WIRELESS INTELLIGENT SENSORS BASED IN NANOSTRUCTURES WITH ENERGY SELF-SUFFICIENCY TO STUDY THE CONSEQUENCES OF HIGH TEMPERATURES IN COMBUSTION MOTORS

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ABSTRACT

In this research are proposed the consequences of high temperatures in Internal Combustion Motors (ICM) as correlation of its performance according to give information of the ICM fault detector, which also can be useful for preventive maintenance. It was possible to achieve the proposed target because of it was designed a smart sensor based in nanostructures prepared over Anodic Aluminum Oxide (AAO) samples, which proportionated short response time and high robustness in the measurement tasks of the smart sensor, as well as, the designed sensor has the possibility to work by energy self-sufficiency and sending the measurement data to external users by wireless. In fact, it is waited that this research could be a support for researchers of ICM enhancement, who could look for new techniques of environment conditions cares in compensation to keep the balance between the useful energy obtained from ICM and the environment conditions, where are developed economical activities such as public transport or mining in Peru.

Keywords Internal Combustion Motors (ICM), wireless communication, smart sensors, energy self-sufficiency, nanostructures, Modulating Functions (MF), Least Mean Square (LMS), and Anodic Aluminum Oxide (AAO).

1. INTRODUCTION

It is expected that after some years the combustion motors will be replaced by electrical motors or engines based in Hydrogen for special activities such as in transport. Nevertheless, there are countries where the replacement of that motors will need more time than it could be needed in Europe or in the USA, such as for example in Peru, because of usually the big percent of the public and private transport depends on older busses and cars that use combustion motors. Hence, there is the identified problematic, and described by the following questions: What consequences are caused in the environment conditions due to damaged combustion engines from public and private transport? How to correlate the temperature and vibration of the motor surface owing to get information of its performance, also when the motor is working under high temperatures?. [1], [2], [3].

There are some researches in which are proposed how older motors and damaged motors of public and private transport can improve their performance by an analysis of the temperature and vibration produced in them, many times as a consequence of not optimal fuel or complex external conditions. Furthermore, there are some researchers that proposed how to get the thermal and dynamic information of the combustion motors by a matrix of sensors, which can obtain the physical variables measurement over the motors. Therefore, we propose the experimental results analysis of a prototype designed regarding a smart sensor with the capacity to keep self-sufficiency energy based on the sun energy transformation to electrical energy stored in small batteries that can proportionate its energy to be used by the sensor according the necessity of the transduction task, as it is depicted by the figure 1. In which, for the designed smart sensor “E”, the sun panel “A” based in nanostructures receives the sun radiation owing to convert the sun energy to electrical energy that is stored in small batteries “B”. The microcontroller “C” has the task to coordinate the stored energy with the transducers subsystem “D” (based on nanostructures too) and the antenna “F” has the task of emission/reception of the measured data with an external user.

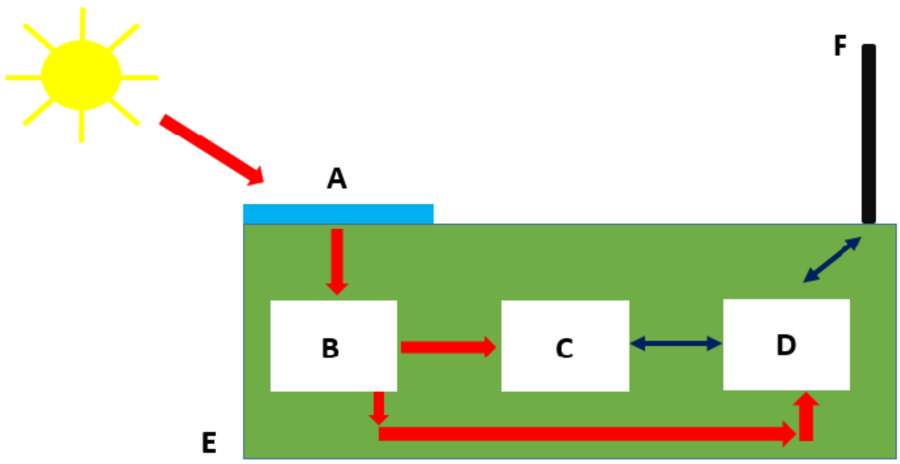

Figure 1: Scheme of the designed sensor prototype.

The user can get communication with the smart sensor prototype by a simple designed protocol in order to get information of the measured data. Finally, there were achieved the following conclusions:

The designed prototype keeps its faster response time and robustness for the measurement of the physical variables: temperature and vibration of motor surfaces (both variables depending also of the fuel flow needed for the ICM operation), which is based on the nanostructures properties of the designed transducers. However, the designed prototype has dependence of its range of work, which is from 10°C to 350°C for the ICM surface temperature (consequently its combustion chamber), the operation of the fuel flow transducer under the range of work condition 0.01L/min to 4L/min, and finally the operating range for the wireless data communication by the frequency range from 1Hz to 2000 Hz approximately.

The designed sensor has a microcontroller in order to execute polynomial models based on Modulating Functions for the measured data transduction, in spite of the measured data could be nonlinear. Nevertheless, the microcontroller has the disadvantage of electrical energy consume and taking more space of the final hardware design. The designed sensor has the possibility to store electrical energy as a consequence of the sun energy conversion, even though, the quantity of energy stored in batteries produces a limit in the active properties of the transducers owing to the consuming time of the stored energy by the prototype designed, that was in overage 5W for 3 hours in continuous operation.

In fact, the designed sensor can measure the physical variables: temperature and vibration by infrared and the capacity of sending/transmission the measured data by radiofrequency. Notwithstanding, there are limits in the scope of the distance reception/transmission for 100m around for the prototype designed for the presented research. It is necessary to increase the working range of the physical variables measurements and the scope of the sending/transmission data due to take more information of the combustion motors of the public and private transport, moreover it is expected that information of the temperature and vibration correlation from the engine surfaces can give information of the stage of the motor according to detect possible damages and drivers can repair it by previous diagnostics also in the time when fuel stores could be in shortage.

