Contemporary Engineering Sciences, Vol. 11, 2018, no. 76, 3781 - 3788
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.87347

Implementation of a Fuel Measurement System Based on the Gravimetric Principle for Applications in Engine Test Bench

Jorge Duarte[1], Guillermo E. Valencia[2], Javier Cárdenas Gutierrez[3], Javier Guzmán[4] and Andrés Porto[5]

[1] Efficient Energy Management Research Group – Kaí, Universidad del Atlántico
Carrera 30 Número 8 - 49, Puerto Colombia – Colombia

[2] Mechanical Eng., Efficient Energy Management Research Group – Kaí,
Universidad del Atlántico, Carrera 30 Número 8 – 49
Puerto Colombia – Colombia

[3] Civil Engineering Program, Faculty of Engineering
Universidad Francisco de Paula Santander, Cúcuta – Colombia

[4] Universidad del Atlántico, Carrera 30 Número 8 – 49
Puerto Colombia – Colombia

[5] Universidad del Atlántico, Carrera 30 Número 8 – 49
Puerto Colombia – Colombia

Abstract

This paper documents the implementation process of a fuel measurement system based on the gravimetric principle for applications in Engine Test Bench. To do this, the design of the measurement hardware consists of a gravimetric scale with serial output, feed pump, and a valve; which interact with each other thanks to the programming developed in the Arduino UNO® environment, it is possible to guarantee protection against possible disturbances that may affect the data measured by the scale by means of an acrylic structure. For the visualization and interaction with the information collected by the meter, an executable application

is made using the LabView ™ computational tool. Finally, a series of runs are carried out to guarantee compatibility with the existing testbench in the laboratory and to demonstrate the functionality of the system.

Keywords: System, Measurements, Gravimetric, Flow, Arduino UNO® programing, LabVIEW™

1. Introduction

Diesel engines and ignition engines have been a fundamental tool for the industrial and technological development of man, being of great importance in fields such as transport and power generation, to name a few.

Currently, fuels [1] and alternative processes applied to this type of finished machines [2-3] have been explored, in order to increase their performance more and more, thus reducing the emission of polluting gases in the exhaust and the consumption of fuel, resulting in a more efficient and more environmentally friendly machine [4]. Internal combustion engines, in general, must maintain a precise relationship between fuel and air, to optimize consumption, thus reducing costs and pollutant emissions. This ratio of the mass of fuel and air is known as engine dosing [2].

The height concerning the level of the sea directly influences the dosage of the engine, making the mixture rich or poor; being richer as it rises concerning sea level, since the density of air decreases [5]. To determine if the mixture is homogeneous, the exhaust gases of the engine are analyzed [6]. This dosing is regulated by controlling the amount of air and fuel that enters, so it is necessary to apply accurate and reliable control systems [7], which mostly require sensors whose prices mean high costs [8]. In addition to this, for the visualization of physical phenomena, thanks to advances in computational technology and industrial instrumentation, it is generally used a data acquisition system or also known DAQ [9], basically given by a physical input signal captured by a sensor, a DAQ hardware, which receives the signal, which may be this current, voltage, resistance or other electrical attribute that varies with time. Finally, a computer with a programmable software that allows to store and visualize the measured engineering variable. In this way, the productivity, processing, and visualization that a DAQ system offers to the research centers in motor test banks allow the possibility of obtaining more precise measurements in real time and control over the system in a flexible and reliable way [10]. There are several mass and volumetric flow measurement systems, which vary depending on the physical principle of operation; for applications where the mass flows are low, as is the case with the test and research banks, meters such as the Coriolis type are more commonly used [11].

In the latter, the measurement of the quantity of mass supplied in a time interval is made [12-13]. Also, this alternative measurement is relatively inexpensive but does not mean that it is less precise, in fact, this method is internationally recognized according to the API MPMS (American Petroleum Institute - Manual of Petroleum Measurement Standard) as the primary reference standard for calibrating large-scale mass flow meters [14]. Due to its high degree of precision, economy, low maintenance and mobilization capacity, it can easily be used to measure the amount of fuel that enters an internal combustion engine [15], is widely used in research projects and the development of doctoral theses in recognized international research centers.

