Electronic system control and data acquisition on an automotive dynamometer for didactic use

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Abstract: Integrated commercial controls for dynamometers do not have appropriate characteristics to perform teaching or research tasks. This limits its didactic use, because these standard controls let not analyse or determine engine characteristics not contained in such standards, such as torque, speed, temperature and humidity which hinders its use in an academic environment. A control with didactic purposes becomes a great ally in the professional training made by the institution and allows better use of dynamometers for research and teaching, allowing the student to gain knowledge in control systems and data acquisition.

Keywords: Dynamometer, data acquisition, didactic.

1. INTRODUCTION

Dynamometers are used to measure torque and power since the beginning of the 19 Century, when the English William Froude designed a dynamometer to determine the power and torque of a naval steam engine [1]. Since them these equipment where continuously developed and became a very important tool to understand and help to enhance the efficiency, specially, of internal combustion engines. Having this in mind, this work will demonstrate the importance of the use of these machines in an academic environment to aid students, as well as teachers, to understand engines behaviour under different conditions. It will also show the importance of data acquisition, (Torque and RPM) and explain how it works and the issues to do it.

2 Torque and power definition

According to [2] the torque generated by one engine creates mechanic resistance that can be determined by means of a dynamometer attached at that engine. In agreement to that, the Equation 1 express how torque is calculated:

$$T(Nm) = F(N)xd(m) \ (1)$$

where F is normal force and d is the distance from the center of the rotor.

The power, calculated by Equation 3, delivered from the engine to the dynamometer is determined by the product of engine torque (Equation 2) and angular velocity:

$$T(Nm) = 2\pi N(\frac{rev}{s})xT(Nm)(2)$$

$$P(kW) = 2\pi xN(rpm)xT(Nm)x10^3 \text{ (SI) (3)}$$

Equation 3 is given in International System units.

For Imperial System, use equation 4 as follows:

$$P(hp) = \frac{2N(\frac{rev}{min})xT(lbf.ft)}{5252}; \cdot(4)$$

where power is given in HP (Horsepower), angular velocity in RPM and torque in lb/ft (pound-foot). The constant 5252 is obtained over the units conversions (SI to Imperial).

2.1 Torque and angular velocity data acquisition

In practically all engineering areas there is a need to measure physical units, as force, temperature, velocity, speed. Those parameters are determined by devices known as sensors that can convert one physical entity in an electric interpretable signal. The active elements of the sensors are known as transducers [3].

Load cells are described as transducers that generate a voltage signal as result of one force applied, generally in one direction. This kind of force transducers are often by an elastic material (metallic base that is compressed, pulled, bent or twisted) and one deflection element (strain gauge) that generates a resistance or capacitance variation, allowing, this way, to measure the applied force [4]. Those voltage variations presents very low values, in the 10^{-6} scale (millivolts), hindering the process of data acquisition, one time that the values are susceptible to external interferences. Moreover, load cells needs positive and negative supply voltages, compelling the system to have a symmetric power supply source (Figure 8). In addition to that, there is no signal conditioning, so there is no control regarding offsets and gain. Having that in mind, one system to condition the signal was designed. The IC selected was the Burr Brown® INA 125. It is an instrumentation amplifier frequently used in load cells applications. Additionally to INA125, one operational amplifier was used, STMicroelectronics® LM358N to control the offset position. The first basic circuit was breadboard mounted, according to INA125 schematics, that uses one potentiometer to increase or decrease gain. Then, the operational amplifier LM358N was added to control offset values.

As stated before, two different parameters are crucial to determine power output of a testing engine. One is torque, that was just explained, and the second is the angular velocity, which will be explained as follow.

Internal combustion engines usually reach relatively high angular velocity in order to achieve higher power output or decrease vibrations. To precisely collect this parameter two different types of sensors are generally used: Hall Effect sensor and inductive sensor.

The Hall Effect sensor needs a power source supply, frequently within a range between 0 and 12V. and one pull up resistor (10kΩ) connected between power and signal. It works together with a toothed wheel (60 teeth) and returns a digital signal (square wave) allowing a posterior conditioning by a microcontroller, in this case the Arduino® board. In addition to that, there are three pins to connect the sensor to the microcontroller and one shielded cable to avoid external interferences. This system is easier to install, compared to the inductive model, once it only needs a direct controller/sensor connection as well as no signal condition.

Magnetic reluctance can be described as resistance to magnetic flow and matches with electric resistance of one electric circuit [5]. This kind of sensor does not need a power supply to work, and often have only two wires, signal and ground. There are some models that have one metallic shield connected to ground, to eliminate external interferences.

On the other hand, it generates one sine wave that is harder to read by the microcontroller. This way, one conditioning circuit was designed using the Texas Instrument® integrated circuit (IC) LM1815N. This IC read a sine wave and generates a square wave, or a digital wave, that is easily read by the microcontroller. Using the configuration according to IC datasheet as base, one first sketch was assembled using a breadboard and one electric motor with a 60-2 toothed wheel, in order to observe the different pulse coming out of the missing teeth with an without conditioning circuit.

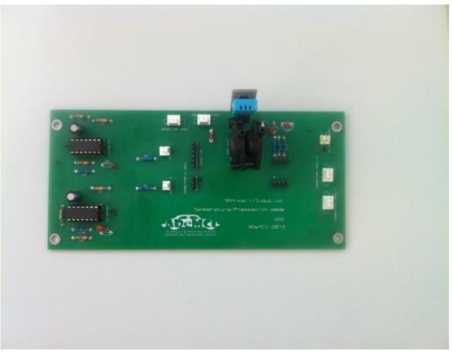

Figure 1:RPM conditioning and weather station. (Source: Authors).

