INEXPENSIVE MAGNETIC FIELD CONTROLLER

A.A. Malafronte, M.N. Martins

Laboratório do Acelerador Linear, Instituto de Física da Universidade de São Paulo, CP 66318,
05315-970, São Paulo, SP, Brazil

Abstract

In this work, we describe a low cost magnetic field controller based on a commercial Hall sensor. The problem is addressed and a brief description of both hardware and software of the controller are given. Results for magnetic field stability are presented, including an evaluation of the precision of the magnetic field probe.

INTRODUCTION

The Physics Institute of the University of São Paulo (IFUSP) is building a two-stage 31 MeV continuous wave (cw) racetrack microtron. This machine has several dipole magnets, like the first and second stage recirculators, and other smaller ones in the transport line. These magnets must produce very stable magnetic fields to allow the beam to recirculate along very precise orbits and paths. Besides, the fields must be reproducible with great accuracy to allow for an easier setup of the machine.

Since the machine will operate with different beam energies, different magnetic field settings will be necessary in the transport magnets, causing a hysteresis offset that may complicate the machine tuning. This offset could be eliminated by a cycling procedure of the current in the magnets; or it could be disregarded, and a new set of currents must be found to bring the beam to the right path. A better approach is to use a magnetic field controller that reads the field and, through a feedback, controls the power supply current [1]. This kind of controller could also manage variations due to the power supply, caused by internal sources like the temperature dependence of regulation circuits (TC); or by external sources, like variations in the load (because of heating of the magnet coils). Temperature effects in the magnet itself could also be eliminated [2].

Figure 1 shows the behavior of the magnetic field and power supply current of a transport line dipole. It can be seen that in the first hour there is a great variation of the current, so to begin the machine operation, it would be necessary to wait a relatively long time for field stabilization. This could be avoided by the use of a magnetic field controller, allowing for a much quicker startup.

Due to the large number of magnets, this controller must be cost-effective, therefore it was built around a low-cost industrial Hall sensor and linked to a microcontroller in order to be able to communicate with the accelerator control system.

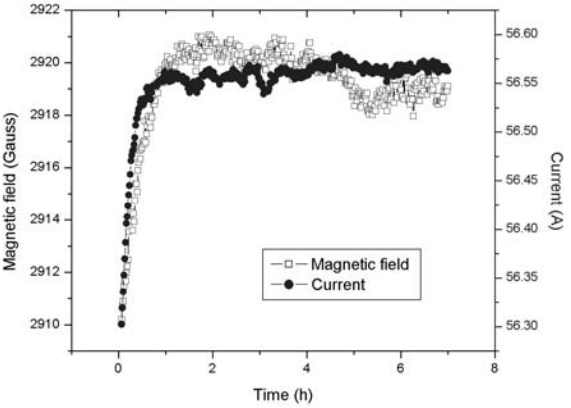

Figure 1: Time behavior of current and magnetic field for a magnet

DESIGN

A Hall sensor is a magnetic sensor widely used in automotive and computer industries, so the mass production made it a low cost device. These sensors output a voltage that is proportional to the magnetic field, but unfortunately exhibit strong dependences on temperature and mechanical stress. Despite the poor characteristics of these inexpensive devices, the integration of auxiliary circuitry in the same chip allows for offset reduction, temperature compensation and signal amplification [3]. Therefore a temperature compensated sensor was chosen, the Analog Devices AD22151. This sensor provides a dynamic offset drift cancellation and a built-in temperature sensor. This "thermistor", associated with an instrumentation circuitry, minimizes the temperature related drifts. This temperature compensation circuitry requires an external resistor, whose value is found through a data sheet curve [4]. But, because the plastic encapsulation package generates some mechanical stress, this compensation is not perfect. So a series of bench experiments were done in order to choose the best resistor for the compensation. In these experiments, the sensor was subject to the magnetic field of a permanent magnet and the resistance value was changed around the value suggested by the data sheet. The output voltage was recorded as function of the temperature. The permanent magnet used was a NdFeB type, which has a relatively high temperature coefficient (about –0.1 %/°C). To avoid temperature variations in the magnet, it was immersed in a thermal bath while the Hall sensor temperature was being changed.

As a result, a temperature coefficient of 0.01%/°C was achieved for a temperature range of 25 °C to 42 °C, with magnetic fields around 700 Gauss. These conditions are similar to those found in the magnet gaps of our accelerator. Figure 2 shows the variation of magnetic field versus temperature for the primary resistor value, while Figure 3 shows the same parameters for the optimized resistor value.

