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Development of a Digital Controller with Data Acquisition to a Test Bench for Eletric Motors

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***Abstract*— The electric motors' test benches are greatly used by electric motors manufacturers and drive system designers. In this paper it is described the conversion process of an older manually controlled test bench, in an automatic digitally controlled one with integrated data acquisition system. The renewed test bench is based in a two quadrant eddy current electromagnetic brake, in which the manual torque controller and analog indicator have been replaced by an automatic digital controller, by which is possible to predefine a torque profile for the test. With the data acquisition system it is possible the acquisition and recording of speed, torque and internal temperature on the brake. Special focus is given to the power converter used to control the current in the electromagnetic brake and to the torque data acquisition system, namely, the calibration of the load cell.**

Keywords - Eddy Current Brake; Data Acquisition; Load Cells; Electric Motor; Test Bench.

I. Introduction

The great increase in the cost of the oil verified in the last years, associated with environmental and ecological concerns expressed by the public opinion around the world, resulted in great efforts and investments to create alternatives to the vehicles based on Internal Combustion Engines (ICE). As a consequence of these efforts, in the last years appeared many models of Electric Vehicles (EVs) and Plug-in Hybrid Electric Vehicles (PHEVs). The advantages of EVs and PHEVs over the ICE vehicles are rapidly increasing, mainly due to the strong research in the areas of power electronics, electrical machines, and battery technology. According to a study made by the International Energy Agency, the rationalization and the efficiency improvement of electrical machines will contribute to a worldwide reduction in terms of electricity consumption of about 7% [1].

In order to test new types of electrical machines, to assess their performance and to design the drive systems it is necessary to develop test benches, which allow the application of a controlled load to the electrical machine that is under test. These kind of loads can be implemented by means of mechanical brakes, hydraulic brakes or electric brakes [2]-[4].The test benches are also used during the design phase of electrical machines as verification tools, to evaluate the properties of the electrical machines in their life cycle and, if necessary, to readjust their characteristics [5]. They are also very useful in the EVs research and development, enabling the study of several aspects related with EVs, namely, to determine their performance, behavior under different scenarios, and even to determine their autonomy. In order to improve the obtain results in the tests, it usually are added flywheels to the system to represent the road vehicle inertia [6].

In this paper is presented the development of a digital controller and data acquisition system to measure the torque and speed in an electromagnetic brake test bench. The work presented in here consisted in converting an old analog and manually controlled test bench, with an eddy currents electromagnetic brake, in an automated and digitally controlled test bench. In this sense, is presented the development of the digital control system and the data acquisition system.

II. Description of the Test Bench for Electric Motors

The old manually controlled test bench was composed by an electromechanical brake, a torque sensor with an analog indicator and by a support platform to attach the motor under test. To allow the test of machines with different sizes and heights, the support platform is coupled to a mechanical system that permits to adjust the position of the motor to enable the correct positioning and coupling to the brake. Fig. 1 shows a picture of the manually controlled test bench before the automatization process.

The electromechanical brake is based in the eddy current principle and only works in two quadrants [7], i.e., it only puts torque in clockwise and anticlockwise direction and does not works as motor.

The main advantage of the eddy current brake is the absence of friction in rotating parts, and hence does not produce noise or hot friction. This brake presents a very low dynamic, nevertheless, it was only used to make tests with constant mechanical load [8].

In the manually controlled test bench the load applied to the motor under test is controlled by a variac. This variac allows the regulation of the voltage applied to the brake, and this way controlling the torque applied to the motor under test. The measurement of the torque can only be made in a single direction of rotation at each time. So, to change the rotation of the motor it was necessary to stop the test to change the position of the dynamometer sensor.

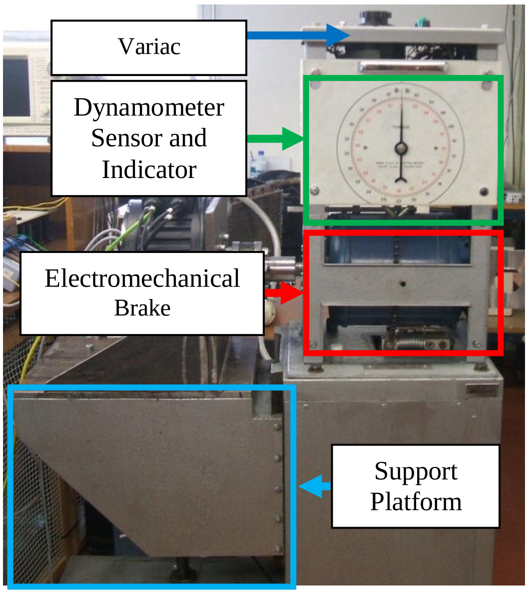

Figure 1. Test bench with eddy current brake.