In the figure 2 is depicted the setup of the studied system that is composed by the combustion motor “CM”, which needs of the fuel flow “ϕ” to work, producing torque “Ʈ” and Revolution Per Minute (RPM) on machines or automobile movement system. The fuel flow is not constant (“ϕ1 to “ϕ2”) due to the consuming of the CM user, in fact the physical variables fuel flow “ϕ” and CM surface temperature “T” are measured by the designed smart sensor “SS”. The measurement of the ICM surface temperature is based on the Infrared IR radiation that is emitted by the combustion chamber through the ICM surface, this signal is received by the smart sensor and correlated with the difference of pressure detected by the fuel flow on the fuel flow transducer NS, both signals are sent to an external user by wireless data EW1.

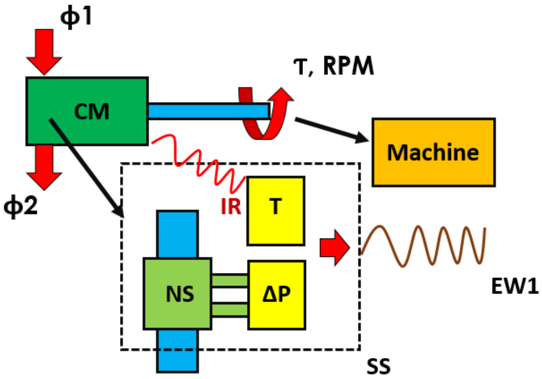

Figure 2: Scheme sensor designed for the combustion motor

In the figure 3 is depicted the scheme of the designed smart sensor “SS”, in which “TR” is a differential pressure sensor that proportionate the static pressures “P1” and “P2” by one of the transducers “ANT”, as well as, there were designed transducers “ANT” to measure the ICM surface temperature by Infrared “IR”. Hence, the designed smart sensor contains the differential pressure sensor, in which the fuel flow through it and giving as a result the difference of the static pressure “ΔP”, furthermore the temperature transducer “T” receives the IR signal from the ICM surface temperature since to correlate both signals by the microcontroller of the smart sensor, which send the matrix of data measured to the user by wireless. This matrix of data measured is depicted by “EW1” that is received by the user, from which is possible to get much information of the ICM operation.

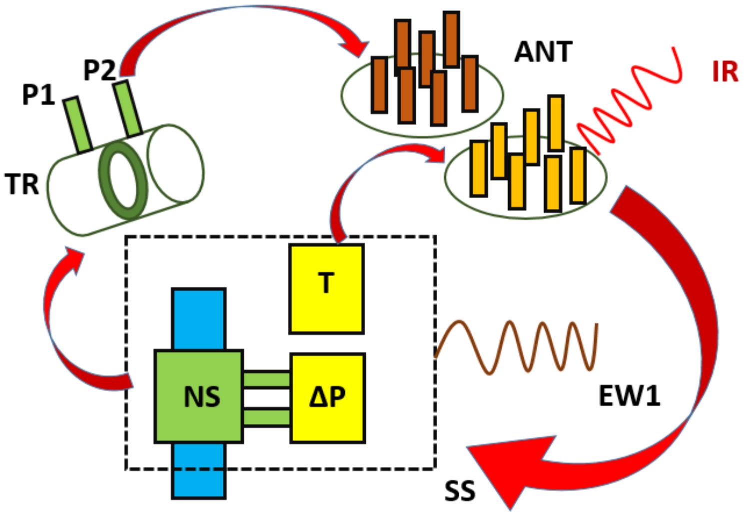

Figure 3: Scheme sensor designed for the combustion motor

2. THEORETICAL ANALYSIS

The main target of this research is given in the design of the smart sensor, which has specific properties according to study the effects of ICM high temperatures surface. Nevertheless, the designed sensor is composed by transducers based on AAO nanostructures, which were prepared by previous electro-polishing (electrochemical cleaning) and anodization in order to get nano holes over the aluminium samples [4], [5], [6]. It is possible to get a balance between the quantity of nano holes over a sample that depends on the porosity property, as well as it is correlated by the porous diameter and the base diameter. Therefore, the equation 1 shows the volume of an AAO unit base “V_b”, which is a hexagonal cylinder of height “L” and side “l”.

$$V_b = \frac{6\sqrt{3}}{4}\, l^2 L \qquad (1)$$

Moreover the porous volume “V_p” is given by the following equation 2, where “D_p” is the porous diameter and “L” is its height.

$$V_p = \frac{\pi D_p^2}{4} L \qquad (2)$$

As well as "D_b" is the diameter of the structure aluminum base given by the equation 3, where "l" is the side of the hexagonal cylinder.

$$D_b = \frac{l}{2} \qquad (3)$$

Hence, the porosity is achieved by the following equation 4 that is obtained by the previous equations 1, 2 and 3.

$$P = \frac{\frac{\pi D_p^2}{4} L}{\frac{6\sqrt{3}}{4} l^2 L} \qquad (4)$$

In fact, its reduction is given by the equation 5.

$$P = \frac{2\pi D_p^2}{3\sqrt{3} D_b^2} \qquad (5)$$

The figure 4 shows a scheme of nano-holes designed over aluminum samples, from which it was possible to look for a controlled porosity as dependence on the diameter porous (nano-hole) by half porosity in order approximately 1000 nm of porous diameter "D_p".

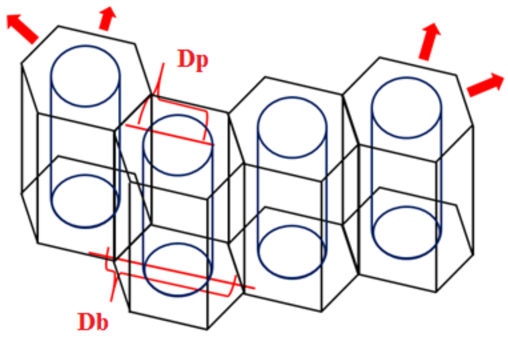

Figure 4: Schematic representation of AAO nano holes

After to prepare the nano-holes, it was stored atoms by electro-chemical deposition in order to obtain nanostructures (for this research, it was obtained amorphous nano-wires based on silicon "Si", silver "Ag", gold "Au", cooper "Cu" and titanium "Ti"). The prepared nanostructures are the base for the transducers as part of the designed smart sensor. The sensor receive energy from the battery that store energy by a small sun panel fixed in the smart sensor system (it is suggested to charge it previously to be used). As a consequence, the transducers receive the physical variables as target to measure (fuel flow and surface temperature of the ICM), these signals are processed by the microcontroller of the smart sensor and sent to an external user by wireless.

