

IMPLEMENTATION OF A CONTROLLER FOR A MAGNETIC LEVITATOR WITH EDUCATIONAL PURPOSES

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Abstract. *The engagement of students is frequently one of the greatest challenges faced by educators. Whenever possible, applying concepts to a playful context might help trigger some interest, especially in a field as practical and with abundant examples as engineering. This paper presents the implementation of a magnetic levitator controlled through the LabVIEW software, aimed at the teaching of data acquisition and control concepts. Magnetic levitation was chosen as scenario for the fascination it naturally exerts on students. Both the hardware (the mechanical structure and electric circuit) and the software are detailed in the paper. The levitator is comprised of a coil and a magnet guided by a nylon rod. There is a temperature sensor inside the coil and a fan can be turned on to keep it from overheating. A laser sensor reads the height of the magnet. The sensor signals are wired into an acquisition board. Board analog and digital outputs are wired into the bridge of PJT darlington transistors and can be used to control the height of the magnet. All board inputs and outputs can be read/written in a LabVIEW interface. With this setup, the magnetic levitator can be presented to students for the creation of a control algorithm or for the study of the acquisition device.*

Keywords: magnetic levitator, LabVIEW controller, practical education

1. INTRODUCTION

The Magnetic Levitation phenomenon has been studied for the purpose of high performance trains since 1934 when Hermann Kemper, from Germany, patented it (Lee, Kim and Lee, 2006). Hillebrand (2008) affirms that the first prototypes, from a joint venture between Siemens AG and ThyssenKrupp AG, appear in 1969 and 1979, however, the first high-speed based on Magnetic Levitation was opened for public use in 2003.

According to Dolga and Dolga (2007), the Magnetic Levitator, also named MagLev, is a mechatronic system and is frequently an object of study in mechatronic courses, due to the synergetic interaction of the sensors, controllers and actuation systems. The historical description of Mechatronics is a combination of the subjects of Electrical Engineering, Mechanical Engineering, Computer Engineering and Applied Control Engineering (Grimheden and Hanson, 2001).

Craig, Kurfess and Nagurka (1998), Hurley, Hynes and Wölflé (2004) and Santos, Camargo and Nascimento Jr. (2010) also proposes the MagLev example for undergraduate and graduate education. The experiment topology, based in a coil in the top to generate the electromagnetic force to pull and levitate a piece of metal in the bottom, is the same in these papers.

This paper presents a magnetic levitator development using a graphic programming language. It is a final project from an ITA (Instituto Tecnológico de Aeronáutica) subject about Data Acquisition in LabVIEW. The objective of this work, based on study programs, is detailed on Figure 2.

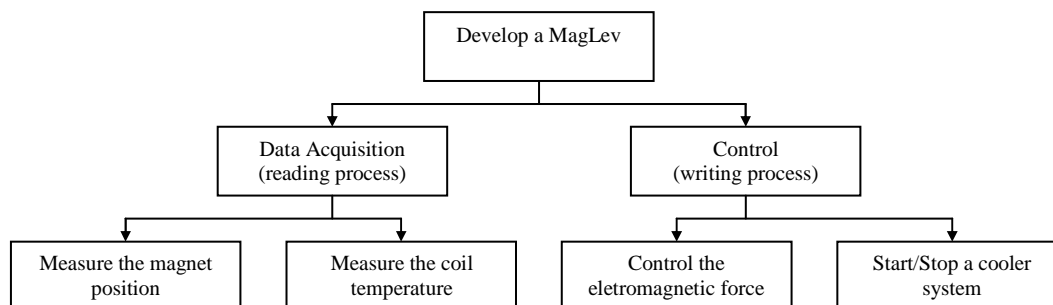


Figure 1 - Project objectives.

2. MAGNETIC LEVITATOR

The MagLev is based on the magnetic and electromagnetic effects. The attraction and the repulsion forces between two magnets are well known, and since 1820, based on studies by Hans Christian Oersted, is possible to use electric current to generate a magnetic force, named electromagnetic force (Araújo and Müller, 2002).