With the automatization process of the manually controlled test bench it will be possible to automatically control the applied torque to the motor under test, locally or from a Personal Computer (PC), connected to the test bench through a USB port. With this feature it is possible to apply a predefined load curve to the motor under test, which was previously defined and stored in a file on the PC. It will be also possible to make the acquisition of the speed, torque, and mechanical power, during the test period. All these measured parameter can be stored in the PC. Moreover, it will be possible to measure the torque in both directions of rotation, without having to change the position of the torque sensor.

To accomplish these requisites it was necessary to implement a current control for the brake, and to install some sensors, to measure temperature, speed, and torque. This last one should allow the measurement of the torque in both directions of rotation, as stated above.

Fig. 2 shows the block diagram of the automatic controlled test bench. The test bench acquisition system was designed to acquire several parameters as voltage, current, speed, torque and temperature in the brake and send the information to a PC. The signal conditioning circuit serves as interface between sensors and the microcontroller. All the sensors are fed by a circuit that rectifies and adjusts the electrical grid voltage to the necessary voltage level. It was also included a signalization light to warn the persons around and establish safe test conditions.

III. Automatization of the Test Bench

In this item are described in detail the different parts that compose the automatic controlled test bench. It is presented the simulations and experimental results of the current control of the brake. It are also described the sensors to measure torque, speed, temperature, voltage and current in the brake. Finally it are described the developed Human Machine Interfaces (HMI) of the test bench and in the PC.

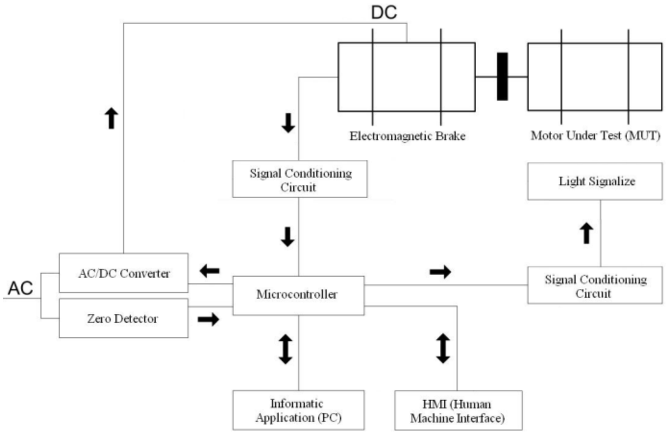

Figure 2. Block diagram of the automatically controlled test bench.

The control of the test bench was made with an *Arduino Mega 2560* board, which is composed by the microcontroller *ATmega2560* of *Atmel* and several other peripherals.

The main characteristics of this microcontroller are: 16 channels of 10-bit analog-to-digital conversion; 16MHz of clock frequency; 256 kb flash memory; 6 timers (2 of 8-bits and 4 of 16-bits); 54 digitals pins input/output which 14 are of digital PWM.

Another advantage of using this microcontroller board is the fact that it is not necessary an external programmer, to program the microcontroller. The platform *Arduino Mega 2560* already has this functionality, it is only necessary to connect the microcontroller to the PC through an USB cable. The software used to create the programs for the microcontroller was the *Arduino IDE*.

The routines in the microcontroller to obtain the speed, rotation direction, and the electrical grid voltage zero crossing detection use microcontroller external interruptions. The communication between the microcontroller and the PC is made using the available USB port, while the communications between the microcontroller and the test bench HMI is made through the serial port. The thyristors control and the signalizing light control are made through digital outputs. For the acquisition of the signals from the sensors it was used 4 ADCs inputs: to the load cell, to the temperature sensor, to the brake voltage, and other to the brake current.

A. *Half-Controlled Bridge Rectifier Simulation*

To help in the design of the brake current controller it was developed a simulation model of it. In order to obtain more realistic simulation results it is necessary to measure the parameters of the electromagnetic brake. For that purpose it was used a RLC meter to obtain the winding parameters: $R = 60\ \Omega$ e $L = 2.9$ H. With these values it was implemented, in the simulations software PSIM, the simulation model of the proposed current control system of the brake, as shown in Fig. 3. The simulation model comprises a single phase half-controlled bridge rectifier, the brake (modeled by an RL series circuit with values previously measured), and the control system. The control system allows the control of the thyristors firing angle between 0º and 180º in both semi-cycles of the electrical grid voltage. All the simulations were made with the software PSIM 9.0 from Powersimtech.

