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)*

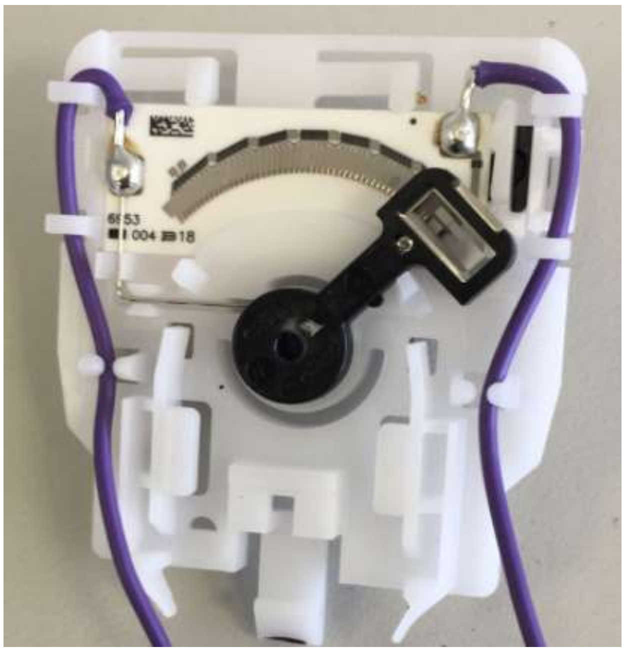

Figure 3 BorgWarner fabricated variable resistor
(BorgWarner Company, 2023)

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).

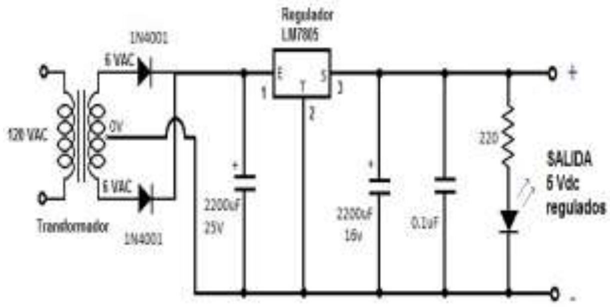

Figure 5 5 Vdc voltage regulator
(Malvino, 1999)

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

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.

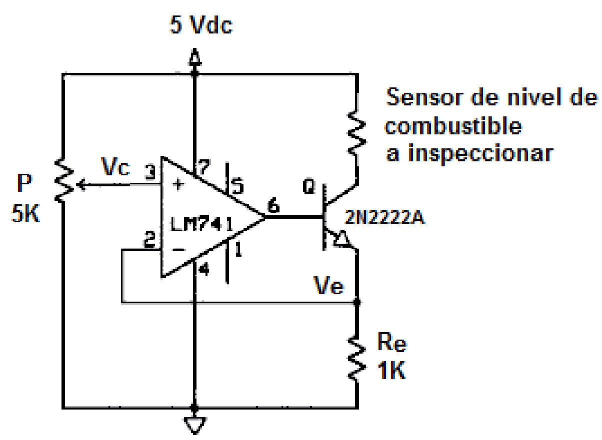

Figure 6 Current regulator
(Malvino, 1999)

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).

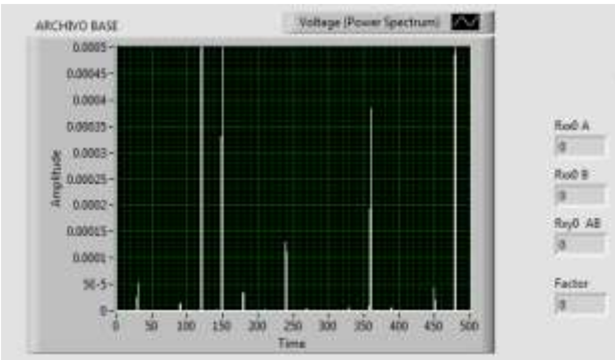

Figure 8 Front Panel developed in LabVIEW *(LabVIEW Handbook, 2022)*

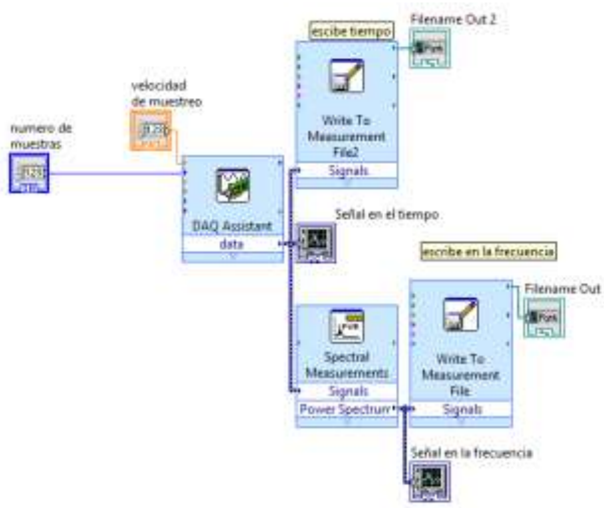

Figure 9 Block diagram panel developed in LabVIEW *(LabVIEW Handbook, 2022)*

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).