Whereas, it is necessary to analyze the mathematical behavior of the measurement tasks, hence, the equations 6 and 7 are obtained as a result to study the response of every transducer in its linear range domain. In fact, the possibility to use transducers based in nanostructures (controlling their geometry and composition) was a good advantage in order to get short response time and robustness, as well as widely linear range of work for the required fuel flow and surface temperature of the ICM (from 0 to 3.5 L/min and from 20°C to 300°C). In this context, "K_{M_1}" is the response gain for the designed fuel flow transducer, moreover "τ_{M_1}" and "L_{M_1}" are their response time and delay time respectively, as them are showed in the equation 6 (The input signal is given by "$X_1(S)$" and fuel flow response sensor is given by "$Y_1(S)$") [10], [11], [12].

$$\frac{Y_1(S)}{X_1(S)} = \frac{K_{M_1}}{\tau_{M_1}S + 1}\, e^{-L_{M_1}S} \qquad (6)$$

Moreover, in the equation 7 "K_{M_2}" is the response gain for the designed ICM surface temperature transducer, moreover "τ_{M_2}" and "L_{M_2}" are their response time and delay time respectively, as them are showed in the equation 7 (The input signal is given by "$X_2(S)$" and fuel flow response sensor is given by "$Y_2(S)$") [10], [11], [12].

$$\frac{Y_2(S)}{X_2(S)} = \frac{K_{M_2}}{\tau_{M_2}S + 1}\, e^{-L_{M_2}S} \qquad (7)$$

Therefore, both equations described in paragraphs above can also be analyzed on the time domain according to get deep understanding regarding their own stability, as well as are summarized in the following matrix of the equation 8, in which are described their solution. Otherwise, it is necessary to understand from this research that for the required operating work, the designed smart sensor based in nanostructures proportionated short response time and robustness, which was not only a good support in the stability on the sensor system, also it supported in the linear response of the sensor system, it means that is possible to analyze the system by transfer functions and by time domain polynomials.

$$y(t) = \begin{pmatrix} K_{M_1}X_1(t)\,(1 - e^{-\frac{t}{\tau_{M_1}}}) \\ K_{M_2}X_2(t)\,(1 - e^{-\frac{t}{\tau_{M_2}}}) \end{pmatrix} \qquad (8)$$

According to find the response sensor by every transducer of the designed smart sensor, as dependence on the focused plant "fuel flow subsystem and ICM surface temperature". It was evaluated for every independent subsystem, hence, the equation 9 shows the open loop subsystem of the fuel flow, in which "K_{P_1}" is the response gain of the fuel flow subsystem (inside the difference pressure measurement hardware), "K_{M_1}" is the response gain of the fuel flow transducer, "τ_{P_1}" is the response time of the fuel transducer, "τ_{M_1}" is the response time of the fuel flow subsystem. Furthermore, as a consequence that the response time of the fuel flow subsystem was bigger than the delay of this subsystem, it was not considered its effect over the equation 9.

$$\frac{Y_1(S)}{X_1(S)} = \frac{K_{P_1} K_{M_1}}{\tau_{P_1} \tau_{M_1} S^2 + (\tau_{M_1} + \tau_{P_1}) S + 1} \quad (9)$$

The equation 10 shows the open loop subsystem of the ICM surface temperature, in which "K_{P_2}" is the response gain of the surface temperature, "K_{M_2}" is the response gain of the temperature transducer, "τ_{P_2}" is the response time of the surface temperature, "τ_{M_2}" is the response time of the temperature subsystem. Furthermore, as a consequence that the response time of the ICM surface temperature subsystem was bigger than the delay of this subsystem, it was not considered its effect over the equation 10, such as it was made in the previous equation 9.

$$\frac{Y_2(S)}{X_2(S)} = \frac{K_{P_2} K_{M_2}}{\tau_{P_2} \tau_{M_2} S^2 + (\tau_{M_2} + \tau_{P_2}) S + 1} \quad (10)$$

The equations 11 and 12 are the theoretical models for general second order systems, according to get the stability analysis for the subsystems fuel flow and ICM surface temperature. Therefore, the coefficients "ε_1" and "ε_2" are the damping parameters for second order general systems, "ω_1" and "ω_2" are the speed parameters of a second order general systems (such as inertia changes) [10], [11], [12].

$$0 = S^2 + 2\varepsilon_1 \omega_1 S + \omega_1^2 \quad (11)$$

$$0 = S^2 + 2\varepsilon_2 \omega_2 S + \omega_2^2 \quad (12)$$

Comparing the equation 9 and equation 11, it was possible to verify the response time of the fuel flow plant "τ_{P_1}", which is given by the following expression 13, in which "τ_{M_1}" is the fuel flow transducer response time, "ω_1" is the speed parameter for its equivalent general second order system.

$$\frac{1}{1 - \frac{1}{\tau_{M_1}}} < \tau_{P_1} = \frac{1}{w_1^2 \tau_{M_1}} \quad (13)$$

Besides, comparing the equation 10 and equation 12, it was possible to verify the response time of the ICM surface plant "τ_{P_2}", which is given by the following expression 14, in which "τ_{M_2}" is the ICM surface temperature transducer response time, "ω_2" is the speed parameter for its equivalent general second order system.

$$\frac{1}{1-\frac{1}{\tau_{M_2}}} < \tau_{P_2} = \frac{1}{w_2^2 \tau_{M_2}} \qquad (14)$$

