra of each of the fibers, using a database provided by the supplier to identify the main functional groups of the molecule. The VERTEX 70® model FTIR equipment was used for this test.

The morphological and microstructural evaluation of the fibers was determined through a Scanning Electron Microscopy equipment, which worked with a potential difference of 10KV, detecting backscattered electrons and amplifications of 500, 1000 and 5000X were made. The SEM images obtained were analyzed using ImageJ® software.

Results and discussion

The coaxial injector was constructed by two injectors (see Figure 2) that are located one inside the other on the same side of the physical structure of the electrospinning system, and in a horizontal position with respect to the collector. This concept consists of an external injector whose function is to encapsulate the whose function is to encapsulate the active component (Fluorescein) in the nanofiber generated during the electrospinning process; it is proposed to have the same length of the internal injector for a better encapsulation, since, otherwise, if it has a longer or shorter length, the nanofibers will not have the necessary conditions and deformations will occur in them.

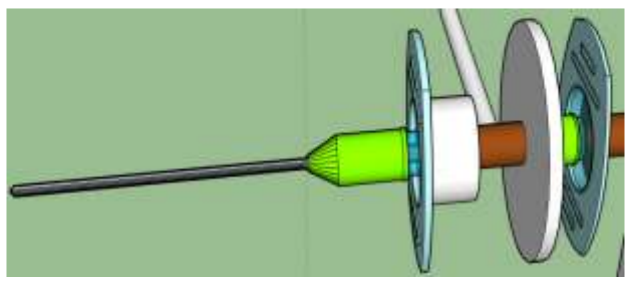

Figure 2 Drawing of the coaxial injection system

This coaxial injection system has a vertical support according to the target specifications that were initially proposed in order to provide greater stability to the collection system. Thus, the function of this system is to encapsulate the aforementioned components, together with the electrospinning equipment by means of carbon brushes to the transverse axis the grounding of the electric field required during the electrospinning process. Finally, the last piece that composes this coaxial injection system are the containers of the solutions to be electrospun, which store the same amount of solution volume in order to increase the stability of the injection system.

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Characterization of the solutions

Analyzing the values obtained for pH and citing the literature on the importance of this parameter, it is commented that pH is a significant variable for the process of nanofiber formation and electrospinning. The pH is a measure of the concentration of dispersed ions present in the chemical structure of the emulsion components. For the case of biopolymers pH is a parameter that controls their physical properties, specifically for the PVA solution used in this study and given its polyhydroxylated nature dipole-dipole bonds, induced dipole-dipole and dispersion forces are present.

Hydrogen bridges are a special type of dipole-dipole interaction between the hydrogen atom of a polar bond, such as N-H, O-H or F-H, and a highly electronegative atom such as fluorine (F), oxygen (O) or nitrogen (N) and exert a constant interaction with H atoms. These bonds are much stronger than Van der Waals bonds and, although they are weaker than covalent bonds, when taking into consideration a high number of them between polymer chains, they result in higher attractive forces in the polymers that present them.

Table 2 shows the viscosity, conductivity and pH values of the solutions used for the electrospinning process.

Solution	Electrical conductivity (mS)	pH
PVA92%-FLUORESCEIN 8%.	0.26 ± 0.01	6.65 ± 0.01
10% PVA solution	0.48 ± 0.01	6.75 ± 0.01

Table 2 Physicochemical Properties of Fluorescein and PVA Solutions

Regarding the analysis of the conductivity data of the PVA and fluorescein solutions, the electrical conductivity values were in the range 0.26 to 0.49 mS and these values were found to be a function of the PVA concentration, since the fluorescein solution is added in a small amount and therefore does not significantly affect the viscosity of the solution. Similarly, the pH of the solutions was determined and it can be observed that the lower the concentration of PVA, the value is slightly higher than the other sample.

The effect of PVA concentration on the conductivity values is due to the polymeric structure, which is characterized by having residual monomers positively charged by the OH- radical, which imparts a polar nature that is reflected in the conductivity of the sample. The increased conductivity of the solution accentuates the ability to become electrically charged, facilitating the stretching of the nanofiber during its formation.

The optimum conditions for obtaining electrospun fibers of polyvinyl alcohol and fluorescein using a coaxial injector were found. The ideal flow rate for both polymers was 3.5 mL h-1 in the coaxial electrospinning system in which. A voltage and a distance between the needle and the collector plate of 15 kV and 15 cm, respectively, were used, as shown in Table 3.

Parameter
Amount of polyvinyl alcohol: 0.5 g
Solution flow rate: 3.5 mL h-1
Applied voltage: 15 kV
Distance between needle tip and manifold: 15 centimeters
Final volume of each polymer solution: 2 mL

Table 3 Optimal conditions for obtaining fibers in a coaxial injector

The progressive decrease in the concentration of PVA in the solution generates a notable decrease in viscosity. As well as a reduction in the concentration and surfactant power of the solution.

Morphology by scanning electron microscopy

To characterize the morphology of the fibers, an SEM study was carried out. The micrographs are shown in Figure 3. The images indicate a uniform and smooth appearance, with no appearance of beads or droplets in the formed mat.

In photomicrographs shown in Figure 3 it is possible to determine that the PVA and fluorescein solution allowed an adequate electrospinning, since no large clusters of material are present in the web.

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According to the results found using ImageJ® software, the 10% PVA solution allowed the formation of the fluorescein fibers, this behavior is believed to be attributable to the concentration of amino acids with residual OH charge to the negatively charged collector and the correct evaporation of the solvent in its path.

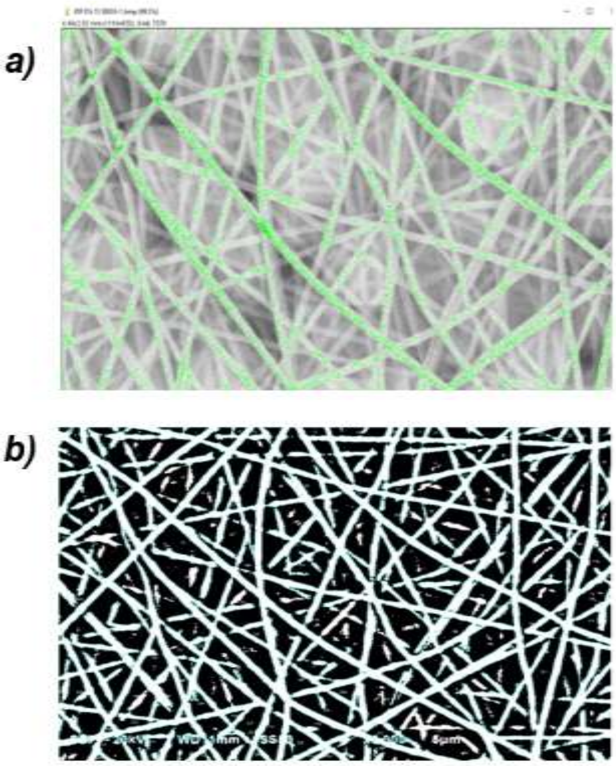

Figure 3 Micrographs of PVA 10% - Fluorescein 90% in ImageJ ® a) 5000x and b) 5000x negative filter

Component analysis by (FTIR); Fourier Transform Infrared Spectroscopy

In order to validate the presence of fluorescein incorporated in the fibers, the Fourier Transform Infrared Spectroscopy technique was used to identify the functional groups representative of the molecules that make up the fibers. Since the molecular structures of PVA and fluorescein are complex, the spectra of the pure substances were compared with the spectra of the different solutions. Figure 4 shows the ATR-FTIR spectra of the PVA fibers with fluorescein in addition to the PVA solution.

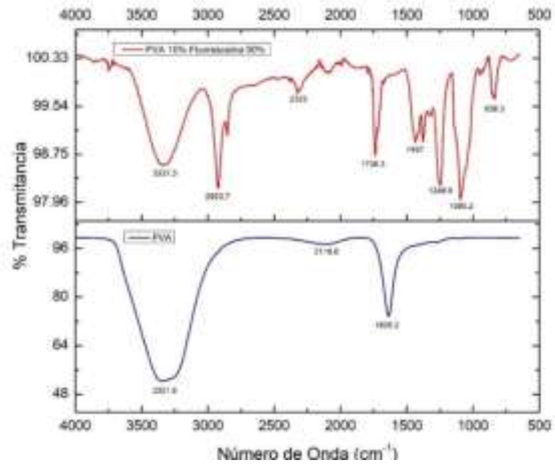

Figure 4 Infrared spectra. a) PVA 10% - Fluorescein 90%, b) PVA

In the PVA solution, vibrations of symmetric and asymmetric extensions of the H-O-H bonds can be seen in the range 3490-3280 cm^{-1} associated with the water containing nanofibers. The peaks between 2962 cm^{-1} and 2972 cm^{-1} correspond to the CH and CH_2 groups. Likewise, a peak of high intensity at 1738.3 cm^{-1} corresponding to the C=O group strain of the residual acetate groups is also observed.

The presence of aldehyde-type compounds was also confirmed, giving rise to a band centered at 2325 cm^{-1}, assigned to C=O stretching vibrations; a band of strong intensity at 1738.3 cm-1 is also distinguished, which is assigned to C=O vibrations in aliphatic aldehyde chains.

Funding

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Conclusions

In this section, the main achievements will be presented, emphasizing the most relevant ones for the objectives that were intended to be fulfilled; on the one hand, the development and testing of the coaxial injection system; and on the other hand, the use of this system to obtain polyvinyl alcohol and fluorescein electrospun fibers.

The optimum conditions for obtaining polyvinyl alcohol and fluorescein electrospun fibers in a coaxial electrospinning system were determined. This is an efficient method for the fabrication of microfibers that allows adjusting the desired execution variables to have a better performance at the time of producing the microfibers. The electrospinning or electrospinning technique allowed the formation of PVA nanofibers in which the encapsulation of the orange essential oil extract was possible.

Considering that the PVA 90% - Fluorescein 10% fibers were the fibers that presented the best characteristics using a coaxial injector with capillaries with internal diameter of 0.3 mm and external diameter of 0.7 mm both with the same length, it is concluded that the electrospinning conditions were: Voltage 15 KV for the positive pole, voltage of 5 KV for the negative pole, collector speed of 100±3 rpm, distance between injector and collector of 15 cm.