2. Methodology

2.1. Operation of the measurement system

To make a complete measurement of the HX711 module being a transmitter of the load cell converts the load cell signal in gram values. Then the final weight is recorded to calculate the mass difference and divided by the elapsed time. In this way, the consumption is found in grams per second and is sent to the output 0-5V. If the minimum weight allowed for the measurement is reached, the filling state is activated where the pump is activated, and the valve is opened to fill the container on scale. Once the filling is finished, it is measured again. The user can suspend the filling and measuring process at any time by activating the emergency switch. To return to normal operation, the user will have to activate the switch again.

2.2. Electronic scale

The electronic scale, whose reference is BL-H2, Bernalo® brand, has a resolution of 0.01 gr, a load cell with a capacity of 1000 gr.

This scale is responsible for measuring the weight of the fuel that passes through the filling container; this measurement is used as a reference to start the filling cycle when reaching the minimum set point, likewise, start the consumption measurement cycle when reaching the set maximum set point.

The scale has an HX711 Module Load Cell Transmitter, which allows serial communication between the load cell and the Arduino UNO®, using the HX711 module is how the scale and the computer interact to be able to carry out the programming in Arduino UNO ®.

2.3. Electronic components

Arduino® is responsible for performing the logical communication between the computer, the relay (which in turn turns on and off both the pump and the valve for filling) and the scale so that everything as a whole work automatically [16].

HX711 is a 24-bit precision analog-digital converter (ADC) designed for weighing scales and industrial control applications to interact directly with a bridge sensor. The input multiplexer selects the differential input of channel A or B to the programmable low noise gain amplifier (PGA). Channel A can be programmed with a gain of 128 or 64, corresponding to a full-scale differential input voltage of ± 20mV or ± 40mV, respectively, when a 5V source is connected to the analog power supply pin AVDD. Which channel A is used for communication with the load cell of the Scale [17].

Each of the mechanical elements had to be connected to each other in such a way that they interact. This must be done through the logical pins designed for each

function. It also respected its color code to facilitate understanding and maintain order, thus avoiding errors that could end in the system not working or damage in possible future manipulations. Correctly connecting each pin to the Arduino is of utmost importance also so that the code developed works correctly and the element performs the function that was predisposed to it [18].
The way in which each of the electronic elements is visualized in the following scheme:

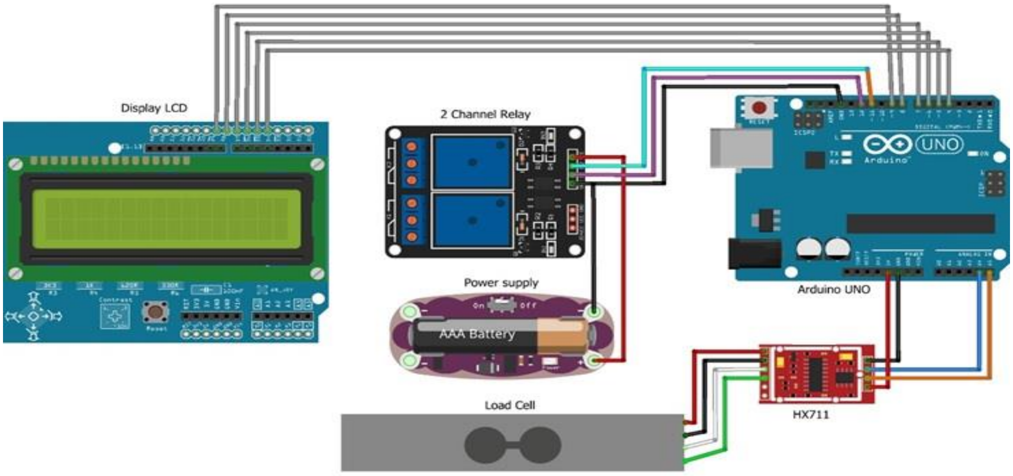

Figure 1. Diagram of connections between electronic components

2.4. Operation of the control system and data processing

The data processing and control system, whose core is the Arduino UNO®, is responsible for receiving the information from the scale (fuel weight measurements) and converting it into electric pulses, to control the filling of the beaker using the valve and pump. The code that governs the operation of the control and data processing system is configured so that each time the weight on scale equals a minimum set point, the relay closes its circuit, thus allowing the activation of the solenoid valve and the pump.
This filling cycle will take place until the weight on scale equals a maximum set point, which is when the relay will open its circuit, cutting off the electrical flow to the solenoid valve and the pump, also activating the consumption measurement algorithm. Fuel, this will be the measurement cycle, identified with the green light on the control cabinet panel. During the measurement cycle the motor will naturally demand fuel from the beaker, the scale will continue to carry out its measurement, with the difference that, in this cycle, each measurement taken by the scale will be subtracted from the measurement taken in the previous second, dividing the result of this difference between the elapsed time:

$$Consumption = \frac{Final\ Weight - Initial\ Weight}{\Delta Time} \tag{1}$$

This action is repeated every 1 second, thus calculating the fuel consumption of the engine with 1 second of frequency during the measurement process. Every second that the calculation of consumption is made, it is shown on an LED screen located on the front panel of the cabinet for manual data collection, in turn, shown in the executable program of visualization and data storage developed in LabView ™.

3. Results and discussion

Below are the results of the main points of the present study:

3.1. Software development through the LabVIEW ™ environment

Defined the signal of the scale and developed in parameters of fuel consumption (g / s), the variable shown through the serial monitor of the Arduino® is used for the processing of said serial signal in numerical data in the programming environment LabView ™ (Fract / Exp String To Number), which proceeds to the visualization of the fuel consumption in the computer through a virtual instrument (VI) developed in said programming environment. By previously obtaining the serial reading thanks to the VISA tool (read buffer) transformed to numerical data, it allows the acquisition and storage of reports thanks to the Report Generation tool, exporting this data to an Excel® spreadsheet (Figure 1).
For the visualization of the consumption data of the two banks of test engines, an algorithm is developed that allows the reading and processing of the signal [19]. This algorithm is basically divided into three stages, which is developed in a While Loop structure.

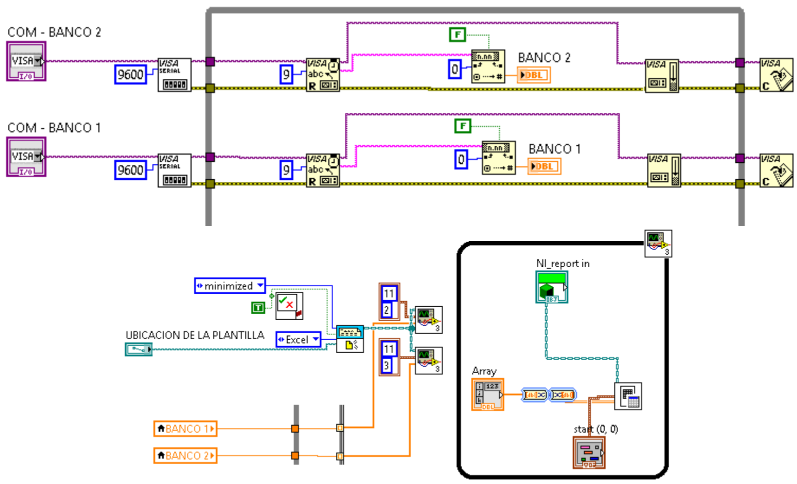

Figure 1. Block diagram of fuel consumption and report

3.2. Tests and discussion

To verify that the fuel measurement system based on the gravimetric principle for applications in banks of thermal engines works correctly, a series of runs were carried out, 1 with the 4-stroke Diesel engine Sokan brand, model SK-MDF300, whose maximum power is 6,6 HP (5,9 kW) at 3600 RPM. In each of the runs, both the one made in the engine and the 3 made with controlled flow output, 8 data were taken with the acquisition software configured to save 1 data per second for 8 seconds, in the same way an flow meter YF-S401, submitting the Fuel Consumption process to the same conditions (Free Exit Consumption, Run 1, 2, 3) the data was taken (Series 1, 2, 3) with the flow meter in order to make a comparison to determine the reliability of the gravimetric measurement system, giving the following results:

Table 1. Results of performance tests

	Time [s]	1	2	3	4	5	6	7	8	**Standard deviation**	**Average**
Consumption free output (Gravimetric meter)	**Run 1 [g]**	9,23	8,98	8,75	8,83	9,07	8,98	9,07	9,18	± **0,163133**	**9,01120**
	Run 2 [g]	13,16	12,96	13,04	12,66	12,87	12,75	12,82	12,9	± **0,159463**	**12,8950**
	Run 3 [g]	15,1	15,26	14,8	14,76	14,67	14,75	14,95	15,26	± **0,236458**	**14,9437**
Engine consumption	**Run [g]**	0,36	0,34	0,36	0,35	0,33	0,34	0,35	0,35	± **0,010351**	**0,3475**
Consumption free output (Flowmeter)	**Serial 1 [g]**	9,13	9,35	9,12	9,06	9,18	9,08	9,12	9,31	± **0,104744**	**9,1700**
	Serial 2 [g]	12,99	13,11	13,05	13,29	13,15	13,24	12,93	12,67	± **0,196246**	**13,0537**
	Serial 3 [g]	15,30	15,13	14,94	15,13	15,03	15,02	14,98	14,94	± **0,122525**	**15,0587**

It can be evidenced in Figure 3 that taking the runs with the gravimetric measurement system and the same conditions with the turbine type flowmeter, the behavior of both flow measurement systems tend to be the same.

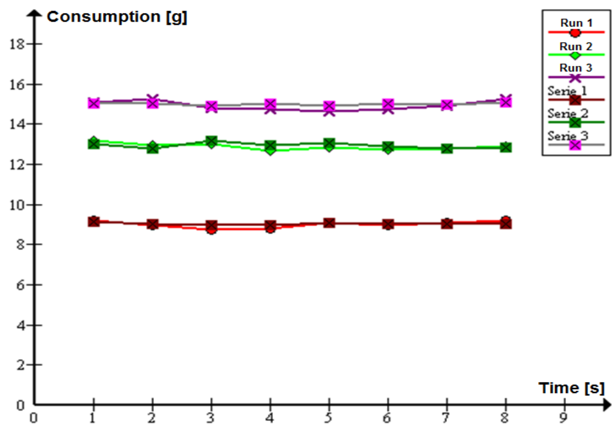

Figure 3. Comparative experimental data of the flowmeter and gravimetric meter

4. Conclusions

The Arduino® code can interpret the signals obtained by the scale and calculate from them the fuel flow rate; no spills due to overfilling, thanks to the two position logic implemented (On / Off). The electronic elements used work at 5 volts and 12 volts, facilitating compatibility with the signals coming from the Arduino®, which, in turn, interprets the measurements taken by the scale with a direct connection to the computer.

It is possible to visualize and store in real time the data resulting from the flow measurement through a simple and intuitive interface, developed through the free trial version of LabVIEW ™. It was verified that the measurement system developed is reliable by means of a series of measurements that were made together with a commercial flowmeter model YF-S401, in order to compare the results, showing that the commercial flowmeter, due to its low Resolution and measurement range, presents difficulties with small flow rates, increasing the percentage of error between both meters. Based on the information obtained from catalogs and scientific sources, the calculation of the uncertainty of the flow measurement system was performed, obtaining as a result that the confidence level of the same is 95% with a coverage factor of k = 2.

References

[1] J.D. Forero, W.G. Estrada and J.S. Guerrero, Desarrollo de una metodología para la predicción del volumen real en la cámara de combustión de motores diésel utilizando elementos finitos, *INGE CUC*, **14** (2018), no. 1, 122-132. https://doi.org/10.17981/ingecuc.14.1.2018.11

[2] H.N. Pallares, S.V. Acosta, J.E.D. Forero and A.R. Montenegro, Implementación de un banco para pruebas en motor Diésel monocilíndrico con aplicaciones investigativas, *Scientia et Technica*, **22** (2017), no. 4, 330-340.