In order to analyze the stability of the designed smart sensor, it was worked by Lyapunov in the transducers subsystems (for the fuel flow and surface temperature measurement). Therefore, it was obtained the equation 15 by its inverse Laplace transformation of the equation 9 [10], [11], [12].

$$\frac{d^2}{dt^2} y_1(t) + \frac{(\tau_{M_1} + \tau_{P_1})}{\tau_{M_1}\tau_{P_1}} \frac{d}{dt} y_1(t) + \frac{1}{\tau_{M_1}\tau_{P_1}} y_1(t) = \frac{K_{P_1}K_{M_1}}{\tau_{M_1}\tau_{P_1}} X_1(t) \qquad (15)$$

In similar context, it was obtained the equation 16 from the equation 10 by the inverse Laplace transformation [10], [11], [12].

$$\frac{d^2}{dt^2} y_2(t) + \frac{(\tau_{M_2} + \tau_{P_2})}{\tau_{M_2}\tau_{P_2}} \frac{d}{dt} y_2(t) + \frac{1}{\tau_{M_2}\tau_{P_2}} y_2(t) = \frac{K_{P_2}K_{M_2}}{\tau_{M_2}\tau_{P_2}} X_2(t) \qquad (16)$$

The equation 17 helped to reduce the equation 15 and 16.

$$v_1(t) = \frac{d}{dt} y_1(t) \qquad (17)$$

$$v_1(t) = \frac{d}{dt} y_1(t) \qquad (18)$$

Replacing the equation 17 in the equation 15, it was obtained the equation 19 [10], [11], [12].

$$\frac{\tau_{M_1}\tau_{P_1}}{K_{P_1}K_{M_1}} \frac{d}{dt} v_1(t) + \frac{(\tau_{M_1} + \tau_{P_1})}{K_{P_1}K_{M_1}} v_1(t) + \frac{1}{K_{P_1}K_{M_1}} y_1(t) = X_1(t) \qquad (19)$$

As well as, it was replaced the equation 18 in the equation 16 in order to achieve the equation 20 [10], [11], [12].

$$\frac{\tau_{M_2}\tau_{P_2}}{K_{P_2}K_{M_2}} \frac{d}{dt} v_2(t) + \frac{(\tau_{M_2} + \tau_{P_2})}{K_{P_2}K_{M_2}} v_2(t) + \frac{1}{K_{P_2}K_{M_2}} y_2(t) = X_2(t) \qquad (20)$$

Therefore, from the equation 19, it was obtained a proposed Lyapunov function given by the equation 21.

$$\frac{1}{2}\frac{\tau_{M_1}\tau_{P_1}}{K_{P_1}K_{M_1}}\ v_1^2(t)\ +\frac{1}{2}\frac{1}{K_{P_1}K_{M_1}}y_1^2(t)\ = E_1(t) \qquad (21)$$

In similar context, from the equation 20, it was obtained a proposed Lyapunov function given by the equation 22.

$$\frac{1}{2}\frac{\tau_{M_2}\tau_{P_2}}{K_{P_2}K_{M_2}}\ v_2^2(t)\ +\frac{1}{2}\frac{1}{K_{P_2}K_{M_2}}y_2^2(t)\ = E_2(t) \qquad (22)$$

From the previous equation 21 and 22, it is possible to verify that "$\boldsymbol{E_1(t)}$" and "$\boldsymbol{E_2(t)}$" are positive functions, it happen only if their coefficients are also positive, which is true because of response time for the designed transducers and plants (fuel flow and temperature subsystems) can not be negative values, furthermore their gain parameters are positive too according to keep stability. Hence, it is validated Lyapunov first condition for both transducers as part of their respective subsystems.

In fact, if the following paragraphs are validated the second condition of Lyapunov stability because of to warrant the performance of the designed sensors as part of the ICM operation. For this reason, from the equation 21 was reduced to the equation 23.

$$\frac{d}{dt}E_1(t) = \frac{1}{2}\frac{\tau_{M_1}\tau_{P_1}}{K_{P_1}K_{M_1}}\frac{d}{dt}(v_1^2(t))\ +\frac{1}{2}\frac{1}{K_{P_1}K_{M_1}}\ \frac{d}{dt}\ (y_1^2(t)) \qquad (23)$$

Reducing the previous equation 23, it was obtained the following equation 24.

$$\frac{d}{dt}E_1(t) =\ v_1(t)\ (\frac{\tau_{M_1}\tau_{P_1}}{K_{P_1}K_{M_1}}\frac{d}{dt}v_1(t) + \frac{1}{K_{P_1}K_{M_1}}\ y_1(t)) \qquad (24)$$

Replacing the equation 19 in the equation 24, it was obtained the equation 25, in the context "$X_1(t)$" is null.

$$\frac{d}{dt}E_1(t) = -\ \frac{\left(\tau_{M_1} +\ \tau_{P_1}\right)}{K_{P_1}K_{M_1}}v_1^2(t) \qquad (25)$$

As a consequence, from the equation 25 it can be verified the second stability condition of Lyapunov, only when the parameters response time and gain responses from the fuel flow subsystem and fuel flow transducer are positive, it means the following expression 26.

$$\frac{d}{dt}E_1(t) = -\ \frac{\left(\tau_{M_1} +\ \tau_{P_1}\right)}{K_{P_1}K_{M_1}}v_1^2(t)\ \ <\ \ 0 \qquad (26)$$

By the other hand, it was looked for the stability of the ICM surface temperature transducer including the temperature subsystem, for this reason analyzing the equation 22 was obtained the equation 27.

$$\frac{d}{dt}E_2(t) = \frac{1}{2}\frac{\tau_{M_2}\tau_{P_2}}{K_{P_2}K_{M_2}}\frac{d}{dt}(v_2^2(t)) + \frac{1}{2}\frac{1}{K_{P_2}K_{M_2}}\frac{d}{dt}(y_2^2(t)) \qquad (27)$$

Reducing the previous equation 27, it was obtained the following equation 28.