The morphology of the nanofibers obtained varied as a function of the PVA concentration in the emulsion, presenting fibers with different diameters ranging from 0.0852 to 0.2936 µm. The fluorescein encapsulation was verified by FTIR spectroscopy, highlighting the potential of the electrospinning technique through the identification of the double bonds corresponding to the fluorescein unsaturation. According to the experimental results it can be concluded that in order to carry out the electrospinning process it is necessary to identify the types of residual charges of the polymeric molecule and their concentration.

The properties of the fibers that are developed by means of the electrospinning technique allow their use in the pharmaceutical area where controlled release of drugs is necessary in which the timely delivery of medicines is allowed.

In recent years, new ways of assembling the system have been investigated in order to provide new features, enhance the characteristics of the developed fibers and allow the encapsulation or electrospinning of materials that did not have the necessary electrical properties and therefore could not be subjected to the process.

These new adjustments have made it possible to process new materials, encapsulate a wide variety of drugs and maintain a better control of drug release.

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System for inspection of fuel level sensor

Sistema para la inspección de sensor de nivel de combustible

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Abstract

This document describes a project developed for the company BorgWarner S. de R.L. de C.V. Chihuahua plant, which is dedicated to the manufacture of gasoline modules. The gasoline modules are made up of three main elements: the gasoline pump, the gasoline filter, and the fuel level sensor. When a fuel level sensor is found to be defective during manufacturing and testing, it is sent to the quality department for inspection. The root cause of the failure must be found in order to improve production processes or determine if the materials that make up the product are adequate. A system for the inspection of fuel level sensors implemented in the quality department of this company is presented. The developed system generates graphs of the sensor resistance depending on the position of the float, which allows detecting failure points in it.

Variable resistor, Gasoline module, Fuel level sensor

Resumen

Este documento describe un proyecto desarrollado para la empresa BorgWarner S. de R.L. de C.V. planta Chihuahua, la cual se dedica a la fabricación de módulos de gasolina. Los módulos de gasolina están formados por tres elementos principales: la bomba de gasolina, el filtro de gasolina y el sensor de nivel de combustible. Cuando un sensor de nivel de combustible es considerado defectuoso durante la etapa de manufactura y pruebas, se envía al departamento de calidad para su inspección. La causa raíz de la falla debe ser encontrada con el fin de mejorar los procesos de producción o determinar si los materiales que forman al producto son los adecuados. Se presenta un sistema para la inspección de sensores de nivel de combustible implementado en el departamento de calidad de esta empresa. El sistema desarrollado genera gráficas de la resistencia del sensor en función de la posición del flotador lo cual permite detectar puntos de falla en el mismo.

Resistencia variable, Módulo de gasolina, Sensor de nivel de combustible

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Introduction

At the BorgWarner Chihuahua plant, gasoline modules are manufactured. During the testing stage some modules are detected with faults. These defective modules must be tested by the quality department and if such defects exist, they must be inspected in order to determine the root causes of the failure. Knowing these causes allows corrections to be made in the processes and in the selection of the materials used to manufacture the products. The fuel module consists of three basic elements: the fuel pump, the fuel filter and the fuel level sensor. When a fuel level sensor is detected with defects, it must be inspected by the quality department which does not have a system to indicate the points of failure in the sensor. The objective of this work is to develop a system for the inspection of the fuel level sensor.

The system developed for the quality department of the company is a valuable tool that detects the failure points present in the fuel level sensors. A fuel level sensor consists of a variable resistor driven by a float. The sensor is located inside the fuel tank so the float drives the variable resistor as a function of the tank level. Therefore, the resistance of the sensor is a function of the fuel level in the tank. The inspection system generates a graph of the sensor resistance as a function of the float position. By observing the graph it is possible to detect a failure point when the resistance value shoots up abruptly. Once the failure points are located, the sensor fault causing the error can be determined using a microscope. Corrective actions will then be generated during the manufacture of the sensor so that the fault does not recur.

Fuel modules

The fuel module injects fuel from the vehicle's fuel tank to the engine injectors. Gasoline modules are made up of 3 main elements manufactured from scratch in the plant. These elements are the fuel pump, the electrical component in charge of pumping the fuel; the fuel filter, the element in charge of removing impurities present in the fuel; and the fuel level meter. Figure 1 shows a gasoline module manufactured at BorgWarner (BorgWarner Company, 2023).

Figure 1 Gasoline module manufactured at BorgWarner (*BorgWarner Company, 2023)*

Fuel level sensor

The fuel level sensor is part of the fuel module which in turn is submerged in the fuel tank. This sensor is a rod with a float that is connected to a variable resistor. Figure 2 shows a fuel level sensor manufactured at BorgWarner. A vehicle's fuel level indicator works by measuring the voltage present at the fuel level sensor. The variable resistors used to manufacture this sensor consist of a resistive material present in small segments joined by a sliding contact unit. Figure 3 illustrates the above (BorgWarner Company, 2023). When fuel levels change, the float drives the variable resistor which causes a change in the resistance connected to the fuel level detection and indication system. Figure 4 illustrates a close-up of the variable resistor of the BorgWarner fabricated fuel level sensor.

Figure 2 BorgWarner fabricated fuel level sensor *(BorgWarner Company, 2023)*

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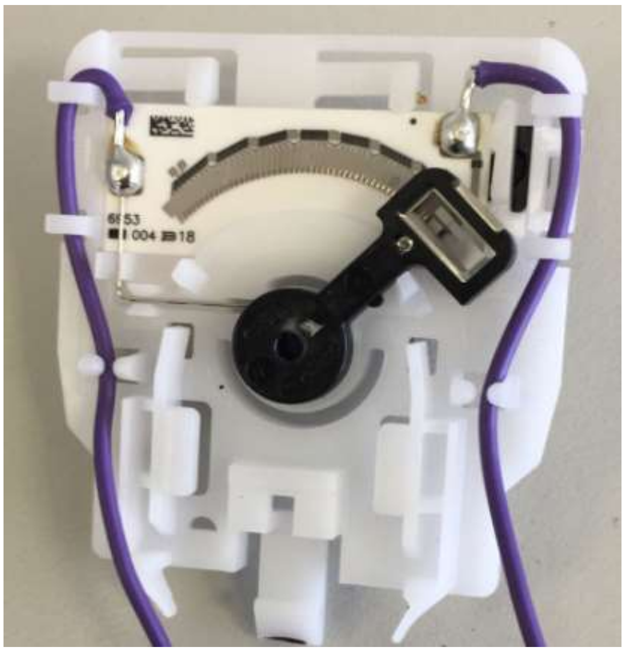

Figure 3 BorgWarner fabricated variable resistor
(BorgWarner Company, 2023)

Figure 4 Variable resistor manufactured in BorgWarner
(BorgWarner Company, 2023)

Volt Voltage Regulator

Figure 5 illustrates the 5 Vdc (direct current voltage) regulator used for the development of this work. The 120 Vdc line voltage (alternating voltage) is reduced by a 12 Vdc center tapped transformer. The total current used by the system is 50 mA (milliamps), so any transformer providing at least this current is functional. A voltage of 6 VAC is then present at each end of the transformer. The regulator ground level (0 VAC) is present at the center tap. The 6 VAC is converted to 8.48 Vdc by means of two rectifier diodes and a 2200 uF (microfarad) capacitor. The above is supported by equation (1) (Malvino, 1999).

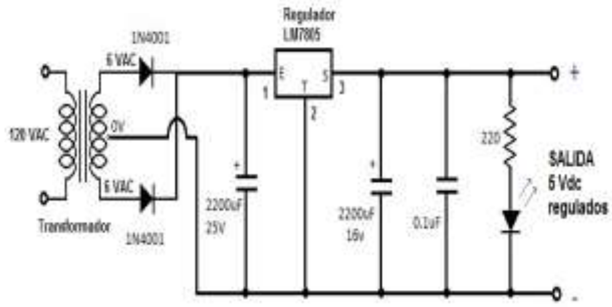

Figure 5 5 Vdc voltage regulator
(Malvino, 1999)

$$DOV = AIV\sqrt{2} \quad (1)$$

Where: DOV= direct output voltage; and AIV= alternating RMS input voltage.

The 8.48 Vdc voltage is converted to 5 Vdc regulated by a LM7805 linear regulator. The regulated 5 Vdc is filtered by a 2200 uf capacitor. High frequency noise present is eliminated by a 0.1 uf capacitor. A voltage indicator LED is also part of the circuit (Malvino, 1999).

Current source

Figure 6 shows the current regulator circuit used in this work.

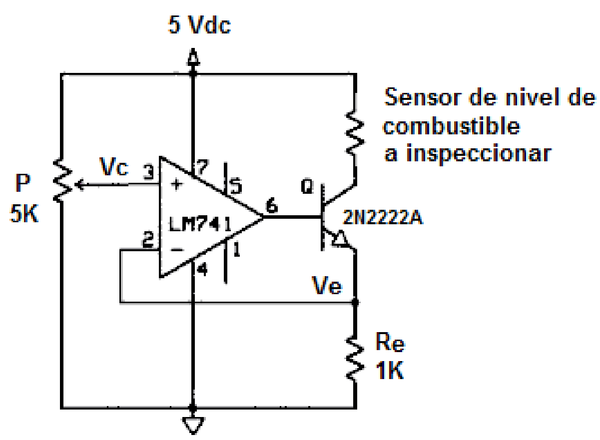

Figure 6 Current regulator
(Malvino, 1999)

The circuit is supplied with 5 Vdc and ground. An LM741 operational amplifier is configured as a voltage follower so the voltage on pin 6 will always be the same as that on pin 3 (Control voltage Vc). The voltage present on pin 3 is set by the potentiometer P which is connected as a voltage divider. The voltage present at the emitter of the transistor is defined by equation (2) (Malvino, 1999).

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$$EV = CV - 0.7 \quad (2)$$

Where: EV= emitter voltage; and CV= control voltage. Since CV is a constant voltage, so is Ve. Therefore, the current I through the 1 KΩ resistor Re will always be constant and is defined according to Ohm's law by equation 3 (Malvino, 1999).

$$I = \frac{Ve}{Re} \quad (3)$$

The current I flowing through the sensor to be inspected, through Re and through the transistor will always be constant regardless of the value of the fuel level sensor; and it is a function of the control voltage Vc. Therefore, there is always a constant current flowing through the sensor which can be adjusted from the potentiometer P (Malvino, 1999). The current I is set for this work to 2 milliamperes.