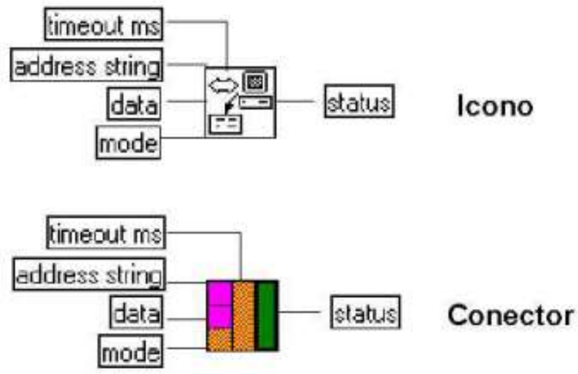

Figure 10 Icon and connector in LabVIEW *(LabVIEW Handbook, 2022)*

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).

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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.

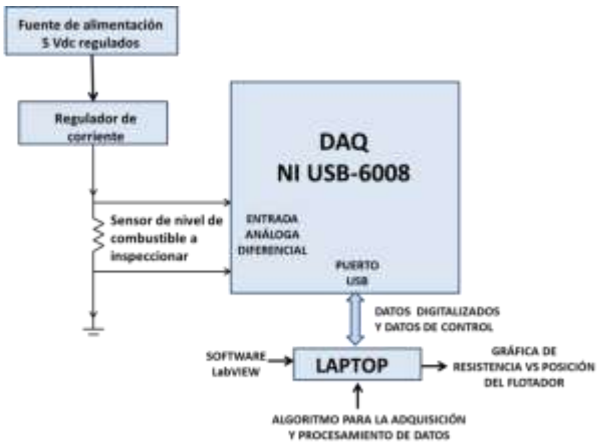

Figure 11 Block diagram of the implemented methodology

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..

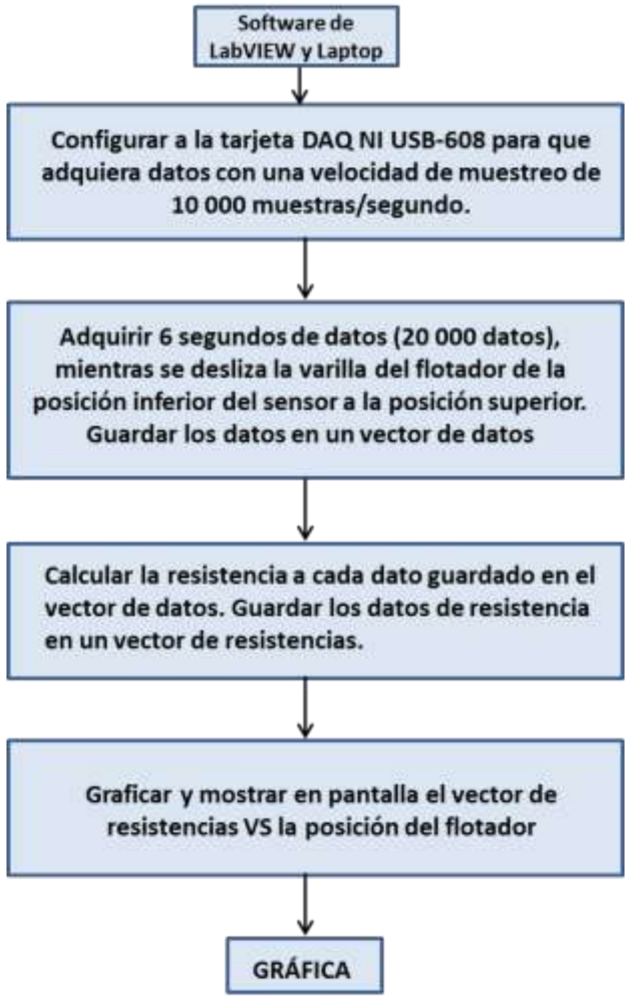

Figure 12 Algorithm developed for data acquisition and processing

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.

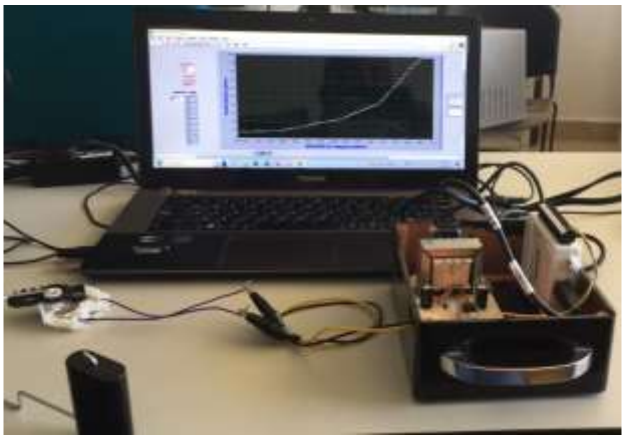

Figure 13 Developed system for fuel level sensor inspection

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.

