Using Magnetic Sensors for Absolute Position Detection and Feedback.

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Abstract

Several types of absolute position detection are commercially available including linear magnetic field sensing devices. In the implementation of an electromagnetic levitation device absolute position detection is the key component to a solid design. However, applying such a sensing device to detect absolute position in a changing field environment proves much more difficult than typical use. Filtering, analog to digital conversion, and digital PD feedback control loops are all considered in the implementation of the design.

Introduction

In this paper the implementation of a levitating device is described. This includes the theories of operation, hardware, software, and possible improvements that could be made upon the device. Particularly, this design involved the use of a linear Hall Effect sensor for absolute position detection which is a deviation from typical designs that use optics. The theories behind the operation of electromagnets, the Hall Effect, and Hall Effect sensors are briefly discussed and analyzed for this specific application. PWM is also used for current output control of a H-Driver IC the operation of which is detailed in this paper.

Theory of Operation

Magnetic Field Formation

The creation of the Magnetic field is based upon a theory known as Ampere’s Circuital Law. This theory states that the line integral of H about any closed path is exactly equal to the direct current enclosed by that path. Accordingly, one can develop the following statements about the application of this law to a solenoid coil which I used to create the field.

- A solenoid of finite length **d** consisting of **N** closely wound turns of wire and carrying a direct current **I** creates a magnetic field intensity **H** given by:[1]

$$H = \frac{NI}{d}$$

- This equation is valid for points well inside the coil and approximates field strength up to 2 radii away.
- The field will exert force along the z axis with direction changing with the direction of the current in the coil.

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Another important aspect in the use of the coil is that when a current is sent through it a dipole is created. That is if one were to sketch the field lines they would come out one end and loop around to return to the other. This phenomenon is shown in Figure #1. The dipole effect turns out to be one of the crucial properties of the controlling magnetic field that make this project work. This dipole phenomenon effectively applies opposing forces of the same magnitude 360 degrees around the object of levitation holding it at center as shown in Figure #2.

Figure #1[2]

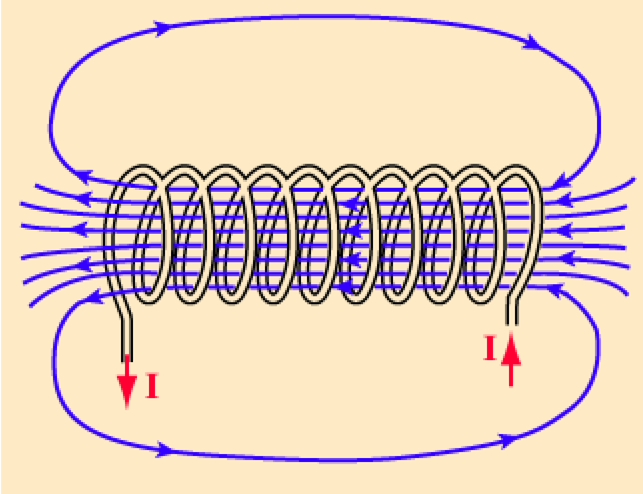
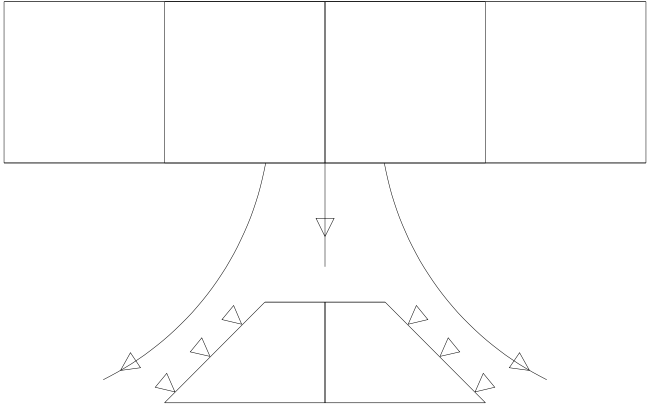


