DEVELOPMENT OF A DATA ACQUISITION SYSTEM FOR A CHASSIS DYNAMOMETER OF AUTOMOTIVE VEHICLES

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Abstract. *Regarding the environmental sustainability different automotive vehicles parameters are evaluated as a way to increase performance and reduce environmental damage. This paper describes the development of a data acquisition (DAQ) system based on state of art electronic circuits to improve the potential of an old chassis dynamometer capable of measuring power, fuel consumption and exhaust gas emissions. First of all an introduction about data acquisition systems for dynamometers is presented, followed by the materials and method detailing, the instrumentation discussion, the measurement techniques explanation and the software description. Finally, the results of the simulation are presented in order to validate the developed DAQ system.*

Keywords: *automotive vehicles, chassis dynamometer, data acquisition system, software.*

1. INTRODUCTION

The increasing number of standards related to automotive vehicles fuel consumption and exhaust gas emissions and the actual rigor applied in these standards demonstrate the importance of environmental sustainability concerns coming up in the next years in Brazil and worldwide (ABDI, 2009). According to these norms engine torque and power, rotation speed, fuel consumption and exhaust gas emissions should be evaluated, not only as a way to increase performance but also as an effective strategy for environmental damage reduction.

The primary function of a laboratory testing engine is produce high-quality reliable data. The reliability and precision of a dataset is directly related to the stability and accuracy of the instruments used on interest parameters measurements. The accuracy of a measuring system is a combination of data acquisition device accuracy, sensor and conditioning circuit quality and how precise all those instruments have been calibrated. The data acquisition, validation, manipulation, display and storage quality should be prime considerations of any laboratory. Compared to a commercial all-in-one 'black-box' system, a custom-built data acquisition (DAQ) system offers not only a high flexibility on multipurpose operation (auto ranging input, logging frequency, sampling rates, displays, etc) but also allows easily adaption overcoming different testing situations. Engine testing has changed considerably in the past few decades, from a purely mechanical measuring task into an inter-disciplinary realm incorporating mechanical, electronics and computer hardware and software engineering. The instrumentation of a modern engine includes a wide range of sensors, generating a variety of electrical signals and communication protocols (analog voltage and current, digital pulse I/O, TTL pulse I/O, pulse-width modulated signals, controller area network, RS-232, GPIB, etc.) (Asad, et al., 2011).

A dynamometer is a force measurement tool that can be used to assess automotive vehicles, contributing on increasing their performance. It is a very powerful tool supplying information like power and torque graphs, fuel consumption, exhaust gas emissions rate and composition, among other parameters. There are two types of dynamometers: bench dynamometer (for engines) and chassis dynamometer (for automotive vehicles). A chassis dynamometer works with the vehicle drive wheels on top of a roll, used to coupling the power transmitted to the vehicle wheels to the measurement hardware (Bettes, et al., 2008). During the testing the vehicle is tied down, so it remains stationary as a driver operates it according to a speed profile and gear change pattern (Franco, et al., 2013). A chassis dynamometer evaluates directly the power transmitted to the vehicle wheels and indirectly the engine power. Figure 1 shows an example using an automated controlling system to measure and log data for post analysis from a chassis dynamometer. In more complex configurations the embedded controlling system remotely "drives" the testing vehicle, using throttle and brake actuators. In other applications, it could provide a driver's aid to guide human actions during the test (National Instruments, 2009).
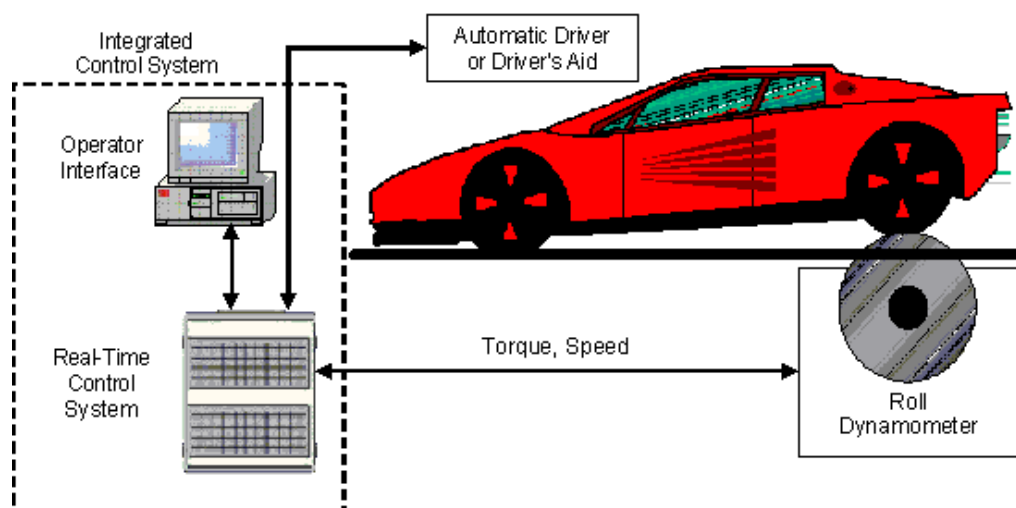
Figure 1. Design of an automated controlling system to measure and log data for post analysis in a chassis dynamometer (National Instruments, 2009)