Multifunction DAQ card NI USB-6008

The NI USB-6008 is a multifunction DAQ card from National Instrument, it is ideal for working under the LabVIEW platform and is used in this project. It has the following main features: maximum sampling rate of 10 000 samples/second; 12-bit resolution; eight analog inputs; 12 digital inputs/outputs; two analog outputs; a 32-bit counter; and data control and digitizing through a USB port. The analog inputs can be configured to operate in differential mode to minimize noise, or with reference to ground (single mode). The maximum voltages supported by the analog inputs are +/- 20 Volts in differential mode or +/- 10 Volts in single mode.

This versatile board is useful both for capturing and digitizing analog signals, and for generating any analog signal through the analog outputs; or any digital signal through the digital outputs. It is low cost, but without sacrificing power (National Instruments, 2008). Figure 7 illustrates the NI USB-6008 multifunction DAQ card.

Figure 7 NI USB-6008 Multifunction DAQ card *(National Instruments, 2008)*

LabVIEW Software

Graphical programming, also known as data flow programming or G language, represents a novel alternative for the development of software for virtual instrumentation. An excellent example of graphical programming is the LabVIEW programming environment, also from National Instruments. The LabVIEW concept, a front-panel user interface combined with an innovative block diagram programming methodology is ideal for creating virtual instruments. LabVIEW works with all aspects of an instrumentation system: data acquisition, data analysis and data presentation. LabVIEW simplifies the development of instrumentation systems. In graphical programming, programs are called Virtual Instruments (VI) and are made up of three main parts: Front Panel, Block Diagram and Icon Connector.

The front panels are a concept taken from traditional instrumentation, since they correspond to the user interface where the physical front panel of an instrument is represented, with the advantage that this is done in software. An additional benefit of using the front panel in software is that generic interfaces can be created, regardless of the hardware used. But unlike a physical panel, in a software panel we can represent only the parameters of interest to our particular application. Figure 8 shows an example of a front panel developed in LabVIEW.

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LabVIEW allows the creation of user-friendly front panels and excellent presentation, giving the user interface an intuitive and simple operation. Programming through block diagrams brings programming closer to the use of flowcharts used by many engineers and scientists. In fact, it is also known as data flow programming. Figure 9 shows an example of a LabVIEW block diagram (Trujillo, 2006; LabVIEW Handbook, 2020).

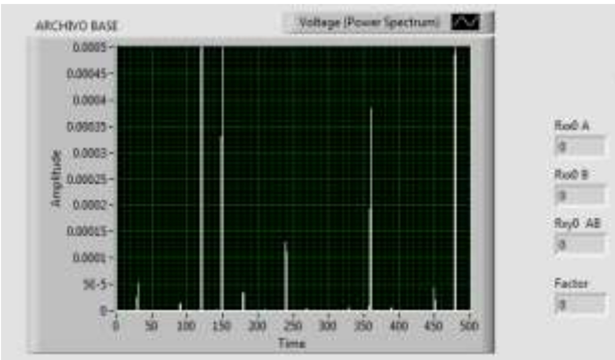

Figure 8 Front Panel developed in LabVIEW *(LabVIEW Handbook, 2022)*

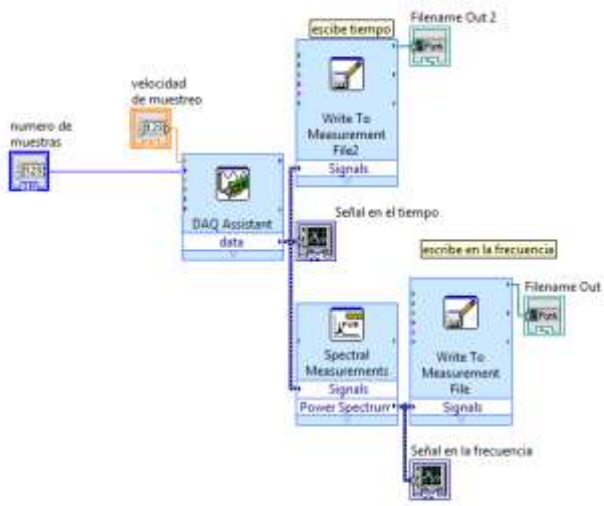

Figure 9 Block diagram panel developed in LabVIEW *(LabVIEW Handbook, 2022)*

The icon is the graphical representation of a virtual instrument, through which a virtual instrument can be represented within another, using it as a function or subroutine. The connector is the representation of the icon that indicates the connection terminals through which we can pass the input data to a virtual instrument and read its outputs when it is used inside another virtual instrument. The icon is the graphical representation and the connector is the input and output terminals of a virtual instrument to be used as a virtual sub-instrument. Figure 10 shows an example of an icon and connector used in LabVIEW (Trujillo, 2006; LabVIEW Handbook, 2022).

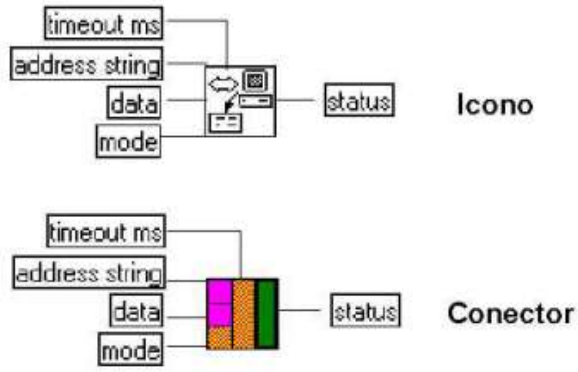

Figure 10 Icon and connector in LabVIEW *(LabVIEW Handbook, 2022)*

Methodology

Materials

-
- Electronic material necessary for the 5 Vdc regulator (diagram in Figure 5).
- Electronic material necessary for the current regulator (diagram in Figure 6)
- Multifunctional DAQ card USB-6008 (characteristics in section 5)
- Laptop

LabView software version 2020 or higher (see section 6) -Miscellaneous and miscellaneous materials and equipment (see section 6)

Miscellaneous materials and consumables –

Methods

Figure 11 shows the block diagram of the implemented methodology.

Hardware developed

A power supply is developed that is fed from the line voltage (120 VAC) and provides a regulated voltage of 5 Vdc (see section 3). The voltage regulator feeds the current regulator which is set to circulate a current of 2 mA (milliamps) through the fuel level sensor under inspection (see section 4). The circuit is closed at the ground which is connected to the negative of the power supply. The voltage drop present at the ends of the fuel level sensor is fed to a differential input of the NI USB-6008 DAQ card for digitization. The NI USB-6008 card digitizes the data fed to the differential analog input with a sampling rate of 10 000 samples/second and 12 bits of resolution (see section 5).

The digitized data is fed to the laptop via a USB port. The laptop controls the USB-6008 also through this port. The laptop is loaded with LabVIEW 2020 software (see section 6). Under this platform an algorithm is implemented for data acquisition and processing, and for the generation of a graph of the sensor resistance VS float position. With this graph it is possible to detect failure points in the inspected sensor.

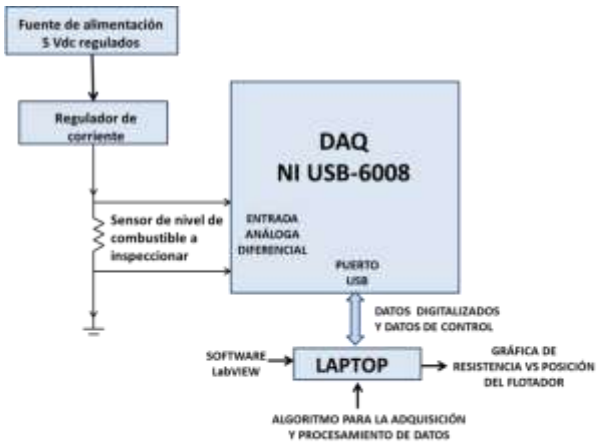

Figure 11 Block diagram of the implemented methodology

Developed algorithm

Figure 12 shows the algorithm for data acquisition and processing developed. The algorithm is written under the LabView platform version 2020. The algorithm configures the NI USB-6008 DAQ card to acquire data with a sampling rate of 10 000 samples/second. Six seconds of data are acquired at a time as the fuel level sensor dipstick is moved from the position of lowest resistance to the position of highest resistance. The acquired data (60 000 data) are samples of the voltage present between the ends of the sensor, and are stored in a data vector as indicated by formula (4) (Proakis, 2007).

$$V = \{V_1, V_2, V_3, \dots\dots\dots, V_n\} \quad (4)$$

Where V= vector of voltage data according to the position of the sensor rod; and n= element number of the vector..

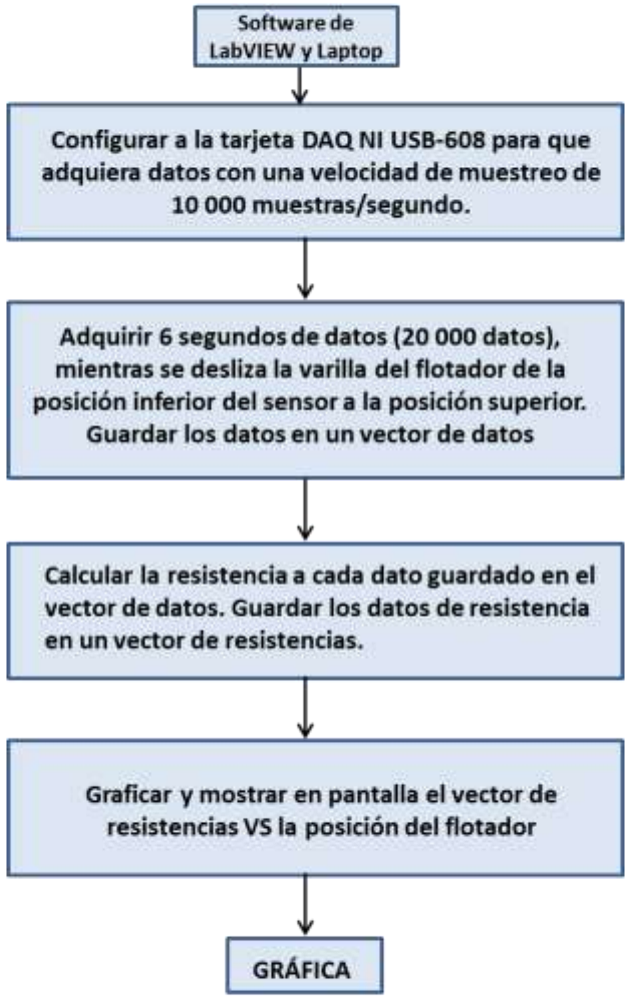

Figure 12 Algorithm developed for data acquisition and processing

The current regulator is known to circulate a constant current of 2 mA (0.002 amperes) through the sensor. This current is always 2 mA regardless of the resistance value of the sensor. The resistance value is then calculated for each V data using Ohm's law as shown in equation (5) (Malvino, 1999).

$$R = \frac{V}{0.002} \quad (5)$$

Where R= vector of resistance data according to the position of the sensor rod.