The basic knowledge necessary to understand the mechatronic magnetic levitator is the permanent magnets attraction and repulsion effect. If different poles of two magnets are aligned, the magnetic field creates a force to attract each other and when the same pole of a pair of magnets are aligned, the force created by the magnetic field will repulse them. Figure 2 shows the attraction and repulsion possibilities for two magnets.

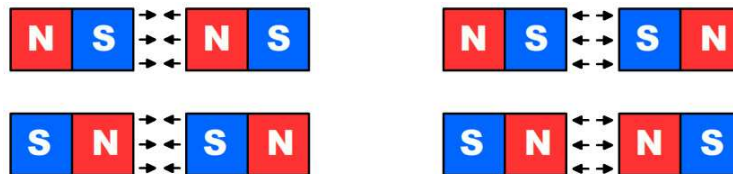


Figure 2 – Possibilities of attraction and repulsion for two magnets.

Lee, Kim and Lee (2006) studied the magnetic levitator for trains and described two different forms for levitation: electromagnetic suspension and electrodynamic suspension.

Electromagnetic suspension is accomplished based on the magnetic attraction force between two electromagnets. This method is unstable and, excluding the possibility of interaction of two permanent magnets, can be made by three different ways. The first way, presented on Figure 3 (a), is to install an electromagnetic coil on the top to control the magnetic field and levitate a permanent magnet on the bottom. Another possibility is to install a permanent magnet on the top to control an electromagnetic coil on the bottom, as shown in Figure 3 (b). Finally, it is possible to install two electromagnetic coils on the top and on the bottom, detail (c) in Figure 3.

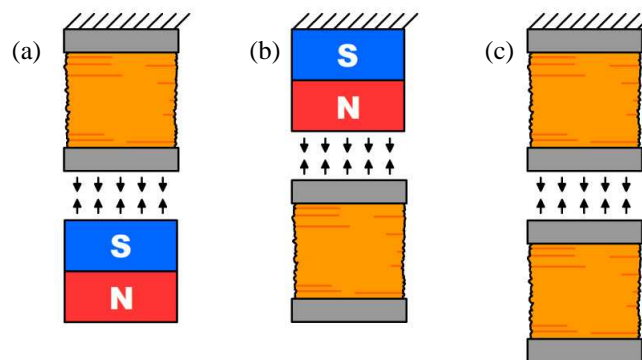


Figure 3 - Electromagnetic suspension methods.

Electrodynamic suspension uses the repulsive force for levitation, while the electromagnetic suspension uses the attraction force. As on the other method, it is possible to use three different arrangements, as an electromagnetic coil on the bottom to control the levitation of a permanent magnet on the top presented on Figure 4 (a). Based on Figure 4 (b), it is possible to use a permanent magnet on the bottom and an electromagnetic coil on the top. Also, it uses two electromagnetic coils, one on the top and the other on the bottom, as detailed in Figure 4 (c).

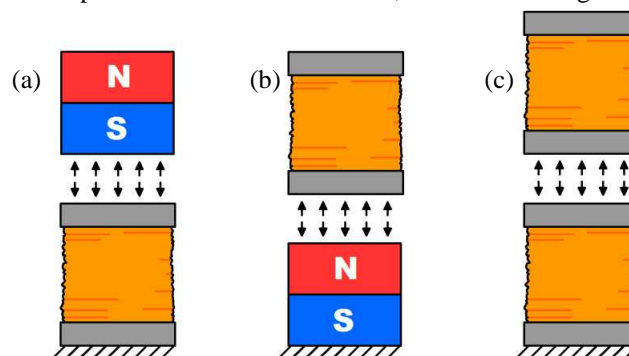


Figure 4 - Electrodynamic suspension methods.

2.1. MagLev design

The most part of MagLev projects developed for students purposes is based on the electromagnetic suspension presented on Figure 3 (a), as the work of Craig, Kurfess and Nagurka (1998), Hurley, Hynes and Wölfle (2004) and Santos, Camargo and Nascimento Jr. (2010).