Technical literature on data acquisition system for dynamometers nowadays is quite rich, for example, a DAQ system to test energy efficiency and driving range of electric vehicles, as a function of gear selection, is reported by Wager, et al., in 2014. In order to evaluate a heavy duty common rail marine diesel engine, operating with two stage injection under load, with vaporized ethanol–water mixtures mixed into the inlet air pipe at various rates a paper was presented by Goldsworthy in 2013. The combustion and emission of hydrous ethanol–gasoline blends in a Flex-Fuel engine has been investigated by Melo, et al., in 2012. Heavy duty common rail marine Diesel engine operating under load with propane mixed into the inlet air pipe, at various rates, has been also presented by Goldsworthy in 2012. Biodiesel impact on buses engines using dynamometer tests and fleet consumption data was studied by Serrano, et al., and published also in 2012. Tractor working in field performance was investigated and reported by Singh, et al., in 2011. A complete dynamics tests in off-road conditions with an instrumented vehicle was performed by Pytka, et al., also in 2011. Among much more works related to this theme.

The Federal University of Bahia (UFBA), in northeast of Brazil, has a chassis dynamometer in its engine testing laboratory which requires a new data acquisition system. This equipment purchased more than ten years ago is not anymore able to provide test data in a correct numerical format because all data output are currently with some kind of malfunction, and maintenance is not anymore ensured by the manufacturer.

This paper reports on the development of a data acquisition system for the chassis dynamometer mentioned above. The measurement of torque and rotation speed will be described in detail, as well as, the instrumentation, measurement techniques and the software development. It is pertinent to mention that DAQ systems are commercially available, however, these systems can also be assembled from commercially components by the test engineers and the focus of this work is on the development of such self-assembled systems. Moreover, this paper does not deal with the subjects like chassis dynamometer operation or automotive vehicles tests. Finally, one presents the results of an electrical simulation in order to validate the DAQ developed system.

2. MATERIALS AND METHOD

Modern data acquisition is understood as the process of measuring and store a given physical phenomenon assisted by a computer. As seen in the block diagram in Fig. 2, a data acquisition system consists of:

- Sensors: also called transducer, convert a physical phenomenon into a measurable electrical signal (i.e. thermocouple, microphone, strain gauge, encoder, etc).
- Signals conditioners: manipulate an electrical signal into a form that is suitable for the data acquisition system input (i.e. amplification, attenuation, filtering, and isolation).
- Data acquisition device: provides a digital (numerical) representation of an analog signal in a numerical word that a computer can handle. Thus it has an analog-to-digital converter (ADC) and a computer bus (i.e. USB, PCI, PCI Express, Ethernet, etc) interface. In practice, analog signals continuously vary over time and data should be taken periodically (sampling) at a predefined rate. These samples are transferred to a computer where the original signal is reconstructed from the samples by software.
- Software: numerical structure based on commands, logic instructions, data and mathematical functions running serially on time in a personal computer (PC) (Von Neumann machine), ensuring a dialog with the user, controls the operation of data taking device, generates visualization windows and stores measured data.
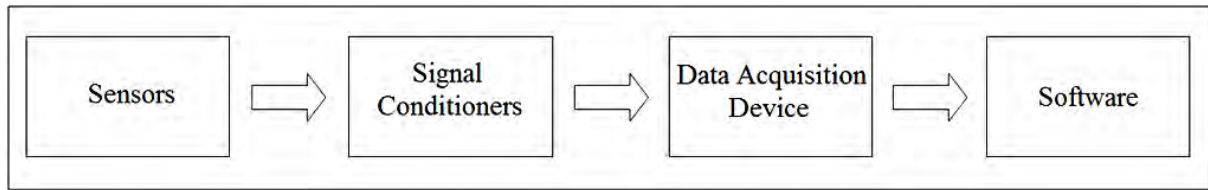
Figure 2. Block diagram of all parts of a data acquisition system

2.1 Sensors

An inductive sensor from Metaltex (see Fig. 3) was used to measure the vehicle rotation speed; the choice of this device is based on its easy operation, robustness and high data reliability.