Finally, the plot of R data as a function of the number of samples is generated. Equation (6) describes the content of R (Proakis, 2007).

$$R = \{R_1, R_2, R_3, \dots\dots\dots, R_n\} \quad (6)$$

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Results

Developed fuel level sensor inspection system

Figure 13 illustrates the developed fuel level sensor inspection system.

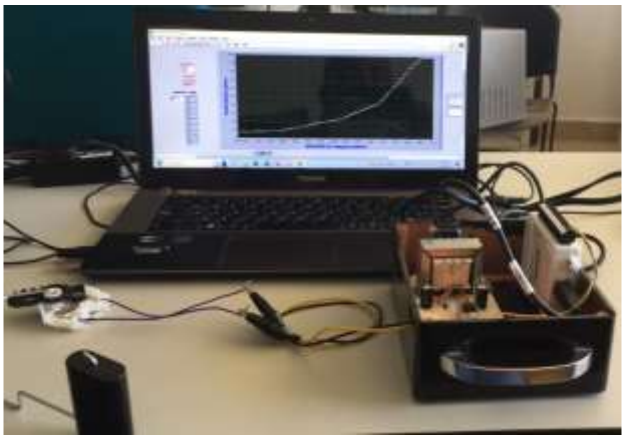

Figure 13 Developed system for fuel level sensor inspection

In the BorgWarner company, fuel level sensors of 2 types are manufactured. Table 1 shows the minimum and maximum resistances of each type of sensor.

Sensor type	Minimum resistance	Maximum resistance
Type 1	10 Ω	150 Ω
Type 2	50 Ω	1000 Ω

Table 1 Minimum and maximum resistances for each type of sensor

Figure 14 illustrates the graph shown by the system when inspecting a fuel level sensor type 2 that is in good condition. The information provided by the graph is:

On the X axis.- Samples plotted with an existing time between samples of 0.1 milliseconds. This information allows to estimate in which sample number a failure occurs and which is its duration time.

On the Y-axis - Resistance presented by the sensor for each of the samples; it also describes how many seconds data were acquired (this parameter can be changed); and how many samples were acquired during the inspection exercise.

Also illustrated is the vector R which contains which resistance value was calculated for each of the acquired samples. In this vector it can be consulted what resistance value each sample presents, which is of great help to determine the points of failure in the fuel level sensor being inspected.

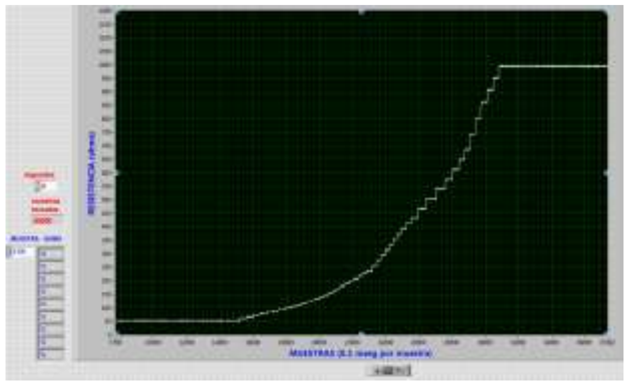

Figure 14 Samples VS Resistance graph of a type two sensor in good condition

The system software allows selecting those segments that are of interest for sensor inspection. Figure 15 illustrates only the area of interest to the quality inspector during the sensor inspection shown in Figure 14.

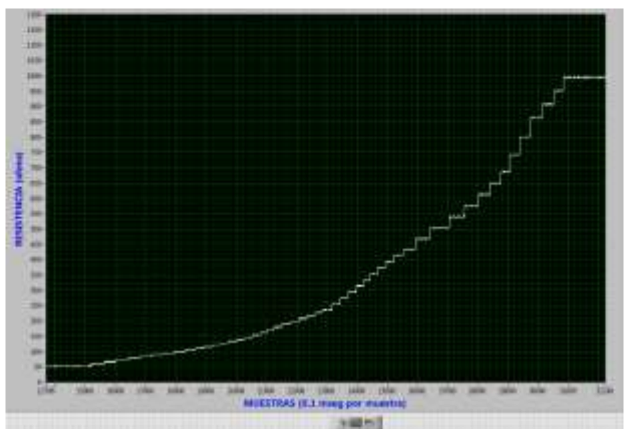

Figure 15 Selection of the segment of interest during the sensor inspection

Figure 16 illustrates the graph the system produces when a type two fuel level sensor has multiple points of failure.

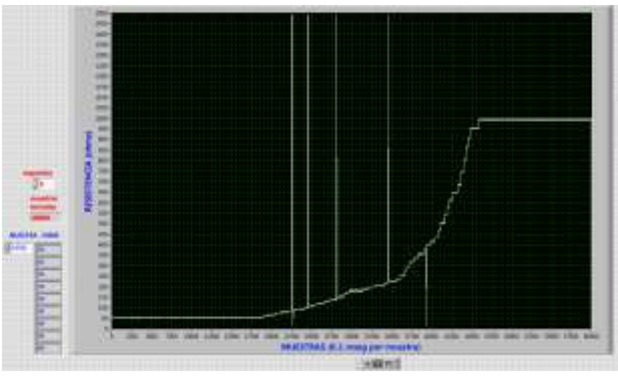

Figure 16 Plot of a fuel level sensor with five points of failure

It can be seen that the sensor has five failure points. The system software allows zooming and detailing of fault points. Figure 17 illustrates the selection of a fault point present in the graph of Figure 16. The information obtained from this graph is that the fault started at sample 28104 (143 Ω) and ended at sample 28112 (148 Ω), i.e. it lasted 8 samples equivalent to 8 milliseconds. In the vector R, the resistance value for each sample can be consulted, which allows to know what resistance value has the beginning of the failure point and the end of it.

Taking these values as reference points it is possible to know with the help of a microscope the causes that originate the failure in the fuel level sensor such as dirt, defective resistive material, deformities in the materials, etc. Knowing the root cause of the defects allows adjustments to be made to the processes and materials used to achieve the goal of zero defects.

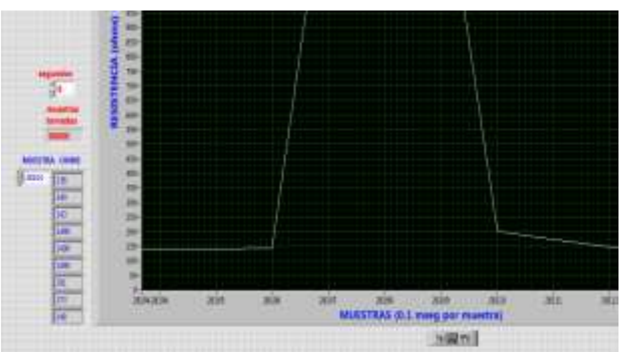

Figure 17 Detailed graph of a failure point

Figure 18 illustrates the graph produced by the system during the inspection of a type one fuel level sensor. Multiple points of failure are observed. The system software allows detailing each of these points to know at what resistance value each failure began and ended; and thus determine the causes of these.

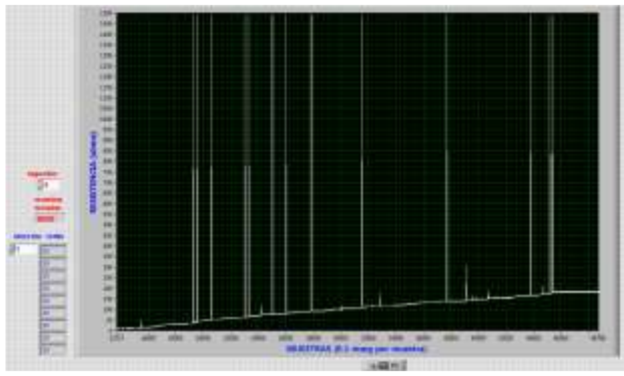

Figure 18 Graph of a fuel level sensor type one with multiple failure points.

Conclusions

A system for the inspection of defective fuel level sensors was developed and implemented for the quality department of the BorgWarner Chihuahua plant. The department did not have a technological system for this purpose. By carrying out the validation of the system for the inspection of fuel level sensors, it is clear that it works well, which makes it valuable for use in the company's quality department. The implementation of the system in the quality department allows to inspect the defective fuel level sensors in order to know the root cause of the failures. This will allow adjustments to be made in the selection of appropriate materials and processes to increase the quality and decrease the defects of the fuel level sensors that are manufactured.

Acknowledgements

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Design of a mechanism for applying sensitive films to gas sensors based on quartz crystal resonators

Diseño de un mecanismo para aplicación de películas sensibles a sensores de gas basados en resonadores de cristal de cuarzo

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Abstract

Gas sensors based on quartz crystal microbalance (QCM) are used to measure mass changes through frequency shifts, using the piezoelectric principle. These sensors are employed in odor detection and are essential for the development of electronic noses. For optimal performance, a sensitive film is applied to the surface of the crystal electrode, which is compatible with a specific compound. There are different methods of film deposition: ultrasonic atomization, spray coating, and casting. The casting method, which involves the manual application of sensitive films using a micropipette, is the most commonly used. However, it is not reproducible. To improve the casting method, a mechanism is proposed as a preliminary platform for a sensitive film application system. The objective is to achieve reproducibility in the construction of gas sensors by applying ethyl cellulose sensitive films onto the sensor surface, thereby reducing the margin of error. Tests were performed on the mechanism to verify the capabilities of the system for the deposition of sensing films using joysticks based on the resistance change principle.

Mechanisms, QCM, CAD

Resumen

Los sensores de gas de microbalanzas de cristal de cuarzo (QCM) son utilizados para medir cambios de masa a través de cambios de frecuencia, utilizando el principio piezoeléctrico, los cuales son usados para la detección de olores, por tanto, son requeridos para el desarrollo de narices electrónicas. Para un funcionamiento óptimo, se aplica una película sensible sobre la superficie del electrodo del cristal que sea afín a algún compuesto determinado. Existen métodos de aplicación: atomización ultrasónica, spray o casting. Este último es el más utilizado los otros métodos el cual, consiste en la aplicación manual de películas sensibles a través de una micropipeta. Sin embargo, no es reproducible. Para poder mejorar el uso del método casting se propone un mecanismo como plataforma preliminar de un sistema de aplicación de películas sensibles con el propósito de aplicar películas sensibles de etíl celulosa sobre la superficie de sensores de gas para lograr obtener una reproducibilidad en la construcción de sensores que sea capaz de reducir el margen de error. Se realizaron pruebas del mecanismo para verificar el alcance del sistema para la aplicación de las películas sensibles mediante el uso de palancas de control con el principio de cambio de resistencia.