This work is based on an electromagnetic levitator using the electrodynamic suspension approach as shown in Figure 4 (a) for academics studies. The permanent magnet used is a cylinder with an inner hole guided by a nylon rod; a temperature sensor is installed in the coil core to measure the internal temperature and activate a cooler to avoid overheating, and a distance sensor is installed to measure the permanent magnet displacement. This arrangement is illustrated in Figure 5.

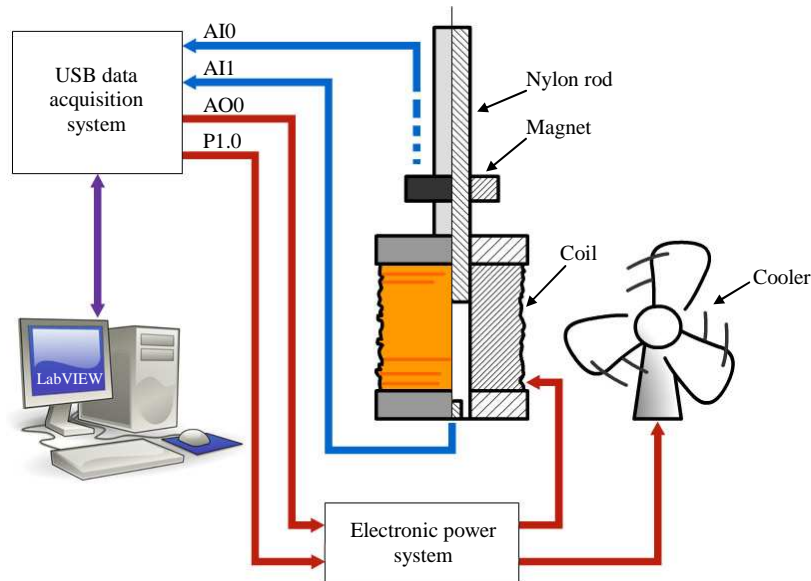


Figure 5 - MagLev system arrangement.

A data acquisition system is connected to a computer by a USB cable and the software to control this system is the LabVIEW. The permanent magnet displacement is measured by a sensor connected on the first analog input of the data acquisition device (AI0). On the second analog input of this data acquisition (AI1) is connected the temperature sensor. The current control of the electromagnetic coil is made by an electronic power system, but the current nominal value is an analog value settled by LabVIEW on the first analog output of the acquisition device (AO0). Finally, the cooler system follows the digital status of the first digital output P1.0.

2.1.1. Electronic power system and the output signals

The electromagnetic system is composed by a copper coil, an iron core, a nylon rod and a cylindrical permanent magnet with an inner hole. The force to push the permanent magnet upward is proportional to the current and an electronic power drive system was developed to control the current value.

This electronic power system uses an ordinary power transistor, TIP120, that can work with currents up to 5A. An amplifier circuit was developed to control the current in the coil, installed in the transistor collector. However, even working right on the quiescent point of the transistor, the collector current was not proportional to the base current because the transistor temperature variation during the fully system operation.

In order to try to solve the transistor temperature problem, a dissipation temperature device was installed, but the results were not satisfactory. The final solution was based on a circuit change to use an operational amplifier to control the base current and correct the values in order to keep the collector current stable. The analog output used to control the coil current value (AO0) is connected on the non-inverting input and the emitter voltage is the feedback value to the inverting input. As a unit gain buffer, this operational amplifier will control the base current to maintain the emitter voltage equals the AO0 voltage.

The collector current is almost the emitter current and could be calculated by the emitter voltage divided by the emitter resistor. This power circuit set up is present in the

Figure 6 (a). The coil voltage is 12V, but the power supply is 24V, because the emitter resistor has 2 Ω and the coil resistance is about 2 Ω . The maximum voltage in the coil is reached when the transistor is saturated, dividing the 24V in two parts: 12V to the emitter resistor and 12V to the coil.