$$\frac{d}{dt}E_2(t) = v_2(t)\,(\frac{\tau_{M_2}\tau_{P_2}}{K_{P_2}K_{M_2}}\frac{d}{dt}v_2(t) + \frac{1}{K_{P_2}K_{M_2}}\,y_2(t)) \qquad (28)$$

Replacing the equation 20 in the equation 28, it was obtained the equation 29, in the context "$X_2(t)$" is null.

$$\frac{d}{dt}E_2(t) = -\frac{\left(\tau_{M_2} + \tau_{P_2}\right)}{K_{P_2}K_{M_2}}v_2^2(t) \qquad (29)$$

Therefore, from the equation 29 it can be verified the second stability condition of Lyapunov, only when the parameters response time and gain responses from the ICM surface temperature subsystem and ICM surface temperature transducer are positive, it means the following expression 30.

$$\frac{d}{dt}E_2(t) = -\frac{\left(\tau_{M_2} + \tau_{P_2}\right)}{K_{P_2}K_{M_2}}v_2^2(t) \ < \ 0 \qquad (30)$$

In order to improve the mathematical results of the physical variables measured by the designed sensor, it was proposed to get an adaptive weight matrix for the physical parameters of the total measurement, which can be obtained by the solution of the equivalent polynomial model (using Modulating Functions) over the measured data[10], [11], [12]. Therefore, the equation 31 shows a general polynomial model proposed to solve it by MF, in which the output matrix is given by "$y(t)$", the input matrix given by "$u(t)$", the parameters of the system are given by "a_j" and "b_j", the error in the proposed model is represented by "$e(t)$", the order of the polynomial model by differential equation is "n" and the auxiliary variable "j" [10], [11], [12].

$$\frac{d^n}{dt}y(t) + \sum_{j=1}^{n} a_j\frac{d^{n-j}}{dt}y(t) = \sum_{j=1}^{n} b_j\frac{d^{n-j}}{dt}u(t) + e(t) \qquad (31)$$

Furthermore, the costing function "J" was possible to be defined by the comparison of the theoretical model of the equations 19 and 20, according to get the optimal solution of the Least Mean Square error as dependence on the obtaining of the adaptive parameters "θ" and the weight matrix "W", which is showed by the equation 32 because of the derivative of "J" under the changes of “θ”, as well as “ϒ” is the reference answer and “Γ” is the internal matrix for every internal variable of the adaptive model [10], [11], [12].

$$\frac{\partial J}{\partial \theta} = (\Upsilon - \Gamma\theta)^T \, W^{-1}(\Upsilon - \Gamma\theta) \qquad (32)$$

The result of the equation 32 is achieved by the equation 33, in which is possible to verify the dependence of the optimal parameters “θ”, for the total response of the designed smart sensor, with adaptive matrix “W”, the internal variables “Γ” and the reference output matrix “ϒ”, this solution also can help to design the simulations algorithms and the experimental prototype, since the warranty that the short response time and high robustness of the designed sensor in the operating range is achieved, moreover the short response time of both subsystems (fuel flow and temperature transduction) can be executed by algorithms in real time operation.

$$\theta = (\Gamma^T W^{-1} \Gamma)^{-1} \, \Gamma^T W^{-1} \Upsilon \qquad (33)$$

3. SIMULATION ANALYSIS

As a consequence of the mathematical analysis discussed in the chapter above, in the following paragraphs of the chapter 3 are studied the algorithm design according to find the simulations of the fuel flow and surface temperature of the ICM as main system.

The figure 5 describes the main algorithm for the simulations of the physical variables as measurement target, for which, it was previously emulated fuel flow and ICM surface temperature data that were obtained solving the mathematical model of the proposed subsystems (described and studied in the chapter above): it was considered a control volume for the fuel flow that through the flow sensor, as well as it was considered a heat interchanger and the mathematical analysis analyzed in the chapter above, regarding the temperature behavior over the ICM surface.

Therefore, it was obtained the adaptive parameters (identification) for both subsystems: fuel flow (control volume) and the ICM surface temperature that are achieved consequently to the response of the main system (composed by the described both subsystems), the adaptive parameters were stored in a matrix, which was evaluated as a weight matrix due to the comparison between the theoretical models with polynomials based on Modulating Functions. In fact, both subsystems had as references the theoretical models according to look for a desired error during the measurement, the desired error is obtained in the steady state (also, it was possible to achieve it through the simulation analysis supported by an error value that the user can propose), whether this desired error can be achieved the matrix of the measured data can be sent to the user by wireless, nevertheless, this effect can be analyzed in the experimental results.