Mecanismos, QCM, CAD

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Introduction

Quartz Crystal Microbalance QCM gas sensors have been widely used in the last decades, due to a wide field of applications, since these sensors are highly precise mass sensors, which are commonly used in the detection of analytes in gaseous and liquid phases, since they contribute with the detection of chemical and biological substances [1]. In order to obtain the optimal functionality of the Quartz Crystal Microbalance QCM gas sensors, a sensing film must be applied to absorb the gas molecules of a particular volatile organic compound for a proper reaction such as ethanol.

This reacts adequate with a dissolution of ethyl cellulose mixed in chloroform as sensing film. This film must be placed on the QCM sensor surface electrode, using several applying methods, such as, ultrasonic atomization, spray. Although, these methods are quite effective they tend to be complex in their application. On the other hand, the casting method is the approach must use for this purpose, which consist in applying two microliters of the sensing film using a micropipette. The inconvenience of this method is the low reproducibility. Therefore, it had been developed the design and manufacture of a mechanism to control automatically such task. (Alanazi *et al* [2023])

A mechanism is a mechanical device with the purpose of transfer a movement and/or a force from a source to an output, where under certain circumstances such transfer could be performed, however, during the development of any mechanism there are areas of opportunities to seek the best design to obtain the long-term device and a reduction of costs for the implementation that can make its manufacture profitable. The mechanism was designed using the software of design assisted CATIA computer (Torrecilla 2013).

In this case, the mechanism to develop is a sensing film sample injector of ethyl cellulose for the adsorption and absorption of ethanol molecules trough QCM gas sensors with the purpose of detect several parts per million (ppm) gases in a controlled environment.

The goal to achieve of the mechanism, is the precision, specifically in the deposition sensing films of ethyl cellulose, since this procedure was performed manually. Although, the results obtained were satisfying, there were a low reproducibility in the application of the sensing films in several sensors (Hu *et al* [2020]).

Experimental Setup

For the development and implementation of the system, the block diagram proposed is shown in Figure 1, which consist of the main mechanism and two sub-mechanism that are responsible of activate a micropipette and transport the QCM sensors through a displacement device.

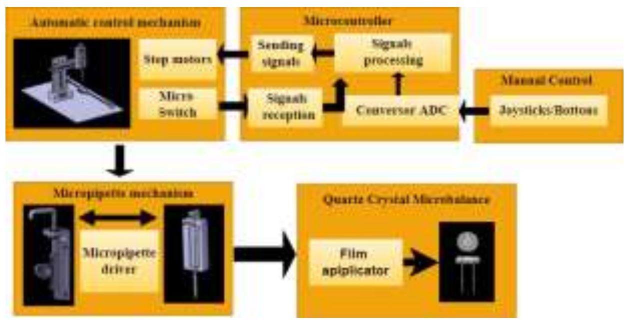

Figure 1 Block Diagram of the system
Source: Own

A cartesian mechanism was designed to be able to deposit a sensing fil if ethyl cellulose using a micropipette which it is moved by two axes and these are driven using stepper motors controlled by a joystick that use the principle of a resistance variation sending the correct signal sequence to move the motors clockwise or counterclockwise and this is possible developing a firmware (García 2009) within a microcontroller (PIC16f877A (Microchip 2002)) used as a processing programmable device to acquire and convert the analog signals from the joysticks to digital registers. In this case, a 10-bit resolution ADC were used.

The previous procedure it is necessary to obtain the desired operation of the mechanism. The motors were activated using electronic power devices. As final product all the components were assembled, resulting in a cartesian mechanism with precise movement using stepper motors, in such a way fulfills the desired task.

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Finally, in this work is presented the design, development and implementation of a two-axis mechanism with the purpose of activate the injection of a micropipette to deposit a solution on the electrode of a QCM gas sensor. In this particular case, the activation of the mechanism is activated manually using a microcontroller and a joystick proving that the system performance was satisfactory.

Experimental setup

Prototype: Sample injector on a QCM.

The mechanism has two degrees of freedom, since it has linear movements in the X and Z axis, these performed movements between one point an another is based on interpolations to ensure its location.

It was not necessary the addition of movement in Y axis, since the second mechanism is independent, described as linear conveyor of the QCM sensor, is in charge of move the components over the Y axis to facilitate the design in both mechanisms and to be able to manipulate the components as can be observed in Figure 2.

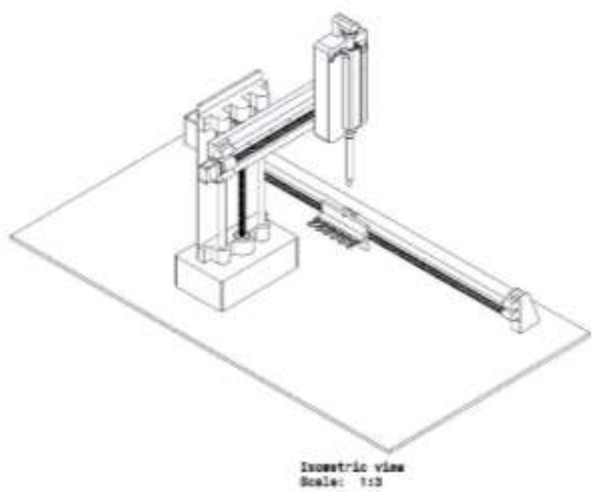

Figure 2 Sensing film depositor prototype
Source: Own Elaboration

Rack-Pinion Mechanism

To activate the micropipette which is the device that deposit the sensing film in the QCM sensor, the mechanism known as Rack-Pinion mechanism was designed. Figure 3, shows a pinion pitch relationship, number of teeth ant tooth module to be able to convert rotational in to rectilinear movements.

The following formula is used to calculate the linear displacement length as a result of the multiplication of the number of teeth (Zp) times the revolutions per minute (Wp) times step (P) of the gear per revolution obtaining:

$$L = Zp * Wp * P$$

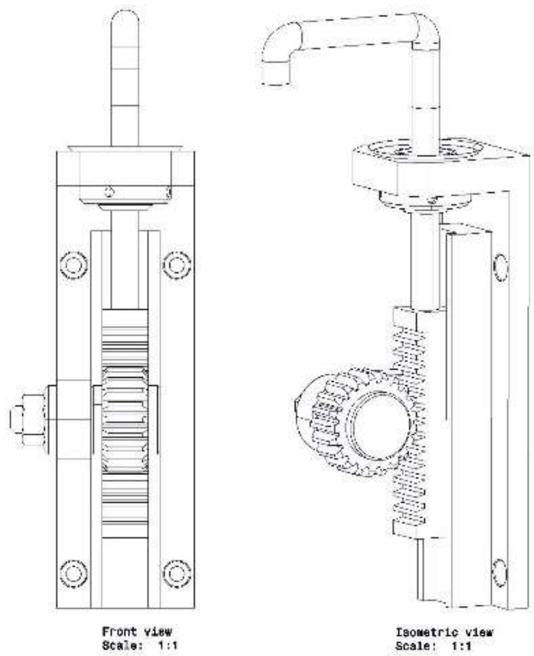

Figura 3 Rack-Pinion mechanism
Source: Own Elaboration

On the other hand, the sensing film will be deposited on the center of the electrode applying a sample of 2 μl of ethyl-cellulose solution. The crystal typically has a ratio of 4.3 mm, as can be observed in Figure 4 with the purpose of mentioned above, which will generate a frequency decrement in the fundamental frequency of the sensor, according of the film thickness, the QCM sensors use the piezoelectric principle.

In order to measure the sensor response, the use of a frequency counter is necessary to detect the frequency shifts when a sample of a volatile organic compound is applied. The Sauerbrey equation is used for this purpose (Sauerbrey *et al* [1959]).

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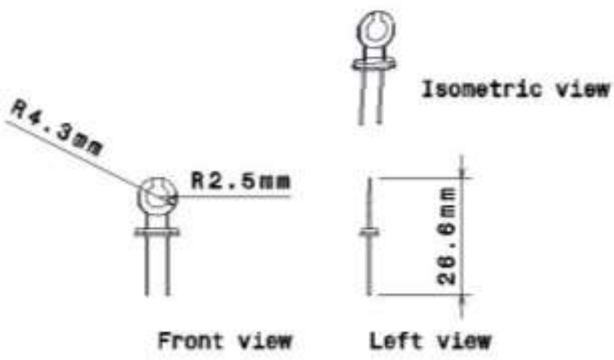

Figure 4 Quartz Crystal Microbalance (QCM)
Source: Own Elaboration

Linear QCM sensor transporter

For the development of this particular mechanism that performs along with the injection mechanism, it was necessary to calculate the design specifications such as the worm gear screw as is shown in Figure 5.

Calculations expressions for linear movements were used, however, the screw velocity must be expressed in revolutions per minute (rpm). The following expression is used for the unit conversion:

$$n = \frac{v}{p}$$

Being:
n: turning speed (rpm),
V: linear velocity (mm/min),
P: step (mm).

For the mean velocity, the following expression were used:

$$n_{mean} = \frac{n_{minimum} + 2 * n_{maximum}}{3}$$

Being:
n-minimum: minimum speed of the section (rpm)
n-maximum: maximum speed of the section (rpm)

Once these values were known, to mobilize the screw where the load is minimal the adequate motor calculation is required. Therefore, an 8 mm (commercial use) screw was selected using the following equation:

The performance η1, is in the range of 0.85-0.95.

$$n_1 = \frac{1 - \mu * tan\varphi}{1 + \left(\frac{\mu}{tan\varphi}\right)}$$

Being:
μ: friction coefficient, 0,003 ÷ 0,01.
P: step.
dn: Nominal diameter of the screw thread.
φ: helix angle.

For the helix angle the following relation is used:

$$tan\varphi = \frac{P}{\pi * d_n}$$

The applied torque TL (Nm) that must be used to the screw is:

$$T_L = \frac{F * P}{200 * \pi * n_1}$$

Being:
F: obtained linear load (N).
P: step of the thread (mm).

The power required to drive the screw PL (KW) is:

$$P_L = \frac{T_L * n * 2 * \pi}{60 * 1000}$$

Being:
n: revolutions per minute (rpm).