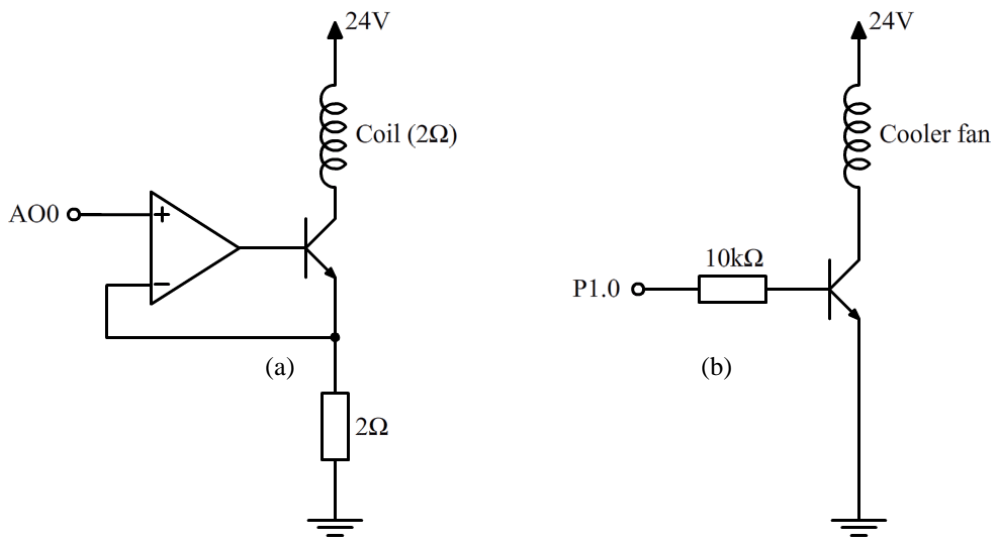


Figure 6 – Output power circuits.

The circuit to control the cooler system, as shown in Figure 6 (b), is composed by a transistor working as a switch. When the digital output P1.0 is activated, the transistor will saturate and the cooler system will be started. The cooler system will be stopped when the digital output P1.0 is not activated.

2.1.2. Analog input signals

The permanent magnet displacement is measured by a laser sensor. This sensor has a range from 50mm to 150mm and the output variation is proportional to the object position (0V to 10V). When the object is 50mm far from the sensor the analog value is 0V and the analog value changes to 10V if the object is 150mm far from the sensor. The accuracy of this sensor is 0,05mm and represents 0,005V of output resolution. The sensor is installed at the top of the nylon rod and the laser is aligned in the permanent magnet surface. According to the Figure 5, this sensor is installed in the analog input AI0.

For the coil temperature measurement an NTC sensor was used. The NTC is a resistor that decreases the resistance value when the temperature is increased. Generally, the NTC curve is not linear, but for small values of temperature, about 0° to 100°C, the temperature will be considered linear. This sensor does not need to be very accurate, just inform if the coil is hot enough to start the cooler system or if the value is already too high to keep the cooler system started and shut down the coil power. The temperature sensor is connected on the analog input AI1 and the electronic circuit used is a voltage divider present on Figure 7.

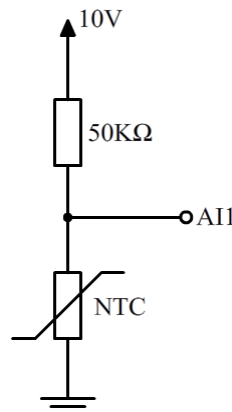


Figure 7 - Temperature sensor circuit.

2.1.3. Data acquisition and software development

The data acquisition system used in this MagLev project is from National Instruments (2008), model NI USB-6008 with 8 analog inputs, 2 analogs outputs and 12 digital inputs or outputs (configurable). The resolution of the analogs inputs and outputs is 12 bits, around 2,44mV for 0V to 10V and fits on the sensor resolution.



Figure 8 - NI USB-6008 data acquisition system.

LabVIEW® is based on graphic language and uses icons instead of text to create software routines. According to Almeida et al (2010), LabVIEW® uses the data flow to execute the routines, while the conventional programming languages use command lines.

During the programming process in LabVIEW, two different screens are available. The first one is the Front Panel with controls and indicators for the software operator and the second screen is the Block Diagram, where it is possible to create the graphic languages by the connection of blocks with different functions.