Figure 3. View of the inductive sensor used to measure rotation speed

An inductive sensor is a proximity sensor based on the self-induction principle and detects ferromagnetic materials without direct contact. When this sensor moves into the vicinity of a ferromagnetic object, the coupling between its magnetic field and an internal coil changes, changing the logic state of its electric output. This change can be detected by a sensing circuitry, which can sign to some other device whenever ferromagnetic material is detected (Fraden, 2004).

This sensor was connected to a rotating axis delivering pulses whenever its front face coincides with a tooth attached to the axis. Coupling the sensor to the roll of the chassis dynamometer allows the measurement of the roll rotation speed and, consequently, the vehicle rotation speed. The technical sheet of the inductive sensor used is shown in Tab. 1:

Table 1. Technical sheet of the main characteristics of the inductive sensor

Type:	PSC18-5NF
Connection	Cable
Diameter	18 mm
Sensing distance	5 mm
Signal output	NPN
Logic	NC
Mounting	Flush
Power supply	10~30 Vdc
Max. frequency	600 Hz

The wheels torque and power are determined indirectly by measuring a force, to do so a load cell from Tedea-huntleigh was used (see Fig. 4), which is a robust sensor and ensures a minimum data error.

Figure 4. View of the load cell used to measure force

A load cell is a quantitative sensor used in force measuring, converting this physical quantity into an electrical signal. Generally, this device is based on four strain gauges; a resistive elastic device whose resistance is a function of its deformation. The strain gauges may be arranged in different geometries, where gauges could be disposed along different axes, usually connected as Wheatstone bridge circuits whose minimum unbalance can be detected (Fraden, 2004).

This sensor is mechanically connected to an eddy current brake of the chassis dynamometer through an arm lever and measures the torque applied to the brake in order to overcome the automotive vehicle wheels power. The technical sheet of the used load cell is shown in Tab. 2:

Table 2. Technical sheet of the main characteristics of the load cell.

Type:	355
Connection	Cable
Capacity	500 kg
Sensibility	2 mV/V
Total error	0.015% Rated Output
Temperature range	-30°C to +80°C
Power supply	10 Vdc

2.2 Signal conditioners

The inductive sensor electrical output is a sequence of pulses and requires a frequency to analog voltage conversion (see Fig. 5) before it is led into a data acquisition system. A frequency to analog signal converter from Brodersen was used to perform this task. The converter frequency range can be selected by a rotating switch and its power supply is 24-48V AC/DC or 115-230V AC.

Figure 5. Frequency to analog signal converter used to condition the inductive sensor electrical output

The electrical signal output from the load cell is few millivolts and requires amplification before it is led into a data acquisition system. As seen in Tab. 2, the electric load cell sensibility is 2 mV / V, for example, supplying the cell with 10 Vdc will result in 20 mV in full scale. An amplifier from Dexter (see Fig. 6) with a gain of 500 was used to do so. Its output ranges from 0 V to 10 V which is suitable for most DAQ system inputs and its power supply can be any value between 15 and 30 Vdc.
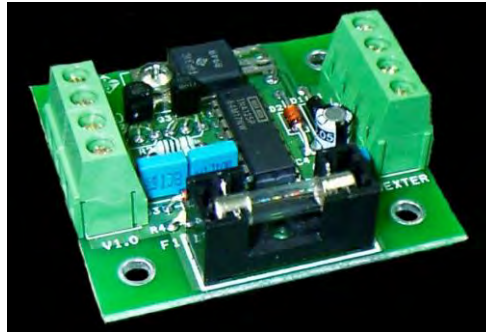
Figure 6. Amplifier used to condition the load cell sensor electrical output

2.3   Data acquisition device

To create an interface between the measuring signals and a computer was specified a data acquisition device (see Fig. 7) capable of providing basic data acquisition functionality for applications such as simple data logging, testing simulation, appropriate for environmental, industrial and educational measurements. The DAQ device selected was the National Instruments (NI) USB-6008 which consists of 8 analog inputs (12-bit, 10 kS/s), 2 analog outputs (12-bit, 150 S/s), 12 digital I/O, 32-bit counter and an USB port, compatible with the National Instruments LabVIEW^{TM} application software template.