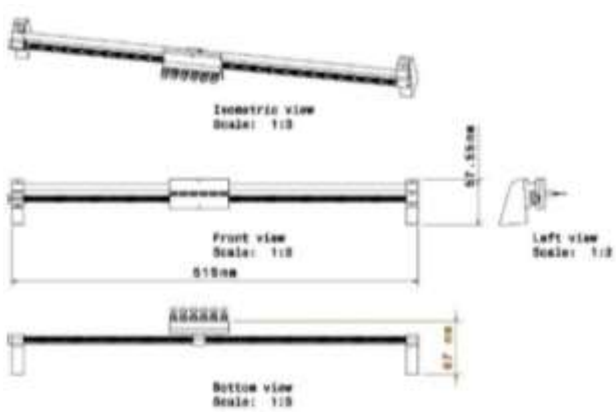

Figure 5 QCM Linear transportator
Source: Own Elaboration

With the screw characteristics obtained by the calculations, it was performed a search for the proper screw that accomplishes the specifications require.

Linear axis

The final component of the proposed prototype are the linear guides that are implemented along a worm gear with the help of a bench mobilize any object attached to it. The dimensions were calculated as well as the linear transporter of the QCM sensors. The design is shown in Figure 6.

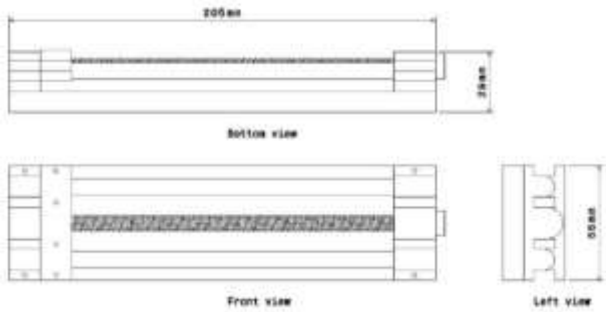

Figura 6 Linear axis of worm gear
Source: Own Elaboration

For the movement of the mechanism axis, stepper motors were used with a load capacity approximately of 3.5 Kg, which is the necessary torque to move the mechanism without causing an overexertion than could cause an overheating in the motors.

For the preliminary manipulation of the stepper motors, a firmware development was performed. In this case, a full step mode was used in order to observe the relation of the motor spin with the step of the worm gear, and thus, determine the exact distance that the axis will move. In order to obtain an accurate displacement of the axis a half step mode should be used, although in this case, is only a preliminary experiment.

Once the motor sequence is set, a firmware was developed using a microcontroller. The step number for the axis to travel is 200, since the motor step resolution is of 1.8°.

A joystick was used as a preliminary experimental setup, in order to manipulate manually the axis displacements of the system. The joystick is basically a set of two potentiometers, where each one of them move an axis. Therefore, an analog to digital converter (ADC) is used to process the signal from the joystick.

The ADC has a 10-bit resolution, which is considered in the programming for the manipulation of the motor to displace the corresponding axis. Furthermore, a speed control considered or the manual manipulation. (Technology Inc [2002])

Micropipette

The principal instrument of the system as shown in Figure 7 is the micropipette, this with the purpose of being certain of an adequate performance of the system. In this process the micropipette a high precision on the deposition of the sensing films as well as the position of application are imperative in order to increase the reproducibility of the QCM sensors. The sample for the deposition is approximately 2 μl. Furthermore, a sample of ethanol will be applied in a measurement chamber with a temperature controlled of approximately of 20 °C to reduce the error percentage, between applications, since the ethanol density is preserved at 0.797 g/cm^3.

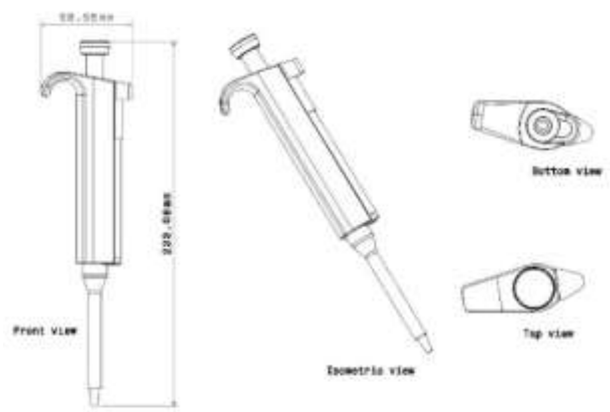

Figure 7 Micropipette p20 (0.5 - 10 μl)
Source: Científica Vela Quin S de R.L de C.V

For the development of the system an analogue micropipette was used, the developed mechanism presses the plunger to collect the sample solution from a bial and for the deposition of the sample. The collected volume is fixed.

Hardware and software development

For the microcontroller programming, a flux diagram was developed to show the interpretation of the firmware.

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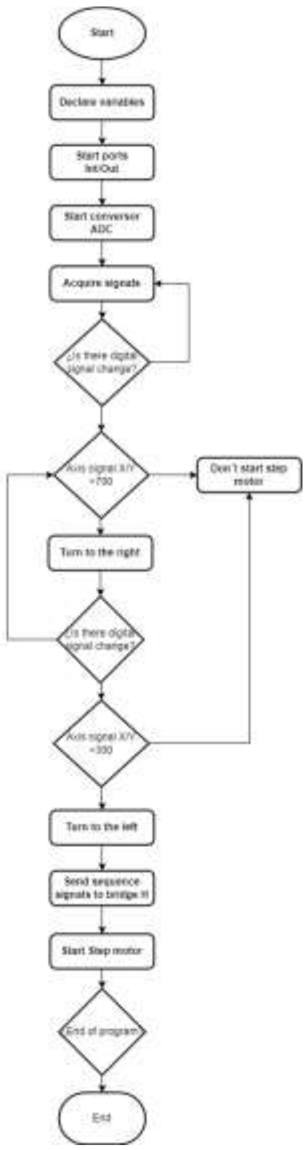

Figure 8 Flux diagram of the firmware developed
Source: Own Elaboration

The diagram describes the logic programming, in this case the commands that are executed according to the input conditions. When the joystick is turned to the right the stepper motor is displaced over the X axis using the full step mode to the right. If the joystick is moved to the left the stepper motor displace the X axis to the right. On the other hand, if the joystick is turner up or down the other stepper motor activates the Z axis displacing them in the corresponding case. Figure 8 shows the flux diagram of the firmware development (Tojeiro Calaza [2009], Schneider Electric Motion [2011]).

The electronic diagram used for the electronic system is shown in Figure 9. Potentiometers were used as the joystick. It can be observed the connections used at the mechanism. An LCD display is used to visualize the movement of the mechanism axis.

To activate the stepper motors, L298 power driver modules were used and these could manipulate the axis X and Z as described above (García [2009]).

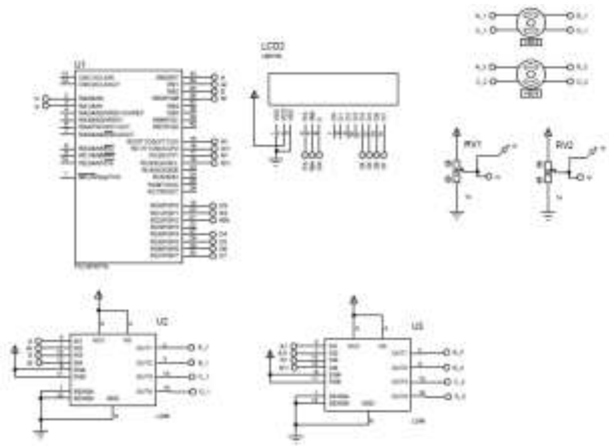

Figure 9 Electronic diagram
Source: Own Elaboration

In addition, to manufacture the mechanism based on the CAD designed in CATIA, a 3D printer was used in order to reduce costs. In Figure 10, a preview can be observed. Using the CURA software the pieces were manufactured using ABS filament due to the physical characteristics as mechanical resistance (Pérez [2018], Palacios [2019]).

Figure 10 Analysed rowlock in Ultimaker Cura
Source: Own Elaboration

Results

Once the manufacture of the 3D printer pieces was finished, the assemble was performed, as well as some elements that were acquired commercially. In this case, aluminum screeds were used due to the mechanical resistance for better support of the axes of the worm gears, as well as the lightness to avoid additional load on the stepper motor.

The ABS material offers more benefits compared to other materials and the result in this system assembled are shown in Figure 11.

Figure 11 Final assembly of linear axis
Source: Own Elaboration

As we can observe in Figure 12, we obtain the final assembly of the quartz crystal microbalance transporter, which operates on the same principle as the "Z" and "X" axes for crystal displacement. The position of the QCM carrier is related to the position of the micropipette, which is displaced by the aforementioned axes. The crystal's position is determined by the formulas discussed in the linear transporter section, which consider the angular velocity of the screw and its thread pitch.

Figure 12 Final assembly of linear axis of worm gear
Source: Own Elaboration

Once the linear axis was assembled the complete mechanism was integrated having as support the aluminum screeds previously welded to warranty a better fastening of the components as well as the printed components added to the aluminum using 4mm Allen screws as can be observed in Figure 13.

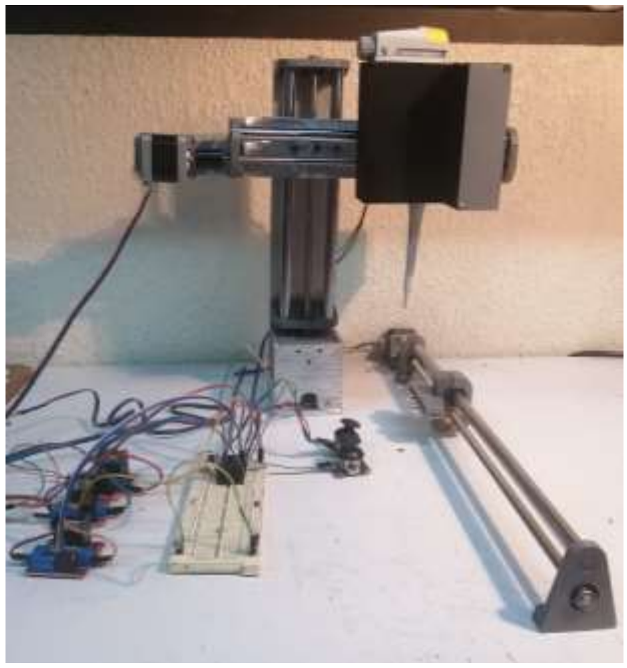

Figure 13 Final assembly
Source: Own Elaboration

Finally, the complete assembled system is shown in Figure 14 with the electronic control circuit to activate the actuators through the microcontroller. Since the system is manipulate manually there are no a proper control on the manipulation of the mechanism at the axis displacements. As future work a vision system will be implemented to control the complete system.