Figure 9 presents the MagLev block diagram. The blocs outside the gray square (looping logic) are related to the start and stop of reading and writing on the USB data acquisition board. Inside the looping logic there are the controls and indicators, the mathematic operations, such as subtraction and division, and Boolean operations.

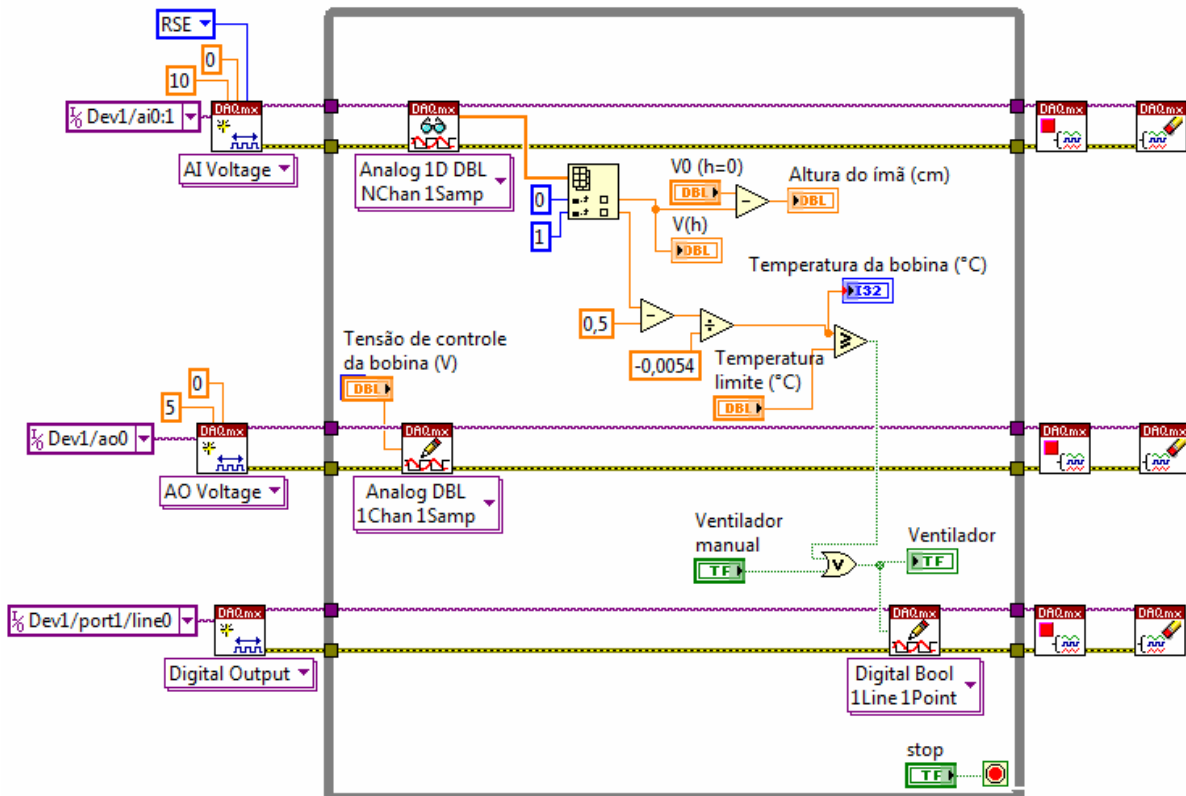


Figure 9 - MagLev block diagram.

The MagLev front panel is presented on Figure 10. It is possible to visualize a graph that indicate the magnet displacement and a vertical bar that present the coil temperature. A knob adjusts the voltage to the power electronic drive that will control the coil current. It is possible to adjust the temperature limit to control the cooler system and the status (on/off) are present on a green LED. Also, is possible to start or stop the cooler system by a manual button.