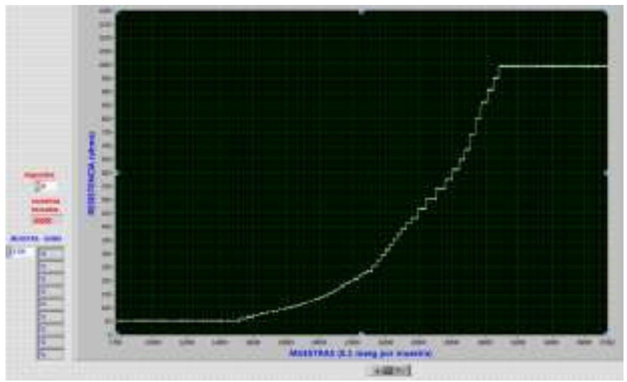

Figure 14 Samples VS Resistance graph of a type two sensor in good condition

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.

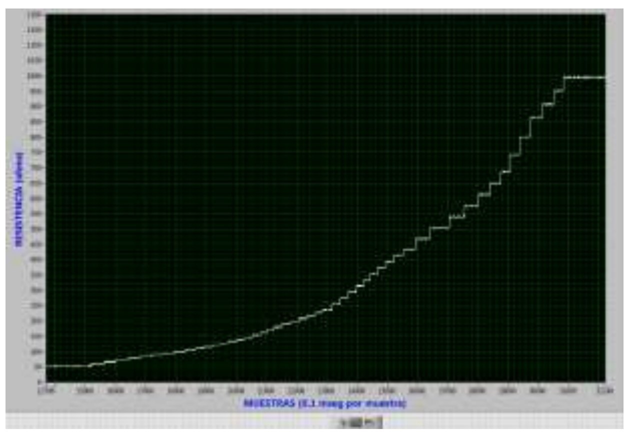

Figure 15 Selection of the segment of interest during the sensor inspection

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

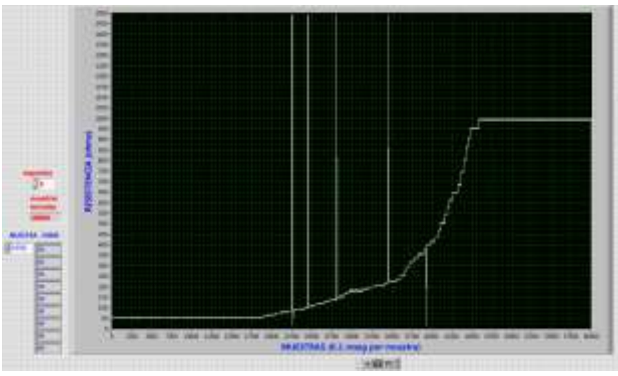

Figure 16 Plot of a fuel level sensor with five points of failure

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.

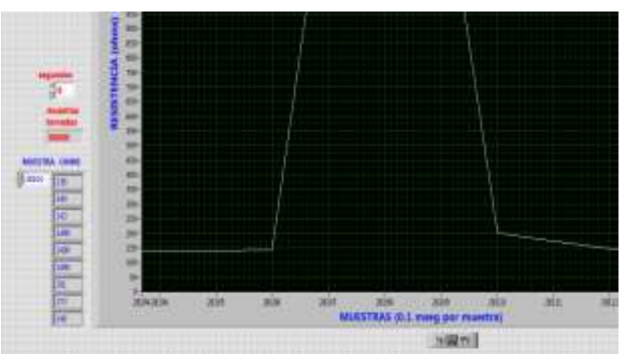

Figure 17 Detailed graph of a failure point

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.

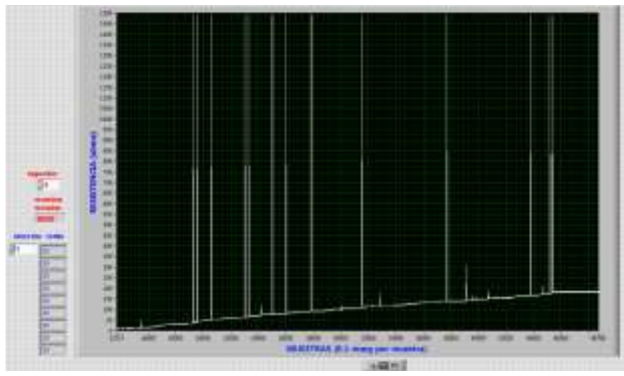

Figure 18 Graph of a fuel level sensor type one with multiple failure points.

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.

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