Figure 7. National Instruments DAQ device used to acquire the measuring signals

2.4 Software

The exploitation software was developed based on the National Instruments LabVIEW^{TM} requirements; written to execute different experimental and post-processing tasks. This software template allows scale from design to test and from small to large systems through a graphical programming ambient with an extensive library of functions and subroutines covering mostly any programming task. It also contains a specific library application for data acquisition, data processing, analysis, data and results exhibition and storage.

Figure 8 shows the main menu of the software written in LabVIEW^{TM}. This window displays the buttons with links to the load cell calibration menu, test setup menu, test run menu, and test graphs menu.

Figure 8. Print screen of the software main menu window developed

Figure 9 shows the load cell calibration menu which enables the zero adjustment, avoiding offset errors due to operating conditions.

Figure 9. Print screen of the software load cell calibration menu window developed

Figure 10 shows the test setup menu which allows setting the user's profile (name, date, time, local and working folder), atmospheric conditions (temperature, pressure and humidity) and the engine setup (type and power correction factor).

Figure 10. Print screen of the software test setup menu window developed

Figure 11 shows the test run menu. In this window it is possible to monitor the actual test in progress, through the torque and rotation speed numeric indicator, as well as the plotting of the torque and power graphs as a function of rotation speed.
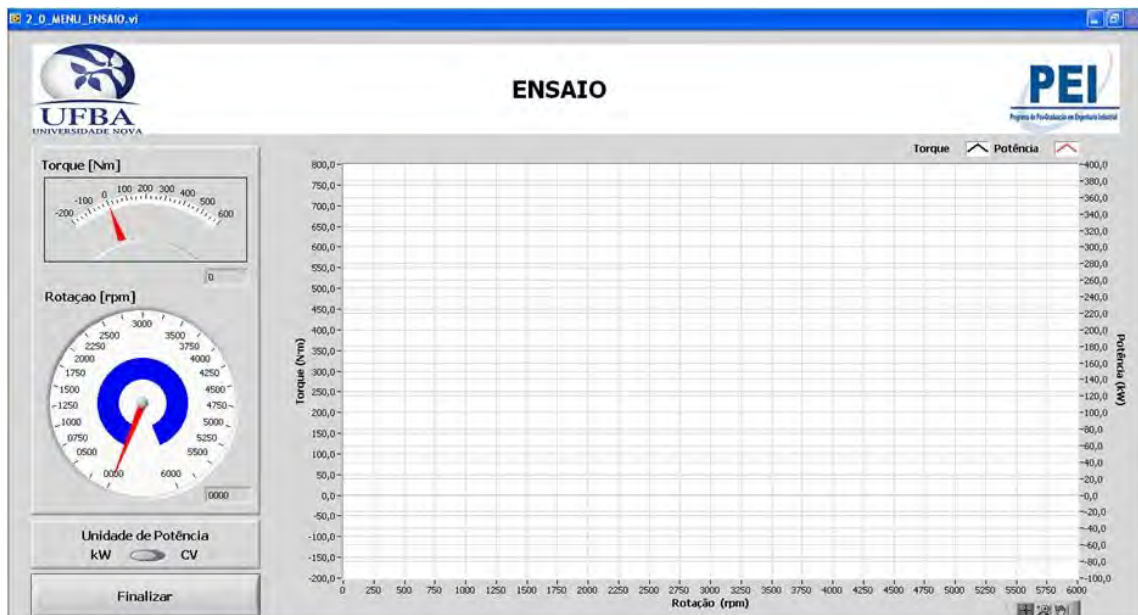