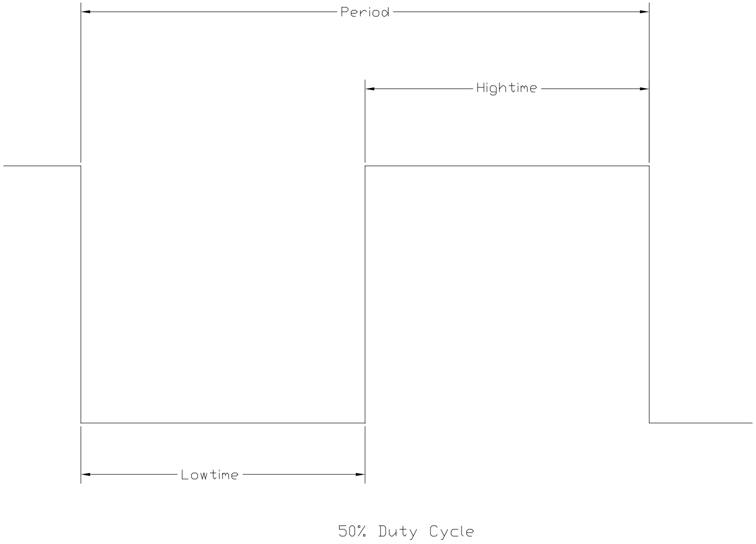
Figure #2



Pulse Width Modulation for Current Control

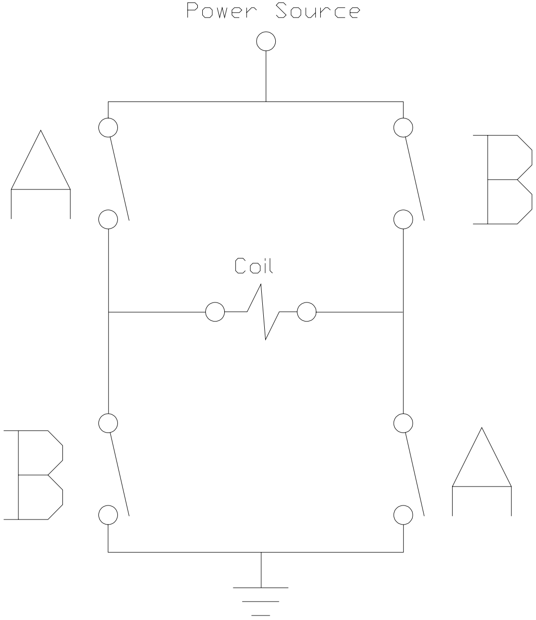
Pulse width modulation or PWM is a common technique employed in digital systems for control of many types of devices. PWM works by varying the duty cycle of a square wave in order to achieve an average value over time. Duty cycle is defined as the percentage of the period of the signal that is high. In Figure #3 a square wave is shown with high time and low time variables for PWM.

Figure #3



As shown above, an equal high and low time corresponds to a 50% duty cycle or an average current of zero. In the actual hardware, this type of encoding is used to control the H-Bridge IC and instruct it whether to sink or source current to the coil. A simplified diagram of an H-Bridge is shown in Figure #4 to demonstrate its operation. There are two switch sets, or in actuality transistor pairs, A and B arranged in an H configuration with the coil in the center as shown. The PWM input then asserts which set of switches will be closed at one instance in time. For example a high signal might close set A while a low signal would close set B, neither being closed simultaneously. In this manner current can be “sinked” or “sourced”, in effect, to change the direction of current through the coil depending upon which set is closed.

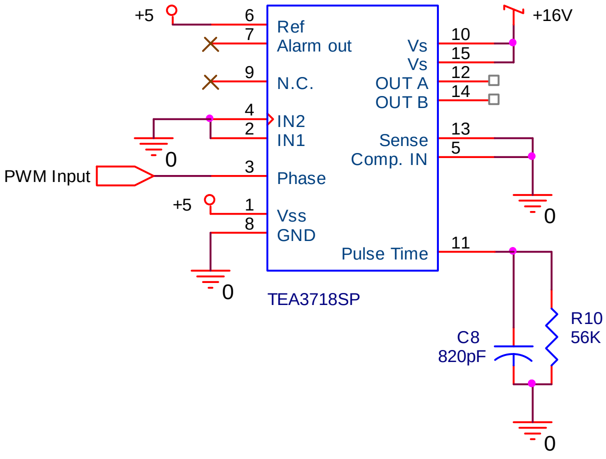
Figure #4



Although the H-bridge configuration is well suited for this application, the IC used in this realization was not necessarily designed to function in this way. Several inputs had to be hardwired to the desired logic levels in order to operate the chip on a single PWM input. The schematic below is the implementation of this setup.