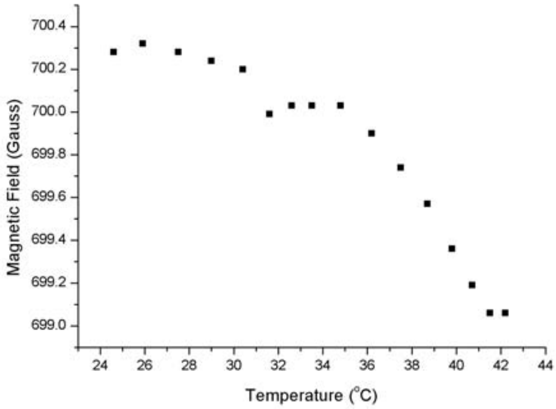

Figure 2: Magnetic field versus temperature for the primary resistor value

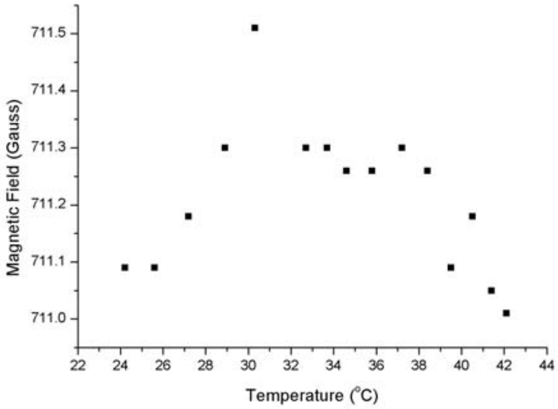

Figure 3: Magnetic field versus temperature for the optimum resistor value

The AD22151 output voltage is continuously acquired by a 16-bit ADC and sent to a microcontroller, which performs a digital averaging, in order to filter high frequency noise. If there is a difference between the measured field and the setpoint field, the microcontroller executes a proportional-integral algorithm to calculate a new value for the current of the power supply, in order to compensate for this variation. This new value is sent to a 16-bit DAC and from it to the remote analog input of the current power supply that controls the current. The field setpoints are sent by the control system to the microcontroller through a RS485 link. Figure 4 shows a block diagram of the controller.

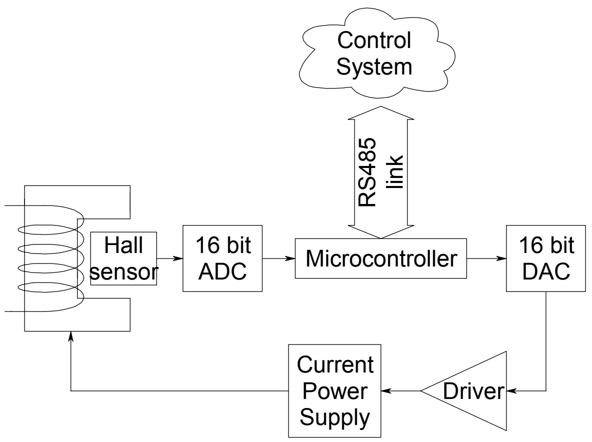

Figure 4: Block diagram of the magnetic field control

RESULTS

Figure 5 shows the magnetic field, as a function of time, when the controller is active

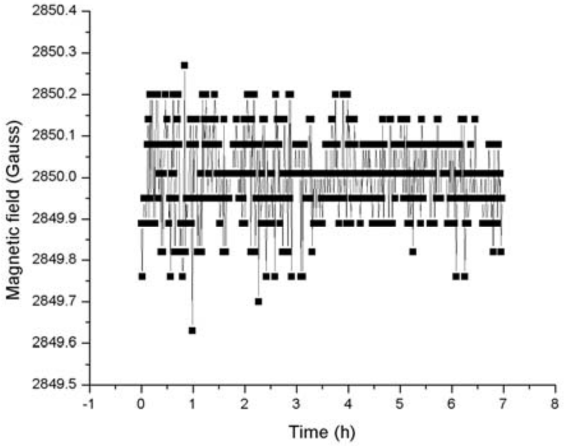

Figure 5: Magnetic field in a bending magnet as a function of time, with the controller active

The results show that the magnetic field reading of our sensor was kept within 0.6 Gauss during a time interval of 7 h. This is an excellent result: for an average field of 2850.00 Gauss and a standard deviation of 0.10 Gauss, we can state that, within a 99.7 % confidence level, the field is kept stable within 0.01 %.