In Fig. 4 are shown the simulation results with the thyristors firing angles of 76º and 256º in positive and negative semi-cycles of the electrical grid voltage, respectively. Changing the firing angle it is possible to control the average value of the output voltage, and consequently the voltage applied to the brake.

B. Sensors Used in the Test Bench

To monitor the current and the voltage in the electromagnetic brake it were used two Hall-effect sensors. These sensors were chosen due to its linearity and accuracy. The signal output from both sensors is in current, making them more immune to noise and also allows to adjust the amplitude of the signal that is acquired to a value compatible to the ADCs range, through a simple resistor. To measure the applied voltage in the brake it was used one LV 25-P LEM sensor. With this sensor it is possible to measure voltages up to 500 V. To measure the current it was used a sensor with a full scale value of 50 A. Since the expected measurements have at maximum 3.5 A, it was necessary to change the sensor sensibility. To change the sensibility of the sensor the fed wire was passed in the interior of the sensor 10 times, thereby obtaining a new full scale for the sensor of 5 A.

The sensor chosen to measure the torque in the test bench was a load cell of 50 kg, with precision Class OIML R60 C3 [9]. It was chosen a load cell type S, because this way it is possible to measure the tensile and compressive force, i.e., in both directions. The load cell was fixed to the test bench by two tie rods in order to prevent the occurrence of transverse forces. The measurement of the arm between the load cell and the center axis of rotation is 0.142 m, allowing the measurement of a maximum torque of approximately 100 Nm.

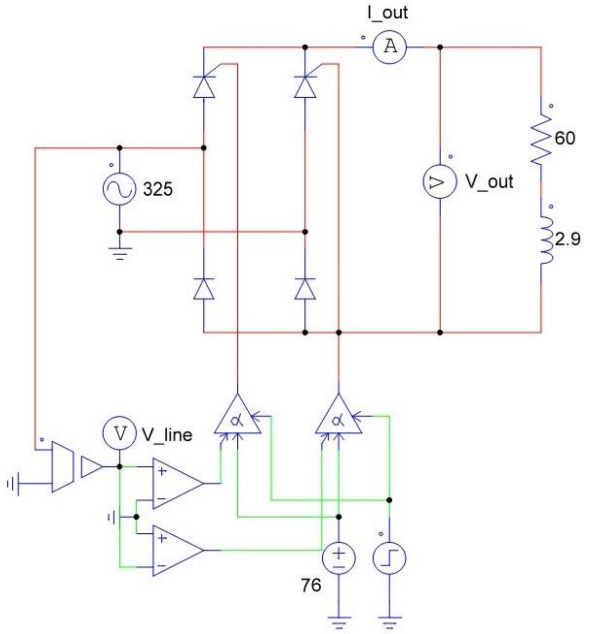

Figure 3. Simulation model of the test bench.

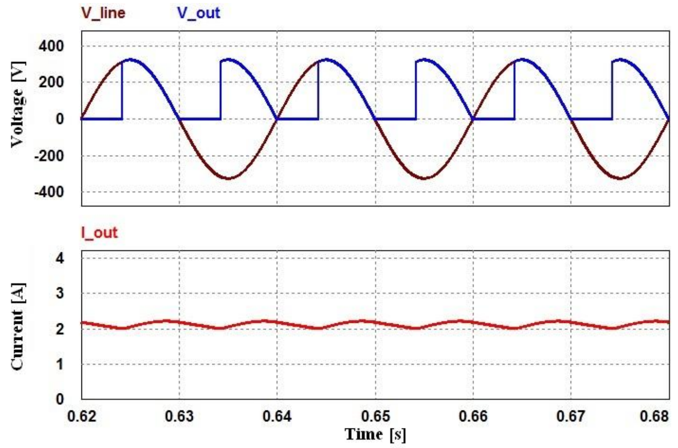

Figure 4. Simulation results of voltage and current in the output of the developed power circuits for the test bench.

The temperature of the brake is monitored to prevent the brake to be damaged by excessive temperature. Due to the inexistence of information about the maximum permitted operating temperature, various tests were performed with the brake at maximum load. To prevent the destruction of the brake by over temperature, it was established a maximum operating temperature of 90ºC inside the brake. There is a difference in the temperature inside the brake and the exterior temperature of approximately 30ºC, implying that the sensor measures a maximum temperature of 60ºC (outside of brake). The temperature sensor chosen was the LM35DT due to their accuracy and operating range of temperature (-55ºC to +150ºC).