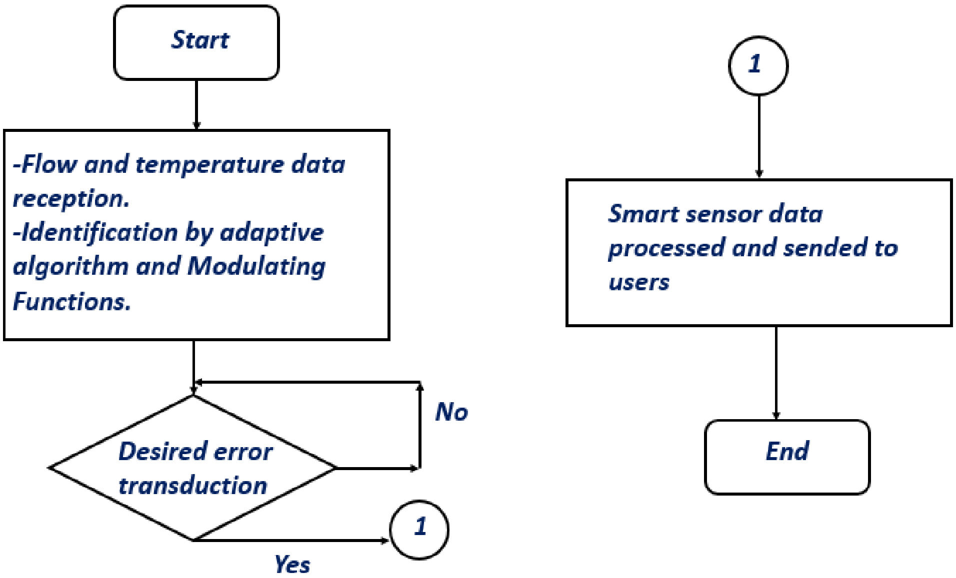

Figure 5: Flowchart of the main algorithm for the simulations analysis

The figure 6 shows the ICM of a Nissan Frontier 2005, in which was studied the performance of the designed sensor. The subfigure "A" depicts the ICM surface temperature, which was analyzed around the combustion chamber, the maximal temperature achieved by the simulations was around "T3" (312°C) and represented by a red color surface. On the other hand, the subfigure "C" depicts the behavior of the fuel flow by the changes of the difference of the static pressure values "DP1", "DP2" and "DP3" (correlated with the fuel flow by the mathematical analysis detailed in the chapter above). The fuel flow bahaviour analysis was obtained by the mathematical models studied previously and the correlated view of set functions criterion [7]. Both subfigures "A" and "C" are also consequence of the ICM parameters shoed by the subfigure "B" that is from a Nissan Frontier 2005.

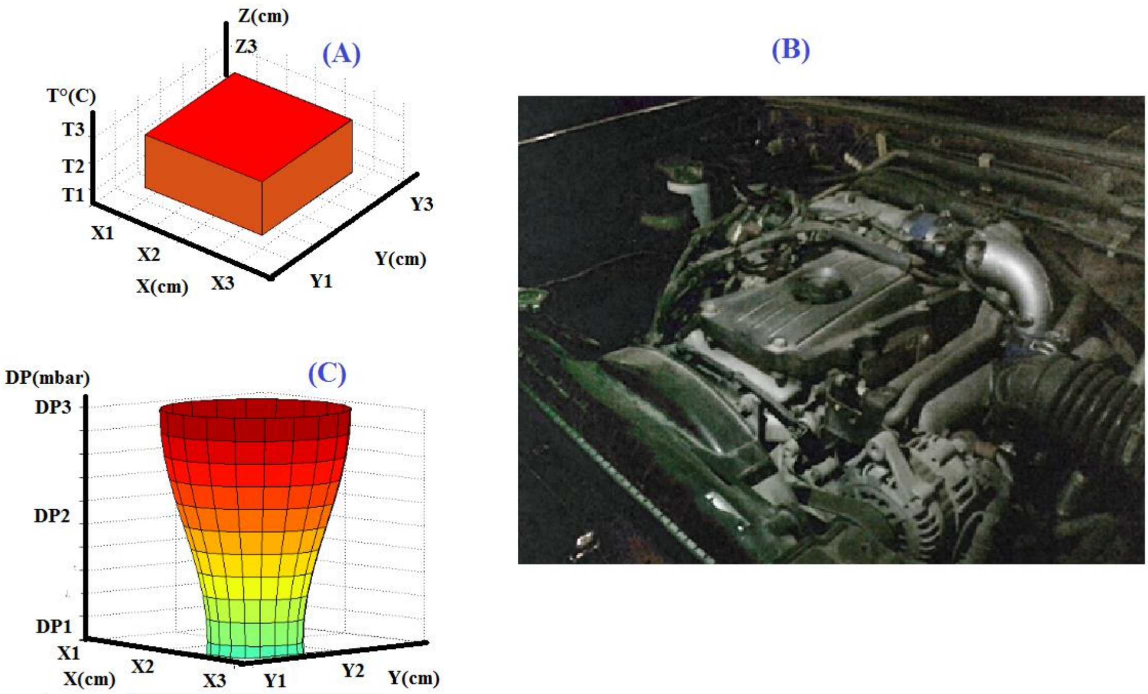

Figure 6: ICM of a Nissan Frontier 2005, and the simulation of its fuel flow and surface temperature.

4. EXPERIMENTAL ANALYSIS

In this chapter are analyzed the experimental results that were made according to evaluate the simulations of the designed smart sensor, concerning its performance during the fuel flow and ICM surface temperature measurement. The figure 7 shows 3 proposed transducers, which are components of the designed smart sensor, the subfigures “A”, “B” and “C” shows the structures prepared in the scale around 1000 nm (1 um), some of them were composed by particles of Si, Ag, Au, Cu and Ti that were deposited by electro chemical deposition (this was described in the chapters above), as well as everyone of the showed samples are the transducers for the fuel flow and ICM surface temperature subsystems of the designed smart sensor.

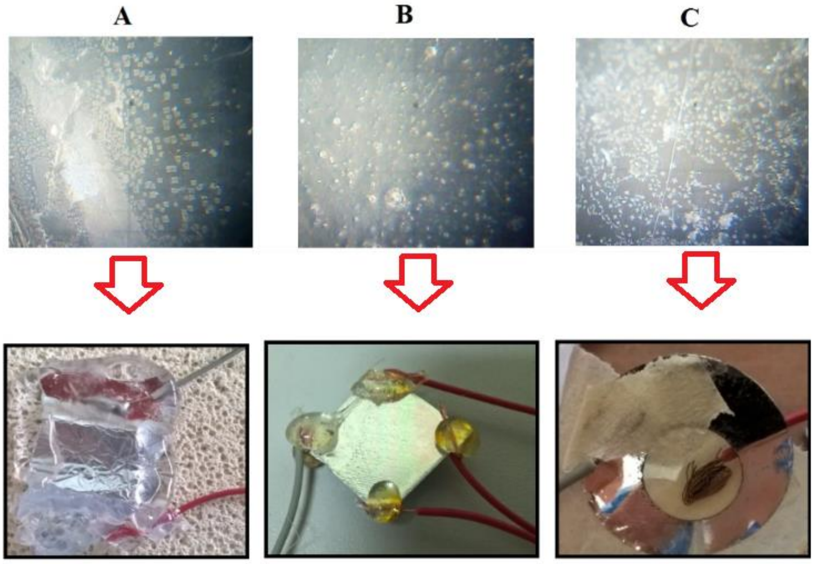

Figure 7: Amorphous nanostructure samples based on AAO for the smart sensor design

The designed smart sensor was evaluated in performance by the static and dynamic tests of its subsystems: “the fuel flow transducer” and “the ICM surface temperature transducer”, whereas the achieved results are under domain of the restricted operating work (that was detailed on paragraphs above). Nevertheless, even though the nanostructures were amorphous due to the deposition of atoms was given by electro chemical techniques, the designed transducers got short response time in comparison with traditional sensors. Therefore, it was possible to get enough time to execute the designed algorithms in order to give robustness in the measured physical variables owing to the adaptive behavior of the designed sensor.