Figure #5

H Bridge Power IC

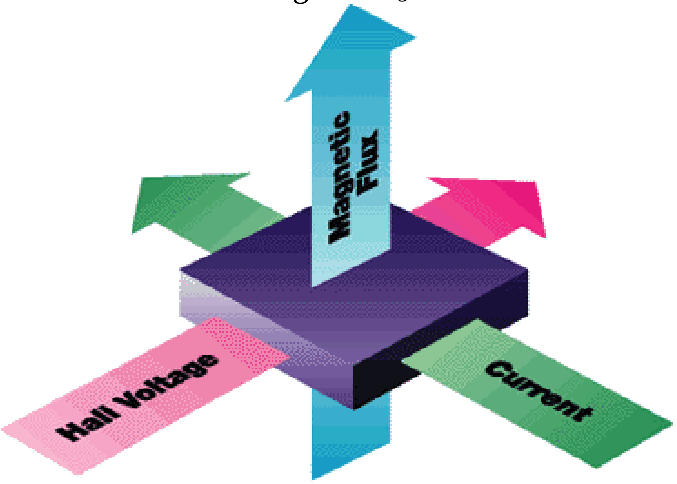


All of this integrated together allows the microcontroller to not only vary the magnetic field intensity but also the direction of the field to either push or pull the object.

The Hall Effect

The Hall Effect describes what happens to current flowing through a conductive material, such as a semiconductor, when it is exposed to a magnetic field. Simply, when a magnetic field is placed perpendicular to a current moving through a conductive material a voltage is developed perpendicular to both the current and magnetic field. This voltage is known as the Hall voltage and can be used to measure magnetic field strength.

Figure # 6[3]



Example of the Hall voltage developed by a magnetic field

Using the Hall Effect for Position Detection

Hall effect sensors are devices that measure the Hall voltage, amplify it, and provide some sort of proportional output that can be used to determine the amount of magnetic flux incident to the sensor. The first obvious conclusion about using a Hall effect sensor for position detection is that the object to be detected must have some magnetic properties in order for the device to register it. This was achieved in the design by simply attaching a permanent magnet to the object to be levitated. This not only provided the field needed to measure position, but also enhanced the performance of the electromagnet by adding some extra pull to the equation.

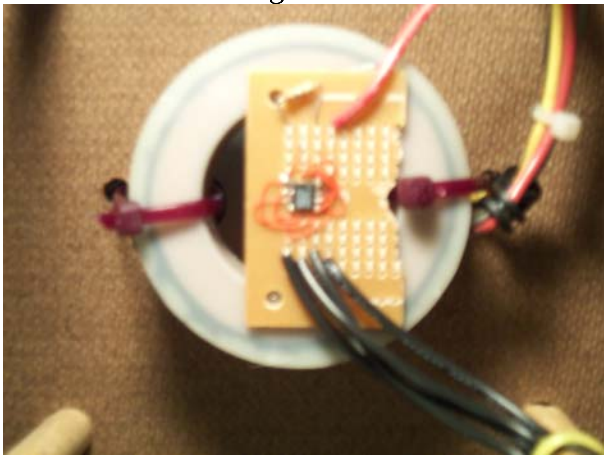
Figure # 7

Pictures of permanent magnet attached to cork

The device chosen for the project was Analog Devices Linear Output Magnetic Field Transducer AD22151G. This device was chosen for several reasons:

- Designed for a single 5V supply
- Linear Output proportional to the field perpendicular to the top of the package
- Adjustable signal gain allowing maximum resolution to be attained
- Built in temperature compensation and drift offset cancellation
- A significant output refresh rate of 50KHz

Figure #8



Magnetic Hall Effect Sensor mounted on Coil

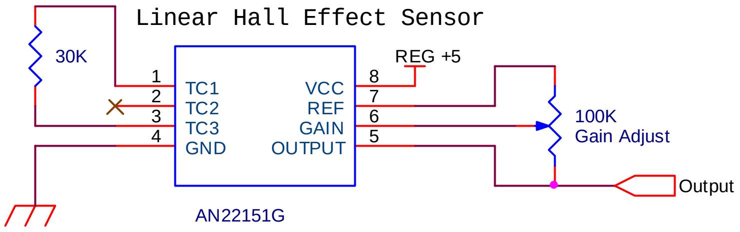
Several other important issues were evident however once the sensor was installed.