Nevertheless, these results depend on the stability of our magnetic field probe. So we made a series of tests in order to determine the precision of the probe. These tests were done using a standard permanent magnet [5] in an environment with stable temperature ($\pm 0.5^{o}$C). The probe readings are shown in Fig. 6. It is clear that the readings present statistical fluctuations (short term fluctuations) built over long-term fluctuations, whose origin could not be attributed to any specific cause, like temperature or power supply variations.

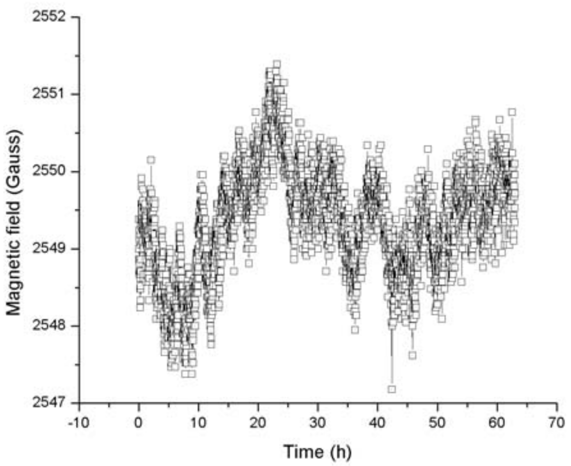

Figure 6: Magnetic field of a permanent magnet, as a function of time. See text for details

In order to separate both effects (short- and long-term fluctuations), we made a smoothing procedure (over 1 h intervals, corresponding to sixty data points), and subtracted the smoothed curve from the data points. With this we obtained the statistical fluctuations of the data. Figure 7 shows a histogram of the complete data set. The average is 2549.36 Gauss, with a standard deviation of 0.68 Gauss.

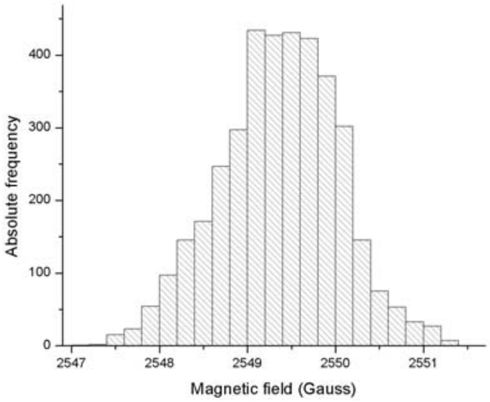

Figure 7: Frequency distribution of the magnetic field readings

Figure 8 shows a histogram of the data set obtained after the subtraction of the smoothed curve, that is, the distribution corresponding to statistical fluctuations. The average is 0.00 Gauss, with a standard deviation of 0.30 Gauss.

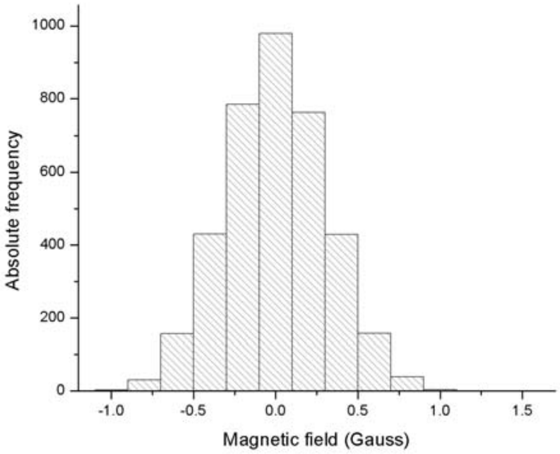

Figure 8: Frequency distribution of the magnetic field readings after subtraction of the smoothed curve

We can now state that, with the magnetic field controller, we are able to keep the magnetic field stable within 0.7 Gauss (1 standard deviation), for a field of 2500 Gauss. This corresponds to a stability of 0.03 % within the 68 % confidence level.

REFERENCES

[1] C. R. Dunnam. Hall Effect Magnetic Regulation Systems for the CESR Injector. Proc 1989 IEEE Part. Accel. Conf, 1989, p 357-359.

[2] L. P. Roobol; S. Brandenburg; H. W. Schreuder. Temperature Dependence of the Magnetic Field. From the KVI (Kernfysisch Versneller Instituut), 1996 annual report, http://www.kvi.nl.

[3] R.S. Popovic, Z.Randjelovic; D. Manic. Integrated Hall-effect Magnetic Sensors. Sensors and Actuators A, v.91, p.46-50, 2001.

[4] Analog Devices. Linear Output Magnetic Field Sensor AD22151, data sheet 2003, http://www.analog.com.

[5] Standard Magnet type 72, Rawson-Lush Instrument Co., Action, MA, USA.