For the first attempts, one provisional test bench was created using one electrical motor, controlled by a frequency inverter, and one 60-2 toothed wheel attached to it. This way it was easier to accomplish not only different tests with different types of sensors ,but also test different configurations, regarding sensor/wheel clearance and orientation. It also enables a more accessible way to create and modify several setups for the programming design. During the tests with the Hall sensor, it was observed that it need a carefully installation, once the position and direction can change the waveform output.

Figure 2: RPM test bench. (Source: Authors).

2.2 Weather station

Different conditions may change engine performance and generate different results. In order to increase accuracy within test results it is important to be aware of the environment test conditions. There are several different international standards concerning engine test conditions and describes temperature, humidity and altitude corrections. Therefore, to generate a more reliable result, this project has one specific topic to point out how the procedure of collect, process and display values of temperature, humidity and pressure (atmospheric and intake manifold) are done. The initial idea was to use three different types of sensor: one for temperature, one for humidity and two manifold absolute pressure (MAP) giving 4 sensors in total. However, after some research regarding humidity sensors, the model Micropik® DHT 11 has proved to be a better choice, due to its capacity to determine both temperature and humidity.

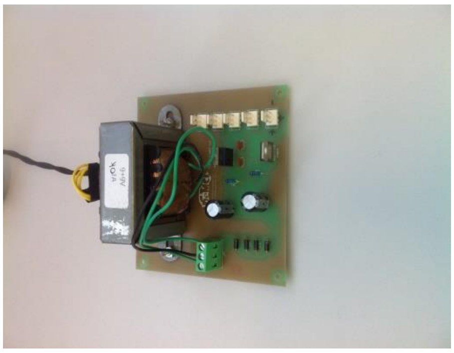

Figure 3: Symmetric source. (Source: Authors).

3 ELECTROMAGNETIC BRAKE

The function of a dynamometer is to impose variable conditions of load and RPM, within a range of these parameters and, as consequence, determine in a precise way, torque and power of a testing engine [1]. The type chosen was the Eddy Current dynamometer once there are four different models within the automotive maintenance laboratory (see table 1) and another one Siemens (same model) in electric machines laboratory.

Eddy Current brakes need a control unit in order to increase or decrease charge applied on the testing engine. These control units share the same objective but work in different ways.

Fist test was done with FYL® control unit and a light bulb to simulate the magnetic brake. In parallel to that, one oscilloscope is attached to the light terminals, to observer the type of wave from the system. To compare results, the second step was to realize the same tests with a fan control dimmer. The circuit and waveform are very similar to the light switch.

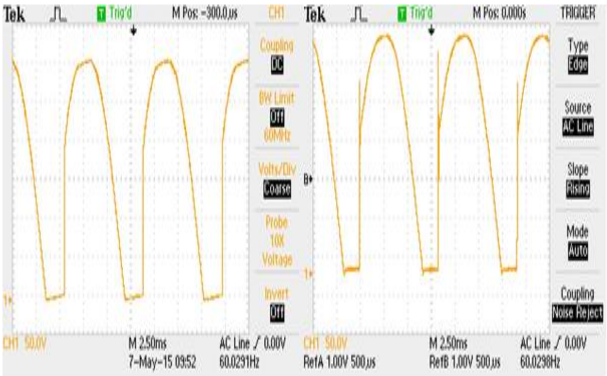

Figure 4: FYL control and dimmer switch waves comparison. (Source: Authors).

4 RESULTS

To execute the first test one FYL brake control unit was used. The test consist in apply one load in the engine by increasing the amount of electric current flowing inside the brake coils. This way, the metallic disks that are connected to the testing engine are stopped by the action of the magnetic field generated. This torque is then captured for the load cell.

Then, its angular velocity is increased to a fix value to start the data acquisition process. Next, it is given full throttle and, at the same time, increases the load in the brake. The results of one of the tests are displayed in the figure 5:

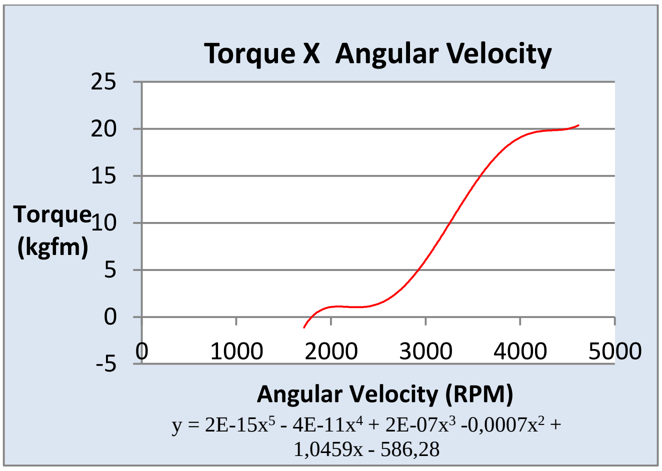

Figure 5: RPM x Torque chart. (Source: Authors).

RPM and torque data acquisitions are accomplished with success, but can receive improvements. Moreover, the weather station allows correcting some parameters and, as torque and RPM, was already completed. Furthermore, the brake control unit is already defined, however the PID (proportional integrative derivative control) is not implemented yet, but it is just a matter of time to be completed, tested and validated.

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