First, since the sensor was mounted at the bottom center of the coil, there will be a field also induced by the coil itself. The induced field could then have a cumulative effect with the magnet field or a difference offset. This definitely leads to a loss of overall total resolution at one end of the detection field where the cumulative effects of the fields cause an early saturation of the output signal. However, the offset in the mid band of the resolution range turned out to be only a small problem because of the size of the field developed by the coil compared to the permanent magnet. By selecting the saturating end of the detection field to be the area closest to the coil, the lower part of the field is then free to be used. Finally adjustment of the gain on the sensor attenuated this offset to a point where the compensator could overcome it. Further compensation of this offset could have been dealt with by software, but this was deemed unnecessary for the goals of the project.

Second, after operation it was evident that sensor had negligible power supply rejection and therefore was susceptible to full scale error as a function of supply voltage. In other words the output would drift as the supply voltage drifted. In turn, this would cause the A/D converter to come out of calibration with the sensor consequently leading to error in the position feedback. Solving this problem simply amounted to the addition of a fixed voltage regulator that ensured a constant supply voltage with very little variation.

Finally, the Hall Effect sensor output signal exhibited significant noise. Immediately it was evident that this was noise put onto the ground from the inductive kickback or EMF of the coil. This behavior was unacceptable for reliable analog to digital conversion. The solution to this problem is discussed in the hardware section.

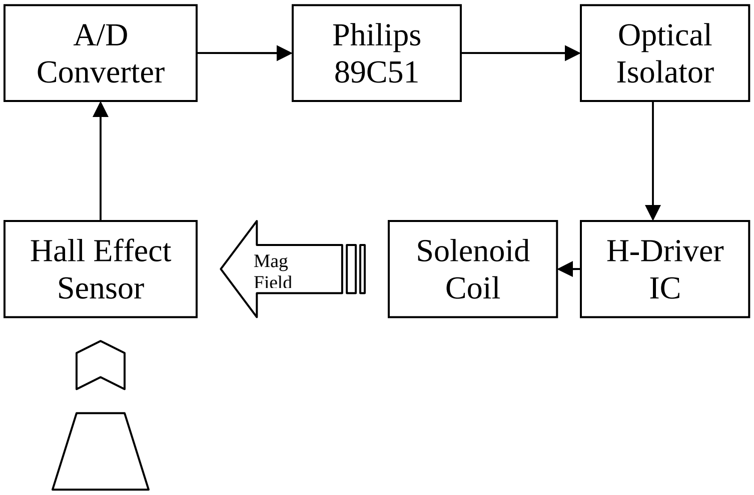
Figure #9



Hardware

The Hardware in this project consists of 3 major sections. First the power electronics which includes the H-Driver IC and supporting hardware, second the feedback electronics which includes the A/D converter, sensor, and supporting hardware, and third the controlling hardware which is the microcontroller, power isolation IC’s, and other supporting hardware. A block diagram of the integration of these three sections is show below in Figure #10.

Figure #10



From the figure above one can interpolate the flow of input and output signals in the hardware. Starting at the 89C51 microcontroller, the PWM signal, to control the H-Driver, is output to the isolation circuitry. The isolation circuitry was an important link in this process because it eliminates any noise from the power electronics from entering the feedback and control portions of the hardware. This is essential for correct operation of the feedback system and to prevent any possibility of an inadvertent reset in the microcontroller. Once translated across the optical isolator, the PWM signal reaches the H-driver which in turn adjusts the current level and direction in the solenoid coil. From here the magnetic field intensity of the coil along with the position of the cork is read by the sensor which is output to the A/D converter. Finally the A/D converts the analog voltage output by the sensor into an 8-bit value for the microcontroller to interpret.