Nevertheless, with a manual control the designed mechanism shows an effective displacement with the design and materials used for the implementation of the system. Therefore, the systems show satisfactory results.

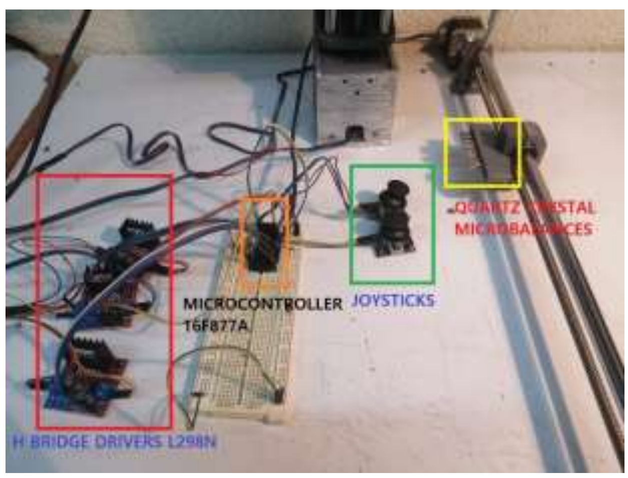

Figure 14 Control system
Source: Own Elaboration

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Conclusions

A robust mechanism had been implemented, the system is capable to perform a casting deposition of sensing films more accurately, which will be used as a platform of applications for such purpose.

According with the forecast if mechanical resistance of the printed pieces of the prototype, they perform the desired tasks, although further tests need to be performed to complete the full cycle of work.

During the assembly of the mechanism, we found areas of opportunity, such as to improve the balance of the system and avoid operation errors.

The design of some components was improved in order to increase the loading support performed by the mechanical elements.

An open loop control was developed for operation tests to obtain a better programming of the actuators to scale the system for a fully automated system to reduce errors under several circumstances in order to achieve a high reproducibility of the QCM gas sensor, as well as to avoid the waste of solution used form the deposition of sensing films.

Future work

Using the current results, it will be possible to continue the improvement of the system to a fully automated using a LabVIEW interface capable of decide the movement of the mechanism using a vision system through a web cam. Using this vision technique, the system will have the ability to generate a coordinate to move the mechanism to the corresponding QCM sensor and deposit the sensing film. With the development of the complete system the reproducibility of the QCM will increase, generating a reliable system.

Once the casting method was automated it could be developed a system robust enough to perform such activity and thus, reduce the percentage of human error. Since the mechanism will work automatically, a user interface to control the movements of the mechanism and execute efficiently the deposition of the sensing obtaining a high reproducibility in such deposition. In order to prove de efficiency in the reproducibility of the sensing films deposited on the sensor substrate using the casting method, a fundamental principle in statistics is contemplated, such as the Gaussian distribution, which lets us know that there are variables in the way in which the sensitive film is distributed, as well as its location for what it is. that the purpose of the mechanism is justified in a better way so that this variety is reduced as much as possible.

Currently several experimental setups had been performed in order to improve the mechanism of the activation of the micropipette.

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Development of a blueberry sorting machine

Desarrollo de una máquina seleccionadora de blueberry

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Abstract

In the municipality of Zacatlan de las Manzanas located in the Sierra Norte of the State of Puebla, many families are dedicated to grow blueberry, basically at the time of cutting the fruit or harvesting the area is accessed with baskets for collection, then begins the process that focuses on the selection of the fruit by size, this task is very late and therefore tedious especially if it is done without using tools, on the other hand should take care of the handling of the fruit to be kept in optimal conditions. The objective of this article is the development of a blueberry sorting machine from the design of a mechanical-electrical system using CAD software and simulation, to its operation to ensure the correct selection, better handling of the fruit and reduce time and movements, in order to improve the process and scheduled delivery to the customer. With this project it is intended that the blueberry sorting machine has advantages over the manual selection of the fruit in the size classification by means of a simple system for this process.

Machine, Sorter, Blueberry

Resumen

En el municipio de Zacatlán de las Manzanas ubicado en la Sierra Norte del Estado de Puebla muchas familias se dedican a cultivar “blueberry”, básicamente al momento del corte de la fruta o cosecha se accede al área con cestos para la recolección, posteriormente se inicia el proceso que se enfoca en la selección del fruto por tamaño, dicha tarea es muy tardada y por lo tanto tediosa sobre todo si se realiza sin utilizar herramientas, por otro lado se debe cuidar la manipulación del fruto para que se conserve en óptimas condiciones. El presente artículo tiene como objetivo el desarrollo de una máquina seleccionadora de blueberry desde el diseño de un sistema mecánico-eléctrico utilizando software de CAD y simulación, hasta su puesta en operación para garantizar la selección correcta, una mejor manipulación del fruto y reducir los tiempos y movimientos, con la finalidad de mejorar el proceso y entrega programada al cliente. Con este proyecto se pretende que la máquina seleccionadora de blueberry presente ventajas respecto a la selección manual del fruto en la clasificación por tamaños mediante un sistema sencillo para este proceso.

Máquina, Seleccionadora, Blueberry

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Introduction

Bilberry (Vaccinium myrtillus L.) is a well-known deciduous dwarf shrub that grows mainly in cold temperate regions and mountainous areas of Europe and Asia (Zorenc et al., 2017) and in recent years the cultivated area of this species has increased markedly as a result of the high demand for the fruit (Intagri, 2016).

Today, blueberry cultivation is widespread in countries such as China, Japan, Chile, New Zealand, Argentina and Mexico. Globally, the area has increased by approximately 15,000 hectares in just 4 years from 2010 to 2014. This growth has been observed in Mexico, driven mainly by the benefits of being close to the U.S. market and by the climatic diversity, as only in 2015 a production of 15,489 tons with an export value of US$121 million was reported (Intagri, 2016). The climatic conditions and proximity to the demanding market make blueberries a highly profitable crop in Mexico.

Blueberry is a berry type fruit in a spherical shape of one or two centimeters, which has many properties: "It is a fruit rich in fiber, astringent, diuretic and also has vitamin C and vitamin K. It is a natural antioxidant and also helps maintain optimal brain function and vision. It is a natural antioxidant and also helps to maintain in optimal conditions the functioning of the brain and eyesight," he added (González, 2012).

In the Sierra Norte of the State of Puebla, particularly in the municipality of Zacatlán, they have focused over time on producing blueberries, which is why in 2009 they became the first in the entire region to receive the certificate for organic crops in their entirety: "Currently, they are the largest producers in Puebla, with 88 tons exported to the United States and Canada" (González, 2012). The growing demand for products in international markets makes compliance with increasingly demanding quality standards mandatory, which is why producers in these communities have found it necessary to acquire machines that compensate for the lack of labor, save time and increase the quality of the final products compared to conventional manual processes (Shimabukuro, 2020).

Several methods have been developed for fruit sorting according to a variety of criteria, based on both mechanical and electronic principles. Therefore, there is a need for quality assurance in the blueberry sorting process prior to packing, especially for small and medium-sized growers (Shimabukuro, 2020).

The constant search for innovative solutions in the agricultural industry has led to the development of mechatronic technologies that optimize fruit selection and harvesting processes. In line with this trend, the thesis entitled "Design of a mechatronic system for blueberry selection" by (Rudas, C. A. 2015), represents a valuable contribution in the search for improvements in the efficiency and precision of blueberry selection in the context of the Pontificia Universidad Católica del Perú.

Mechatronic systems for blueberry sorting by size are currently available. For this purpose, a search of the state of the art is presented: bibliographic references, utility models and patents of invention on sorting machines dedicated to blueberry sorting.

Mechanical methods

Diverging rollers or belts: Two rotating rollers, inclined with respect to the vertical and separated from each other, transport the fruit in the central space. The separation at the upper end is smaller than at the lower end, resulting in a variable space between rollers. Thus, small fruits will fall before large fruits, giving the possibility of sorting them in multiple size ranges.

Variable spacing rollers: Multiple free-spinning rollers form a transport platform for the fruit. The rollers are coupled to a scissor-type chain, which generates the travel motion by means of a motor. The chain is contained in guides with decreasing spacing, so that the scissor links compress vertically and expand horizontally, causing the rollers to progressively separate.

Screens, meshes, sieves: A plate with holes of variable diameter (sieve) or a wire mesh, allow to separate fruits of larger and smaller size than the size established in the mesh or sieve.

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Computer visión

From an image of the fruit captured online, parameters associated with fruit size can be estimated, among the most common being diameter, projected area, length of longitudinal and transverse axes, and aspect ratio (Roberto Shimabukuro, 2020).

In the field of ecological research, the study by (Chang, Wang, Yang, and Qin 2023) stands out as a significant breakthrough in the assessment of ecological suitability of blueberries. Through their work entitled "An improved CatBoost-based classification model for the ecological suitability of blueberries", the authors demonstrate the application of advanced machine learning techniques in predicting the suitability of environments for growing this valuable fruit.

In the dynamic field of food research, the collaborative work of (Lippi, Senger, Karhu, Mezzetti, Cianciabella, Denoyes, Chiara et al. 2023) stands as an essential contribution. Through their study entitled "Development and Validation of a Multilingual Lexicon as a Key Tool for Sensory Analysis and Consumer Testing of Blueberry and Raspberry Fruits," the researchers have charted a path toward a deeper and more accurate understanding of the sensory characteristics of these prized fruits.

The purpose of this project is to detail a methodology for the development of a blueberry sorting machine according to its size, by means of a mechanical-electrical system. The machine presents a mechanism that fulfills an adequate dosage by size and the preservation of the texture of the fruit. This mechanical system was developed using SolidWorks design software, meeting the following specific objectives:

- Collect information on fruit specification.
- Collect information on the standards or type of fruit grading.
- Propose a design for the construction of the sorting machine.
- Design the prototypes of pulleys for the elaboration of the machine.
- Investigate the type of belts for the elaboration of the machine.
- Investigate the type of materials to cover the machine.
- Analyze the cost of materials for the machine.
- To facilitate the process of fruit size classification.