To acquire the speed and the direction of rotation it was used a rotating magnetic sensor that can operate up to 30,000 rpm and that presents several output options. It was created a support to fix the integrated circuit that makes the measurement of the rotations. The magnet used with the rotations sensor was fixed in the brake shaft. This sensor has a good accuracy, it was verified a deviation of ± 2 rpm at 3,000 rpm. The Ri/Index sensor output is used to calculate the rotations and the A/B pulses are used to detect the direction of rotation.

C. Human Machine Interface (HMI)

It has been developed two interfaces for the automatic controlled test bench. One is placed in the test bench itself and the other is a software application that runs in a PC.

The HMI placed in the test bench is composed by a LCD and 6 navigation buttons (Fig. 5). With the navigation menu (Fig. 6) it is possible to select the operation mode of the test bench, to be local or remote. In local mode the required torque can be adjusted from a variac or by the navigation buttons. On the other hand, the remote mode allows controlling the test bench from a PC.

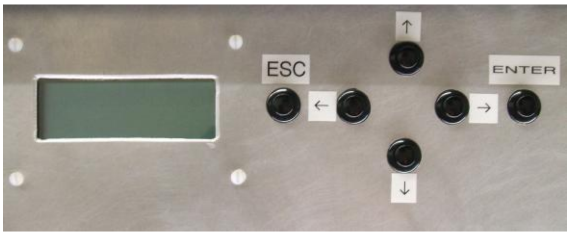

Figure 5. Local Human Machine Interface of the test bench.

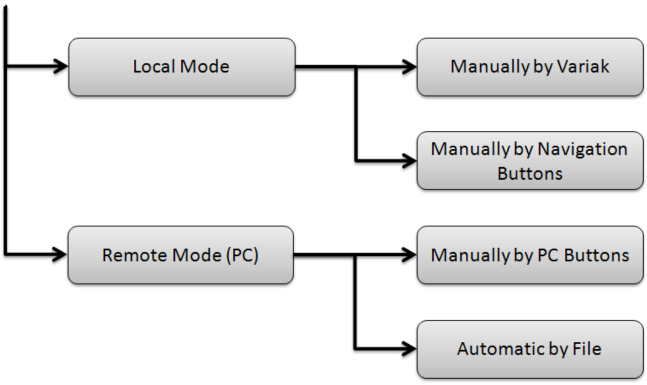

Figure 6. Stucture of navigation menu of the local Human Machine Interface of the test bench.

The HMI for the PC was developed in Qt, which is a cross-platform application framework that is widely used to develop application software with Graphical User Interface (GUI). The Qt was chosen because it is an open platform and it allows the generation of an executable file that does not requires the Qt package to be installed during the running of the application, and does not requires license fees.

In the left side of Fig. 7 is showed a tachometer that presents the torque applied to the machine under test. The full scale is 100 Nm, which is the maximum torque of the test bench. However, with the present control system of the voltage applied to brake, the maximum limit is 52 Nm. The tachometer (on the right) shows the rotations value of the machine. In the center of the application is showed the actual value of the brake temperature and the actual mechanical power of the machine under test, calculated from torque and actual speed.

In the same panel it is also possible to choose the torque that is being applied to the machine that is being tested, using the shown up/down buttons. The torque can be incremented with increments of 1 or 10. This is only possible when the local HMI interface of the test bench is setup to the remote mode.

As security measure, when a test is being done in the test bench, the flashing message "Attention Motor Under Test" appears, accompanied by two warning signals, as shownin Fig. 7. In emergency case it is possible to stop the test through the button "Emergency Stop".

In mode "Diagram" of the application (Fig. 8) it is possible to see the torque and the mechanical power along time, in function of the test speed. After finishing each test, it is possible to give a name to the graph and save is as an image file in the .PNG format.

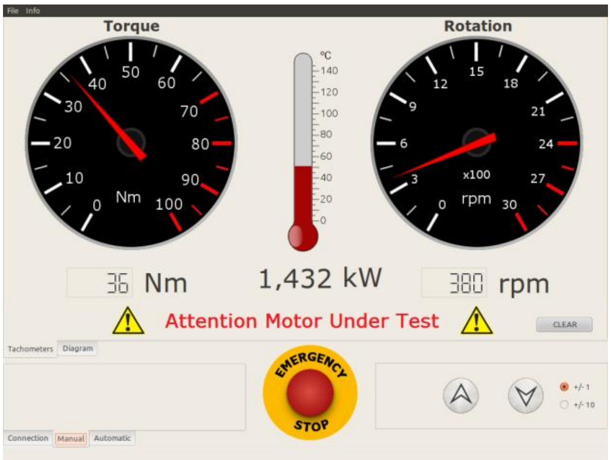

Figure 7. Graphical application of the software of data aquisition in the menu "*Tachometers*".