In fact, the following paragraphs proportionate information of the designed sensor response, as well as its dynamic answer for the ICM analysis. Therefore, there were made many experiments in a Nissan Frontier 2005 ICM for periods of time around 50 minutes, and as a result it was evaluated the correlation among the ICM surface temperature, its fuel flow and the consequently fault detections of the ICM performance, with this information the user can get own opinion regarding what parameters can enhance the ICM performance without getting understanding of the consumed fuel.

The figure 8 (its upper subfigure) shows the static response of the designed smart sensor, for the fuel flow measurement as correlated with the static difference of pressure through the designed transducer (subsystem of the smart sensor). The blue color curve in this upper subfigure was obtained by theoretical analysis of the general model of Bernoulli [8], [9] for the fuel flow measured by the flow transducer, the green color curve was obtained by the consumed fuel registered from the driver screen (driver panel) and the red color curve was achieved by the measurement of the designed smart sensor. Hence, it was identified that the measurement described by the red color had more robust answer under the operation of the ICM operation.

Moreover, the static response for the measurement of the ICM surface temperature is showed in the lower subfigure of the figure 8, in which the blue color curve was obtained by theoretical analysis (such as also it was described in the chapter above because of the simulations) that also is based on the heating transfer from the combustion chamber to its external surface, the green color curve was achieved by a thermocouple type K over the ICM surface (near the combustion chamber), the red color curve was obtained by the designed smart sensor.

As a consequence, from both cases of the static response of the fuel flow and the ICM surface temperature, the responses are not in total linear answers, it can not warrant to work the mathematical analysis through linear algebra (such as transfer functions). However, it was possible to solve nonlinear models consequently to the data measured and expressed by polynomials because of the adaptive parameters in compensation of the weight matrix executed by the controller of the designed smart sensor.

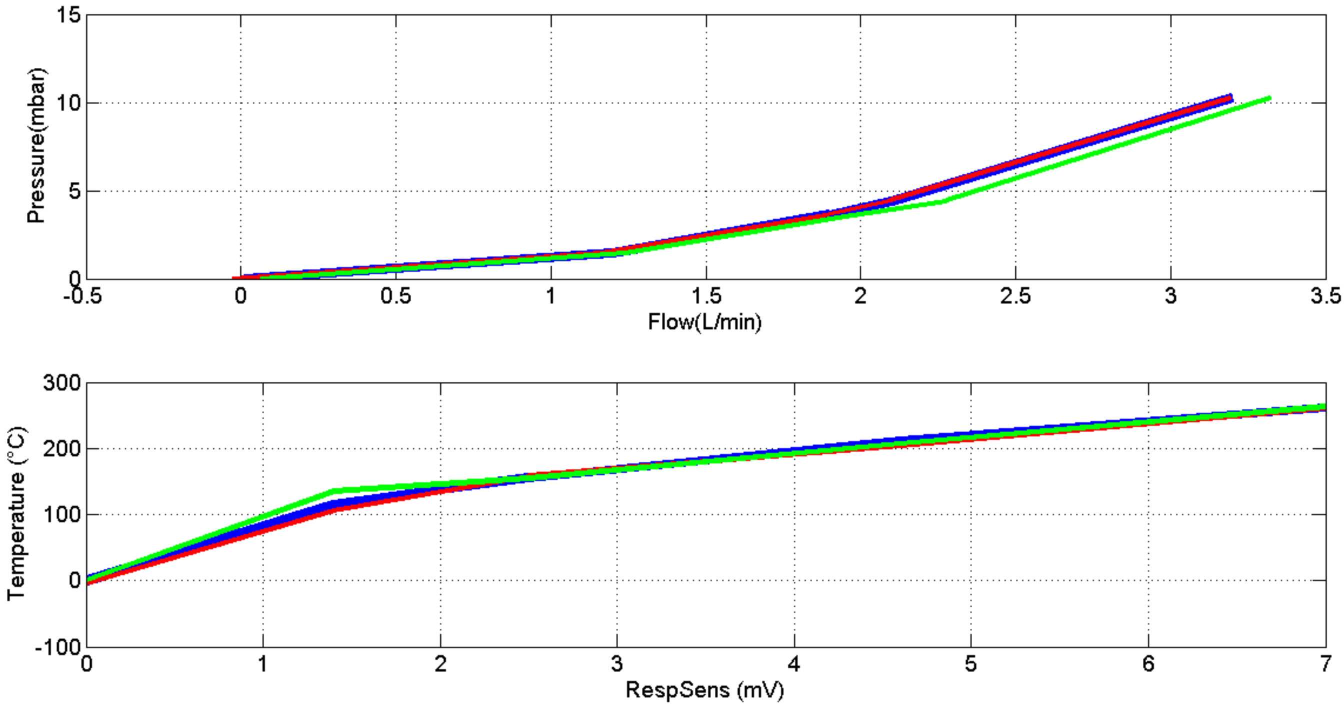

Figure 8: Static response for the designed smart sensor in order to study the fuel flow and the surface temperature of an ICM.

The figure 9 shows the dynamic response of the designed smart sensor for the fuel flow measurement, moreover for the ICM surface temperature measurement. In the upper subfigure is showed by a blue color curve the theoretical fuel flow consume (that result was achieved through the mathematical analysis did and detailed in paragraphs above, as well as the simulations algorithms supported by them), the green color curve is the response obtained by the data registered in the driver panel (previous correlation with the measurement time), the red color curve is the fuel flow data measured by the smart sensor. It was possible to get a robust measurement under presence of disturbances caused by the vibration of the ICM in operation, which is showed in the comparison of the fuel flow curves (red color curve got among 5% of error in steady state in comparison with the green color curve).