[3] J.M. Riesco-Ávila, A. Gallegos-Muñoz, J.M. Montefort-Sánchez, S. Martínez-Martínez, Procesos alternativos de combustión en motores de combustión interna, *Acta Universitaria*, **15** (2005), no. 1, 36-54.

[4] L. Boyuan, Haiping Du, Weihua Li, Fault-tolerant control of electric vehicles with in-wheel motors using actuator-grouping sliding mode controllers, *Mechanical Systems and Signal Processing*, **72-73** (2016), 462-485. https://doi.org/10.1016/j.ymssp.2015.11.020

[5] J. Agudelo, J. Perez, A. Agudelo, Análisis energético y exergético de un motor diesel de automoción operando en diferentes altitudes, *Revista de Facultad de Ingenierían de la Universidad de Antioquia*, (2009), no. 48, 45-54.

[6] E. Gutierrez, *Sistemas de Inyección no Cartográficos Para Motores de Ciclo Otto*, PhD Tesis, Universidad Politécnica de Catalunya, 2002.

[7] J. Agudelo, Control desacoplado para bancos de ensayo para investigaciones en motores de combustión interna, *Revista de Facultad de Ingeniería de la Universidad de Antioquia*, (2011), no. 59, 23-31.

[8] R. Howlett, Simon D. Walters, Peter A. Howson, Ian A. Park, Air-fuel ratio

measurement in an internal combustion engine using a neural network, *Advances in Vehicle Control and Safety (International Conference), AVCS*. Vol. 98. 1998.

[9] S. Qiang, Lv Chenguang, Data adquisition system for electric vehicle's driving motor test bench on VC++, *International Conference on Medical Phyics and Biomedical Engineering*, Elsevier, 2012, 1725-1731.

[10] National instruments handbook, National instruments, [En línea]. [citado 09 sept., 2016]. Disponible en Internet: http://www.ni.com/data-acquisition/what-is/esa/.

[11] O. Armas, Simón Martínez-Martínez, Carmen Mata, Carlos Pacheco, Alternative method for bulk modulus estimation of Diesel fuels, *Fuel*, **167** (2016), 199-207. https://doi.org/10.1016/j.fuel.2015.11.067

[12] A. Andaloussi, *Metodología Para la Parametrización en Tiempo Real del Proceso de Combustión en MCIA*, PhD Tesis, Universidad Politécnica de Valencia, 2013. https://doi.org/10.4995/thesis/10251/31208

[13] P. Gómez, *Actualización y Puesta en Marcha de un Banco de Ensayos Para Motores de Combustión Interna Alternativos*, Trabajo de fin de grado, Escuela de Ingeniería Industrial de Toledo, Universidad de Castilla.

[14] R. Arias, *Trazabilidad e Incertidumbre en Las Mediciones de Flujo de Hidrocarburos*, 1er. Seminario Latinoamericano de Medición de Flujo de Hidrocarburos, Querétaro, 2002.

[15] J, Martín, *Aportación al Diagnóstico de la Combustión en Motores Diesel de Inyección Directa*, PhD Tesis, Departamento de máquinas y motores térmicos, Universidad Politécnica de Valencia, 2007.

[16] 24-Bit analog-to-digital converter (ADC) for weight scales, Avia semiconductor [En línea]. [Citado 19 junio, 2017], Disponible en Internet: http://www.aviaic.com/ENProducts.aspx?sort_Fid=1

[17] R. Pallás, *Adquisición y Distribución de Señales*, Marcombo, 1993.

[18] S. Monk, *Programing arduino next steps. Going further with sketches*, ed. 2, McGraw Hill, 2013.

[19] LabVIEW user manual, National instruments corporation, Austin, Texas, 2003, 349, Part Number 320999E-01.

Received: August 7, 2018; Published: September 12, 2018