Figure 8. Graphical application of the *software* of data aquisition in the menu "*Diagram*".

IV. CALIBRATION OF THE TEST BENCH

Before the first use of the test bench it is necessary to calibrate the different sensors. In order to calibrate the speed sensor it was used a Permanent Magnet Synchronous Motor (PMSM). To verify the calculated speed with the real speed it was used the equation (1):

$$n = \frac{120 * f}{P} \quad (1)$$

Where, n is the motor speed, f the motor frequency, and P the number of poles of the motor.

Since the information of the temperature sensor is only used to prevent that the brake is damaged by excessive temperature, it is not necessary a high precision. So, for the calibration, the measured value was compared with the value given by a termocouple.

On the other hand, the calibration of the torque sensor is very important. So, to calibrate this sensor it was used a lever-arm-mass system, also denominated as deadweight system.

With this system the torque sensor was calibrated with weights hanging on the end of the rigid lever. Knowing the length of the rigid lever it is possible to calculate the resultant torque by multiplying the force by those weights applied in the lever, with the length of the rigid lever.

The advantages of this technique are the fact that the levers with the weight are in equilibrium, the location of the fulcrum point is precise and the bending torque caused by weights in the sensor is null. In this method, the only things that can increase the error in the measurements are the length of the levers and the wires used to fix the weights to the levers [10][11]. The weights were fixed to the test bench using levers with 1.20 m of length, with the center (0.6 m) fixed to a flange and this fixed to the brake shaft. The weights are fixed at a distance of 0.5 m from the rotation center axis. The brake shaft was locked during all the process of calibration, as it is shown in Fig. 9.

The weights used for the calibration were: 499.1 g, 500.0 g, 999.7 g, 999.9 g, 1,990.0 g, 5,026.0 g, 9,900.0 g. The weights' support weights 3,036.1 g. The calibration was made using weight steps of 500 g between 0 g and 20,460.8 g. The calibration process was performed using clockwise and anticlockwise direction, increasing the weight on the lever of calibration between 0 g and 20,460.8 g and decreasing until 0 g, in both directions (Fig. 10). This process allows to identify whether a change occurs in the characteristics of the load cell, and to checks if it exists a change in the value of the passage by 0 g. As the arm of the load cell (0.142 m) is diferent from the levers arm in calibration (0.5 m), it was necessary to adjust the values obtained with the values obtained in the ADC of the microcontroller. In Fig. 11 is shown the conversion curve of the weight, measure with the load cell, to internal values of the ADC.

Figure 9. Calibration process of load cell with weights.

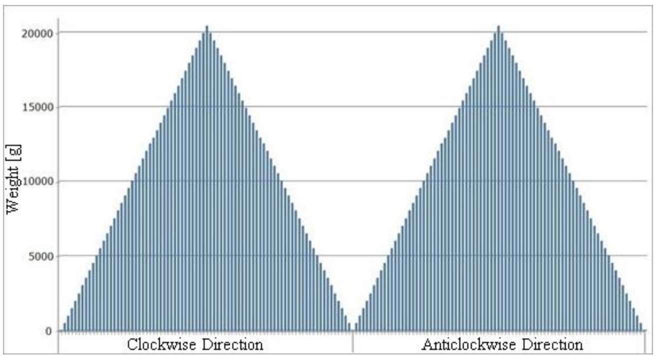

Figure 10. Calibration process in clockwise and anticlockwise direction.

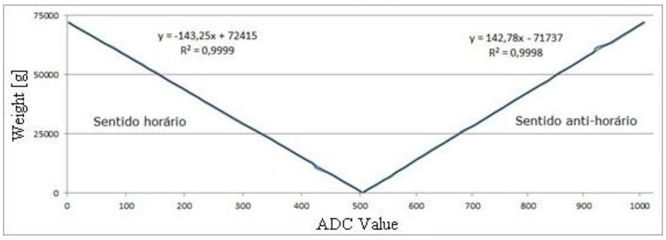

Figure 11. Weight aplied to the load cell with 0.142 m of lever arm in function of the value of the ADC.