Moreover, the ICM surface temperature experimental results are showed in the inter-medium and lower subfigure as part of the figure 9, the blue color curve gives information of the theoretical temperature that achieve the ICM surface over the ICM combustion chamber (analyzed by heating transfer and the first order temperature system studied in chapters above), the green color curve is the measured temperature by a thermocouple that was fixed over the ICM surface temperature, as well as the red color curve is the measured obtained by the designed smart sensor.

Therefore, the designed sensor can achieve better measurement owing to its robustness under vibrations and other disturbances during the ICM operation, whereas in its operating range (described in this research), as a consequence for the evaluated ICM it can be possible to give to the user information of the consumed fuel flow that is correlated with the ICM surface temperatures in the average of 312°C, this value in continuous operation needs to use more coolant fluid. Notwithstanding, whether it can not be enhanced the heating evacuation, the combustion engine can be damaged and causing environment conditions damages, moreover, the user can analyze if the quality of the fuel can improve the ICM performance that also can need the designed smart sensor to study this dynamic.

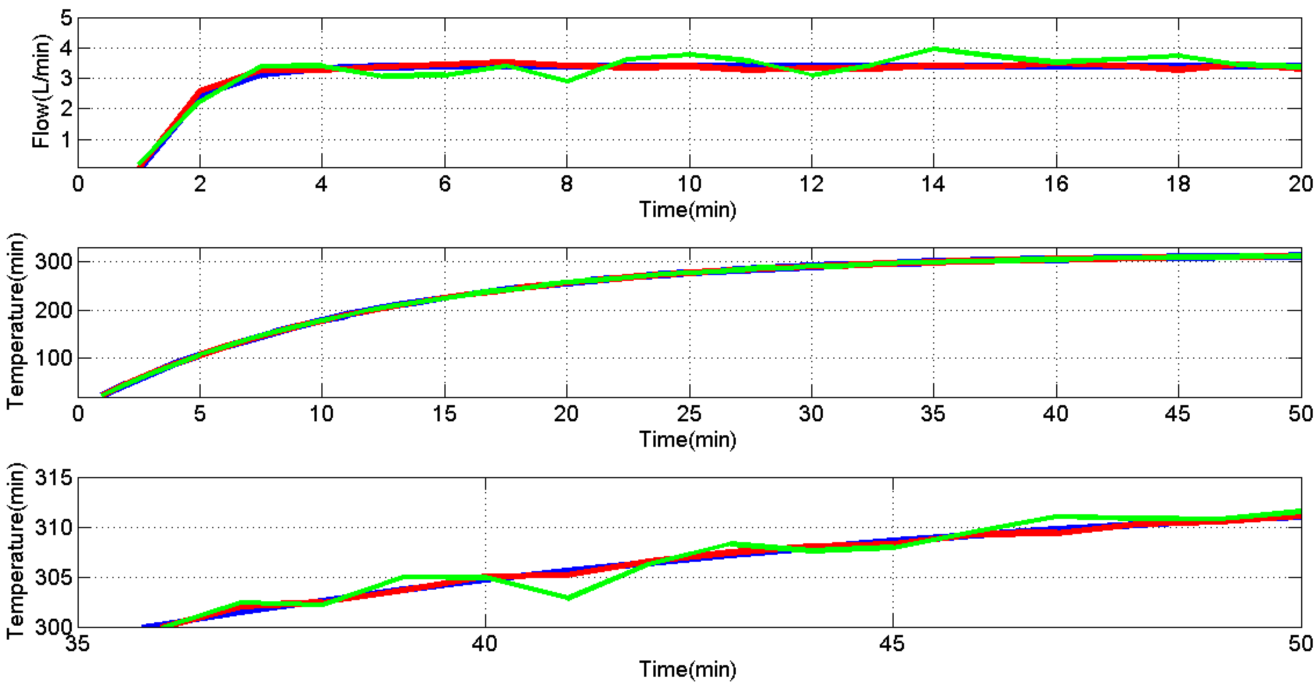

Figure 9: Dynamic response for the designed smart sensor in order to study the fuel flow and the surface temperature of an ICM.

5. CONCLUSSIONS

It was designed a smart sensor with the capability to measure flow and surface temperature of an ICM, according to get information of both physical variables that could be analyzed by users, as well as to proportionate information regarding the fault detector of the ICM performance.

It was designed a mathematical model according to evaluate the performance of an ICM by the fuel flow and its surface temperature measurement, which is achieved by the designed smart sensor.

It was designed an adaptive algorithm for the simulations and the experimental analysis of the ICM performance, which is based on the previous designed mathematical model.

There were designed transducers based on nanostructures (as part of the designed smart sensor) in order to get short response time and high robustness for the measurements.

The designed smart sensor, for this research, can work by energy self-sufficiency (because of its small sun panel and battery), moreover its capacity to share the measured data by wireless with the user.

For the evaluated ICM can be possible to suggest the necessity to make a multiple correlation analysis between the ICM surface temperature and its fuel flow consuming, as well as if the ICM surface temperature continue increasing while it is not controlled the interchanger heating, then the motor can reduce its efficiency, perhaps the user also needs to analyze the quality of the used fuel. This analysis can help to be preventive with the environment condition cares. Therefore, the designed sensor can be a good support for the user of an ICM

6. OUTLOOK

It is proposed to evaluate the designed smart sensor in ICM that uses hydrogen as main fuel.

It is proposed to evaluate the performance of the designed smart sensor in operative ICM under extreme geographical conditions, such as it is given in the Andes mountains of Peru, because of the necessity to use ICM in activities as mining.

In fact, it is also suggested to evaluate the performance of the designed sensor in the research of ICM based on hydrogen due to this sensor can provide multiple variable and correlation analysis to the user, furthermore reducing electrical connections owing to the wireless properties of this sensor.

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