Figure 11. Print screen of the software test run menu window developed

Figure 12 shows the graphs menu. This window displays the plotting of torque and power graphs as a function of the rotation speed applying two adjustments: the power correction factor and the dissipation occurred all the way long from engine to the wheels, producing the wheels graph using it first fit, and the engine graph using both information mentioned. Furthermore, it shows the maximum amounts of torque and power, taking into account the engine power, the power transmitted to the wheels and the dissipated power, moreover the value of the rotation speed and the power correction factor in this circumstance. Finally, one can save the data and graphs.
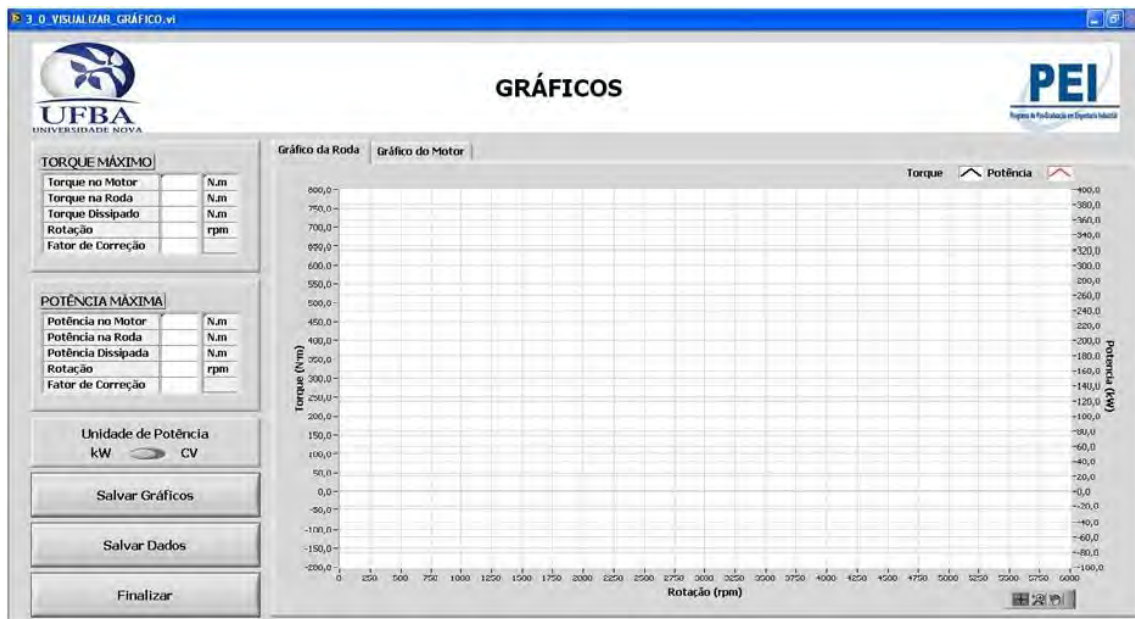
Figure 12. Print screen of the software graphs menu window developed

3. RESULTS AND DISCUSSION

In order to validate the developed data acquisition system, instead of using the chassis dynamometer electric signals, mixed with its own electromagnetic noise, which could lead to doubt or misinformation on the DAQ system validation, the developed system was tested using signals from a numerical simulation performed by an independent PC and a digital-to-analog converter (DAC).

Figure 13(a) shows two different data settings, in black it is represented the simulated double ramp ranging from 1 to 9 volts, in red is presented the results of the data acquisition performed with the DAQ system. Figure 13(b) shows the quality data acquired test. Back to Fig. 13(a) one can see three interest regions on the presented graphs. Initially data is converted with no problem showing a perfect adjustment to the simulated signal, on region 1 it is easy to see the integral error characteristic of most of the successive approximation ADCs. The discrepancy appeared on region 2 seems to be created by a RC cell used as low pass-filter at the DAC output. Finally, region 3 could be related to an internal characteristic of the NI USB-6008, probably due to its pre-amplification or sample and hold stages, those possibilities should be further investigated.
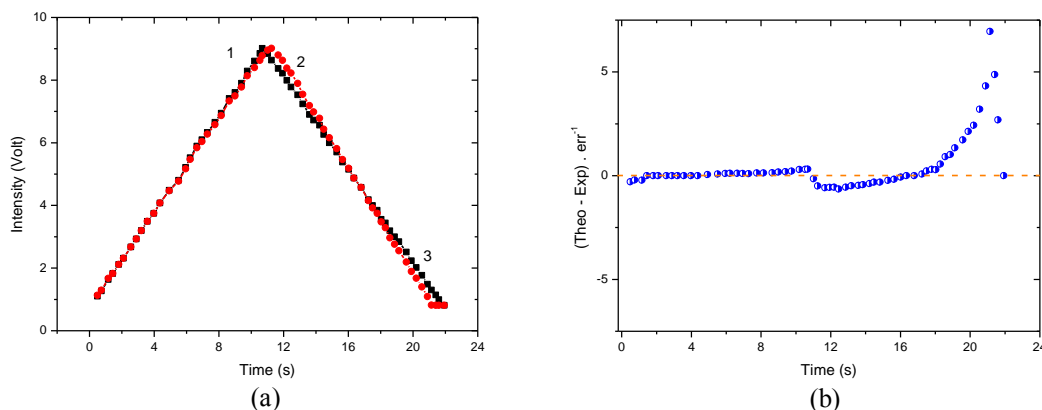