Software

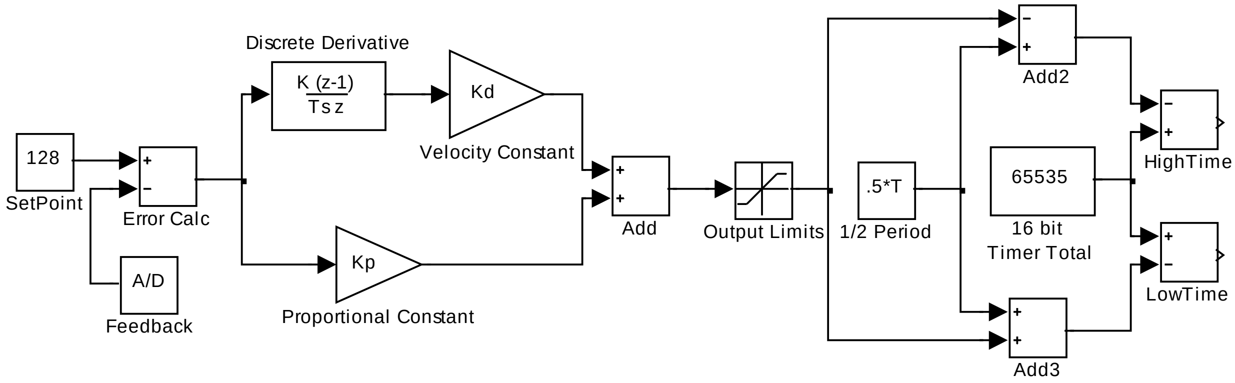
The software for this project was written in Keil C. The modules that make up the software are listed below

- PWM code
- Proportional Derivative controller
- UART communication code
- A/D interface code

The PWM routine written for this project is an interrupt based reload of a 16 bit timer. This implementation requires that the high and low times be computed elsewhere and then loaded into the timer upon interrupt in consecutive turns. In effect the PWM routine times the high time, toggles the output to low, times the low time, toggles the output to high, and repeats forever. The interrupt based PWM provides an easy way for a compensator to control high and low times simply through the use of a global variable.

The Proportional Derivative controller adjusts the high and low times of the PWM based upon the feedback from the Hall sensor. A block diagram of the control scheme is shown below in Figure #11.

Figure # 11



This diagram was created in Simulink and was employed in the original phase of the design in order to sort out any issues that might have arisen with timer overflows and misplaced signs. Before discussion of the code goes any further however it is useful to consider a physical attribute of this system, sample speed verses change in position. Considering that the feedback is refreshing at an extremely fast speed it is reasonable to provide a delay between derivative calculations so that the input actually has time to change. This can be seen to be true experimentally, as the derivative has no effect without the delay.

The pseudo code that implements this controller is given below

1. Delay
2. Read in feedback from port
3. Calculate the error and derivative of the error
4. Compute the compensating output
5. Adjust timers according to the compensator output
6. Loop to top

The UART communication routines just provide a way of tuning the PD loop. Both Kd and Kp coefficients were made available to tune through the serial port along with other diagnostic information to display on the PC screen.

The final piece of software written is the A/D interface code. This code reads the value of the A/D from port zero, processes it, and loads it into the correct variables for use elsewhere.

Possible Enhancements

This project has many areas of operation that could benefit from improved operation and enhanced functionality. Several ideas for this are listed here.

- A genetic self tuning algorithm
- External position control
- Sensor compensation based upon current sensing from the H-Driver IC
- Faster PWM with greater precision (requires faster microcontroller)
- Addition of a core to the solenoid

Conclusions

The use of a linear Hall Effect sensor for absolute position detection in this application is ideal. The resolution provided by the sensor was more than adequate for the space the coil could influence. After construction the key solutions to the problems presented by this implementation are

- Correct calibration of A/D with sensor
- Noise rejection through optical isolation
- Improved sensor performance through the use of a regulated voltage
- Availability of tuning through the serial port
- Delay in software to allow feedback to change
- Adjustable gains on Hall Effect sensor for maximum resolution

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Author Information

Kevin Claycomb was born on July the 18th 1982, and is the son of Jeff and Sarah Claycomb. He is currently pursuing an undergraduate B.S. degree in Electrical Engineering at the University of Evansville with a minor in Mathematics. He also has aspirations to go on to graduate school to study some form of robotics and sensor technologies with applications to the aerospace industry.