V. Experimental Results

In Fig. 12 (a) are shown the voltage and the current waveforms applied to the electromagnetic brake. The DC voltage applied to the brake is regulated using the variac of the test bench, whose maximum values are: 244.5 V and 3.03 A.

Fig. 12 (b) shows the voltage and the current waveforms when the developed half-controlled thyristors bridge rectifier is operating, with a firing angle of 76 º and 256 º in positive and negative semi-cycles of the electrical grid voltage, respectively.

Based on the results obtained in both controls of the test bench it was ploted a graph with the torque applied to the load to be tested, function of the voltage applied to the brake (Fig. 13). The test bench developed control presents a good linearity when compared with the control applied with the variac.

Fig. 14 shows the final aspect of the implemented automatic test bench.

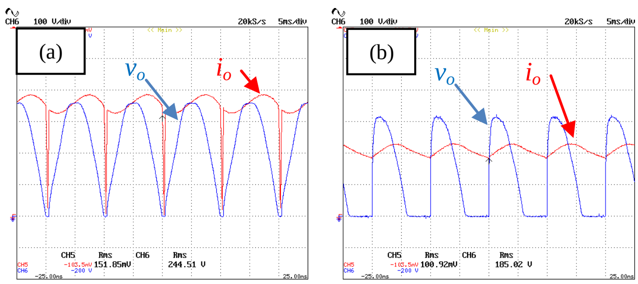

Figure 12. Voltage (v_o) and current (i_o) in the brake: (a) With the variac; (b) With the developed control system (half-controlled bridge rectifier).

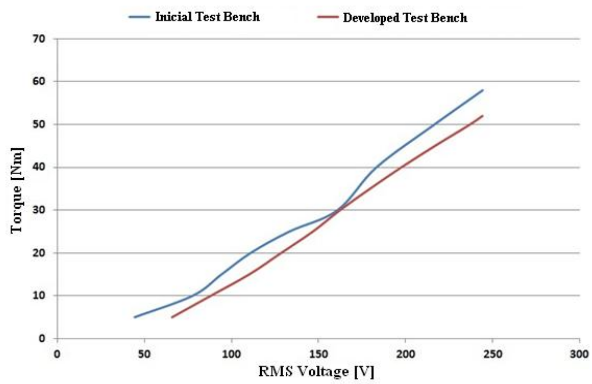

Figure 13. Linearity of relation between the voltage and the measured torque in manually controlled and digital controlled test bench.

VI. Conclusions

In this paper was presented a digital controller and a data acquisition system to measure the torque and the speed of an automated electromagnetic brake. For this purpose it was performed mechanical, electronics, and data acquisition changes on an existing analog manually controlled test bench. It was also presented the calibration process of the load cell used in the test bench, as well as the hardware and software developed for the interface between the user and the test bench, denominated as Human Machine Interface (HMI).

The developed control and acquisition system of the test bench allows the monitoring of the torque in both directions of rotation, without modifying the analog display, as it was necessary in the original system of the electromagnetic brake.

As shown through the experimental results, the measured torque has an accuracy of ±0.5 Nm, while the measured speed has an accuracy of ±2 rpm.

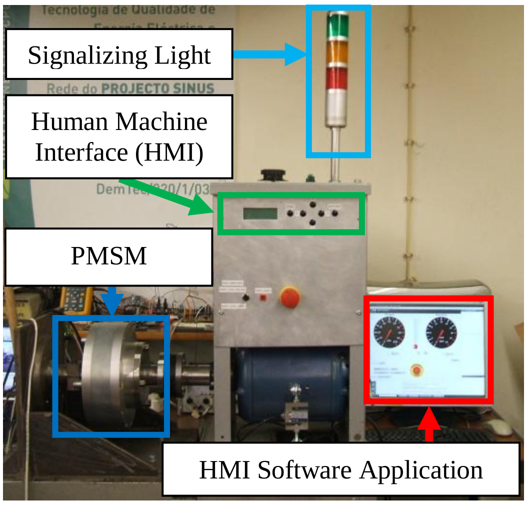

Figure 14. Final aspect of the implemmented test bench.

Several tests were performed, through computer simulations and experimental results, which prove that the developed digital controller and data acquisition system presents a more linear behavior when compared with the original test bench. In this way, with the new developed test bench, it is possible to make more reliable tests to electrical rotating machines, aiming their integration in several applications, like Electric Vehicles and Plug-in Hybrid Electric Vehicles.

Acknowledgment

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