| (a) | (b) |

Figure 13. (a) Simulated electric signal used on DAQ system validation. In black a simulated double ramp, in red the data acquisition performed with the DAQ system. (b) DAQ system quality data test.

From the validation process one can apprehend that the developed DAQ system was capable to acquire analog signal, convert and communicate the numerical words. The DAQ system integral nonlinearity is about 3% for 63% of the converted data, but authors agree that it is more realistic consider its intrinsic uncertainty as 8.4% a little more than the 2 sigma limit.

Once the DAQ system was validated it was applied for torque, rotation speed and power determination, still using simulated signals it could be possible acquire, convert, store, calculate and display the curves of torque (in black) and power (in red) as a function of rotation speed presented in Fig. 14. Now, one can say that the renewing of the digital measuring system of our chassis dynamometer is achieved and ready to be used.
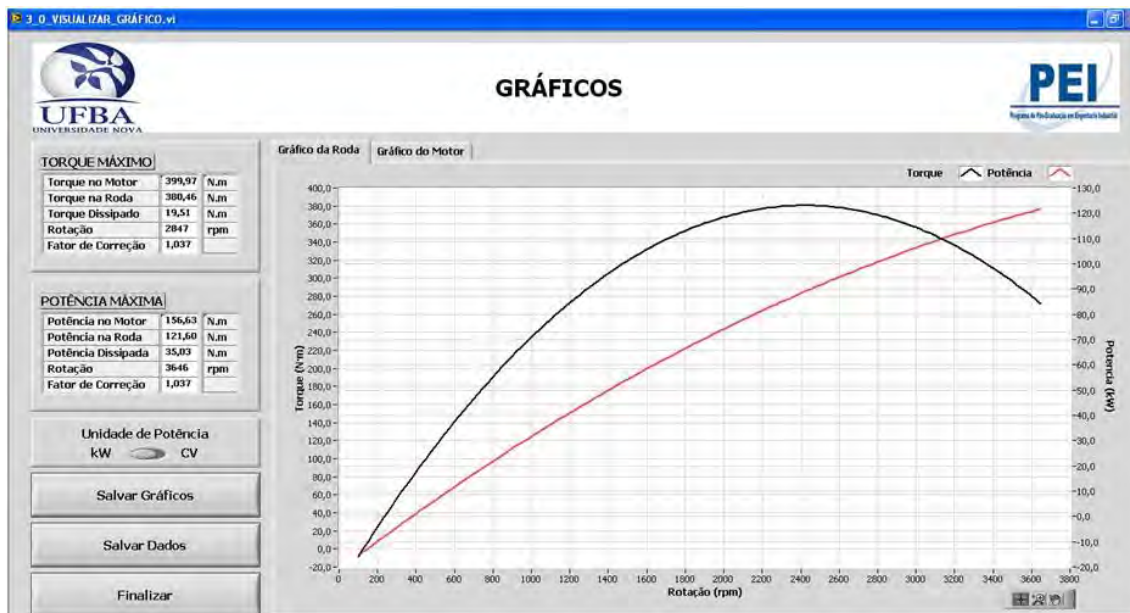

Figure 14. Print screen of the software graphs menu window displaying simulated graphs

4. CONCLUSION

This work provided the Federal University of Bahia (UFBA) a new self-assembled data acquisition system for a chassis dynamometer. Therefore, the authors have described in detail the instrumentation and measurement techniques and the development of software for a chassis dynamometer measurement.

The data acquisition system developed, assembled and validated provides data with intrinsic uncertainty of 8.4%, i.e., a little more than 2 sigma which ensures the reliability of the DAQ system. Finally, it allows the test engineer to explore automotive vehicle performance providing further research in fuel consumption and exhaust gas emissions tests.

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6. RESPONSIBILITY NOTICE

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