Methodology

Most of the inhabitants of Xoxonacatla, Zacatlan, Pue., are dedicated to the harvest of blueberry, this implies that they must apply certain processes to the fruit, one of the manual processes that apply is the process of selection of size and category, this process will invest considerable time and complicated because they do it manually, another of the criteria to be taken care of is to maintain a type of powder called (blum), so that the fruit remains in optimal conditions.

The main objective of this project is to design and integrate a blueberry sorting machine, using design and simulation software, to ensure the correct selection, better handling of the fruit and reduce time and movements, in order to improve the process and scheduled delivery to the customer.

For the development of the prototype, the methodology shown in Figure 1 was chosen.

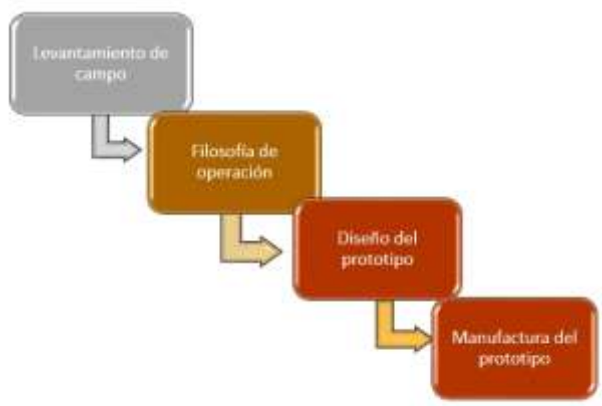

Figure 1 Block diagram of the procedure to follow
Source: Own Elaboration

A. Field survey

Based on the request made by the people interested in the sorter, a type of mechanical-electrical machine is required that can sort blueberry fruit by size, with the objective of reducing a sub-process applied to the product.

To this end, information on the product was gathered and interviews were conducted with producers in order to have a better view of the characteristics required for the proposed design of the sorter.

According to the information obtained, the requirements for the recruiter are as follows:

– That it has the capacity not to damage the fruit.

– Affordable machine in terms of cost for producers.

– Easy to use.

– It must have a durability guarantee of at least 1 to 2 years of service.

– To have 4 types of categories in the selection of fruit size.

– Preserving blum in fruit

B. Operating philosophy.

In this process of researching the characteristics and specifications of blueberry fruit, the standards and types of classification were collected, seeking information from national standards.

For the purposes of the Standard, the terms established in Mexican Standard NMX-FF-129-SCFI-2016 apply, in addition to being complemented by the following:

Basket: Six-sided plastic container with regular shapes that form nets, the upper side being free of these. The dimensions of the basket are: lower base 6.5 cm, upper base 10.0 cm x 10.0 cm, and height 6.0 cm with an approximate capacity of 250 g to 454 g.

Table 1 shows the size standards established for various fruit derived from the fruit:

Size	Equatorial diameter range (cm)		
A	20 mm	or	More
B	16 mm	to	18 mm
C	10 mm	to	14 mm
D	4 mm	to	8 mm

Table 1 Size specifications
Source: Own Elaboration

C. Prototype design

After studying and gathering the necessary information on the requirements and operating philosophy for the blueberry sorting machine, we proceeded to present the prototype of the machine using SolidWorks design software (see Figure 2 and Figure 3), based on the characteristics and observations of the producers.

To this end, the structural, mechanical and electrical model was designed to subsequently build the prototype and run the static and dynamic tests in order to evaluate its performance and, if necessary, reengineer the system.

Figure 2 Final design of the prototype in SolidWorks
Source: Own Elaboration

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Figure 3 Final rendering of the complete machine
Source: Own Elaboration

D. Prototype manufacturing

The following components are used in the manufacture of the sorting machine (See Figure 4):

a. 24-gauge food grade stainless steel sheet, this is used as the coating parts for the equipment.

b. 24 gauge food grade stainless steel tray, primary use is for harvesting the highest quality product with premium designation.

c. Naylamid pulleys with an internal diameter of 1 inch and a thickness of 0.9 mm, this has a long working life, this material is widely used in heavy duty machinery.

d. Floor bearing 1 inch Ucp205-16.

e. 7 inch aluminum pulley type B, this pulley is used mechanically to slow down the motor speed.

f. 1% inch steel PTR pipe.

g. Three-phase electric motor of 1 horsepower.

h. Food grade stainless steel sheet separator. This separator's main function is in the selection area, it plays a very important role, since it prevents the product from mixing with the different sizes of fruit already selected.

i. On, off switch model SP-330 3P 30 A of 3.7 KW, this switch is for industrial use for a better handling of the equipment and for protection.

j. 24 gauge food grade stainless steel tray, this container's main function is the retention of the product in its initial phase.

k. Heavy duty 3x14 gauge cable, which avoids any type of breakage of the cable.

l. Type A39 type B band.

m. 1 ¼ inch PTR rubber buffer, the main use is to keep the equipment stable and avoid vibrations.

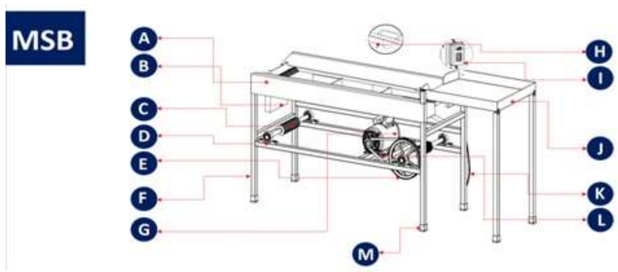


Figure 4 Important components of the sorting machine
Source: Own Elaboration

Results

The process starts at the feeder (starter tray) which contains and supplies the blueberry fruit. The tray supplies the fruit that goes to the circular belts (Polycord) that are fed with the motor (WEG 14347787) that pass through a pulley transmission in speed reduction mode, the speed should not be manipulated as this affects the sorting process.

The belts transport and at the same time make the selection process depositing the fruit in one of four selections separating them by sizes (calibers), the fruit when falling through these separators are transported when falling on a stainless steel sheet at an angle to the right side to fall into a final container, In this are three of the four types of selection and the fourth selection point is at the end of the conveyor belts that falls into a final tray that transports to a container that has the fruit that is not classified in any of the previous sizes, as shown in Figure 5 and Figure 6.

In addition, the machine has an ON/OFF switch on the right side that allows the passage or not of electrical power to the motor.

Figure 5 Finished machine of the sorter
Source: Own Elaboration

Figure 6 Final view of blueberry sorter
Source: Own Elaboration

Scope and limitations of the machine

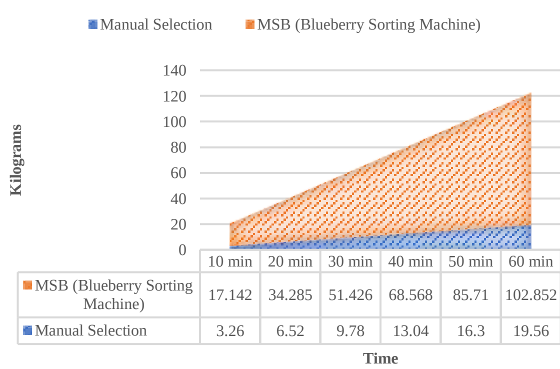
Scope:

- It has a belt system that controls the size of the fruit.
- The electrical source is 127 v.
- The machine has 4 types of fruit classification.
- It speeds up the sub-process and preserves the fruit blum.
- The machine is operated by a trained operator May of age.
- There is a user's manual on the use of the sorting machine.

Limitations:

- Users may only have one sub-process of everything involved in the fruit.
- The configuration of the calibration of the belts can only be done by authorized personnel.
- The project does not contemplate the maintenance of the sorting machine.
- The mobility of the machine is carried out by two or more people.

As for its operation, a comparison was made between the selection process of blueberry, the results are shown in Graph 1, in the blue part shows the selection time manually, in this type of selection the time is a little high and the production was approximately 20 kilograms per sorter in about 1 hour, in the orange part shows the graph of the sorting machine in which clearly shows a significant improvement in production times.



Graph 1 Graph of manual sorting times compared to the sorting machine
Source: Own Elaboration

Once their operation was demonstrated, the blueberry sorting machines (Figure 7) were delivered to the community of Xoxonacatla Zacatlán Zacatlán Puebla, Mexico.

Figure 7 Delivery of the blueberry sorter to growers
Source: Own Elaboration

Acknowledgment

To the community of Xoxonacatla, Zacatlán Puebla for the facilities and support provided for the development of the project, as well as to the Mechatronics Engineering program of the Tecnológico Nacional de México/Instituto Tecnológico Superior de Huauchinango.

Conclusions

A study of the blueberry sorting machine was carried out, which showed advantages over manual fruit selection. That is to say, an optimization in the time and movements in the selection of the fruit for later packaging was obtained, which is a benefit to the producers, in addition to protecting the blum of the fruit in this process.

The fruit selection stage is the most important, which is why a system for this process was integrated. Based on the information collected from the blueberry growers, a structural, mechanical-electrical model was designed and then the prototype was manufactured.

Once the tests were successfully completed, the equipment to be delivered to the producers was manufactured in series, and at the same time the manuals for operation, failure and repair of the equipment, as well as user training, were prepared.

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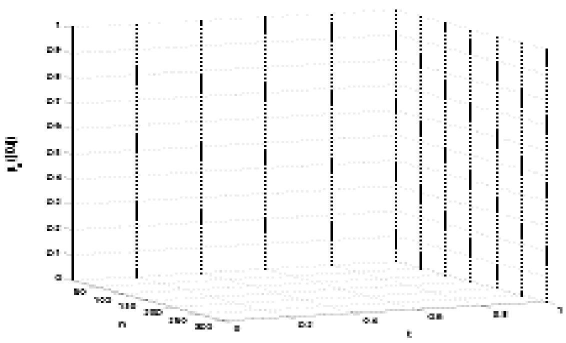

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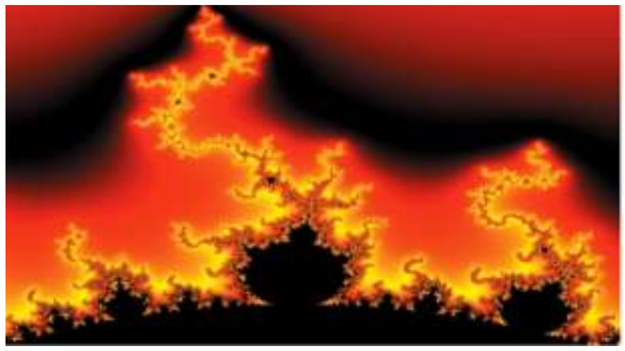

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