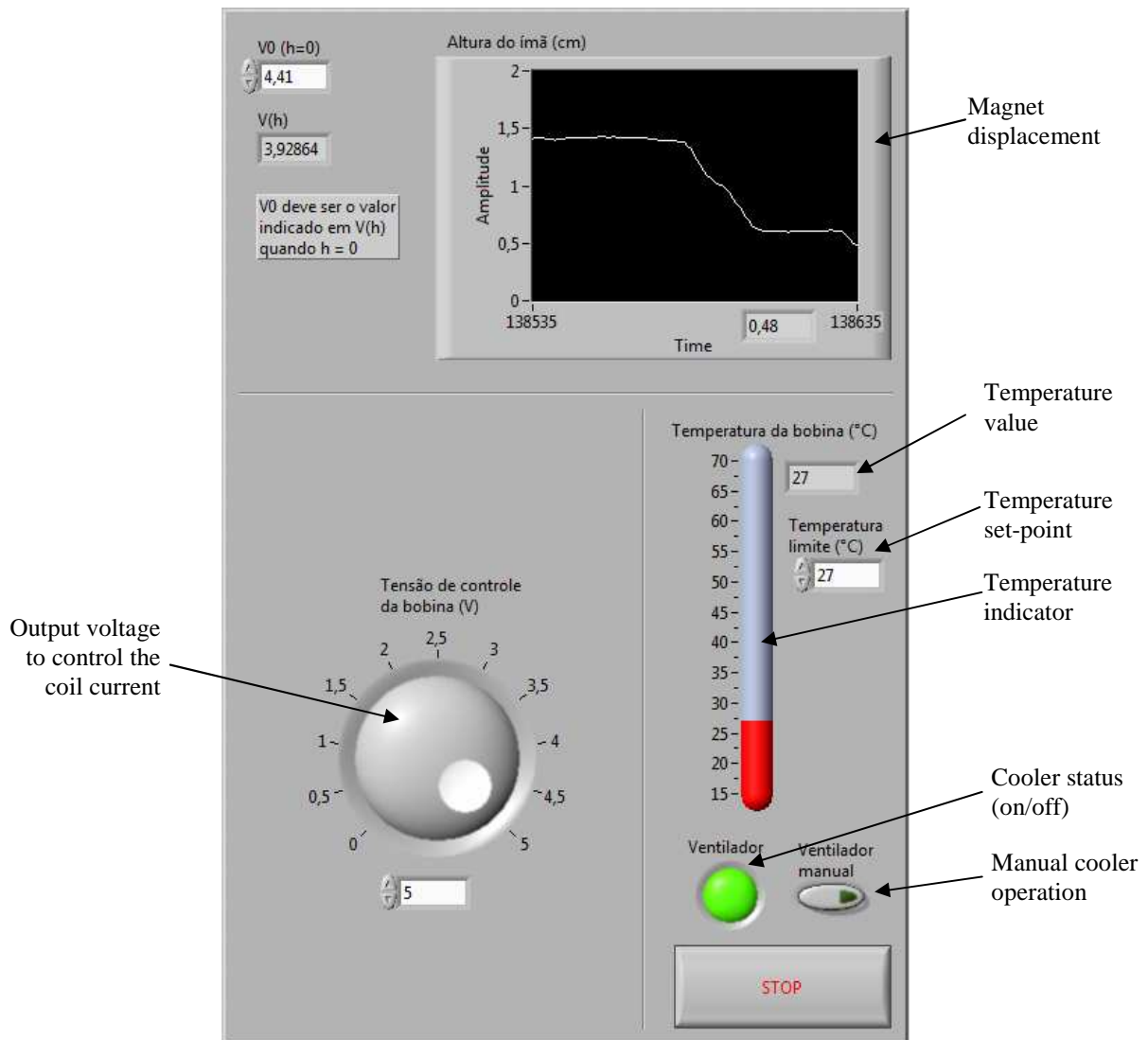


Figure 10 - MagLev front panel.

3. CONCLUSION

This work present the development of a control and data acquisition software, based on a graphic language, for an electromagnetic levitator. The software LabVIEW® was chosen for this application.

The data acquisition using a USB device is compatible with the study propose of this MagLev, and offer an easy integration interface to read the sensors and write the outputs.

It is possible to affirm that the actual power electronic circuit suits in the requirement of keep the coil current stable and will be used in further works.

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5. RESPONSIBILITY NOTICE

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