Demonstration of electromagnets control with ferrofluid movement

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Summary:

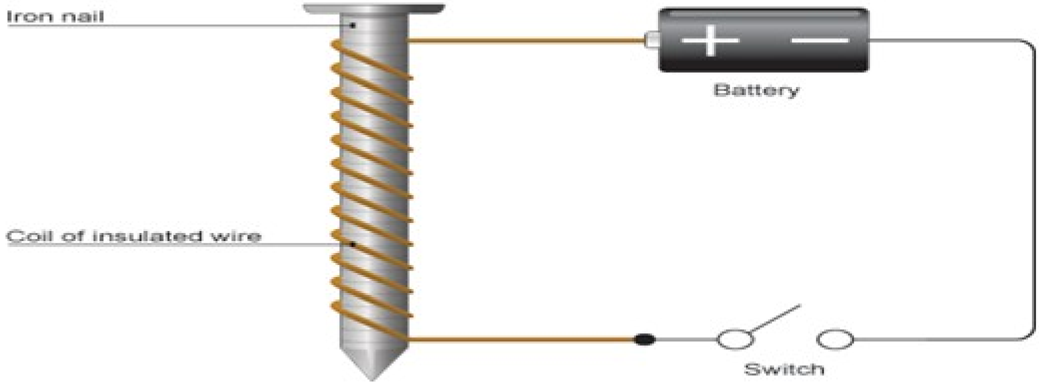
The main goal of the project is the control of the magnetic field intensity generated by two home-made electromagnets. For this purpose, we used XMC1100 microcontroller, based on ARM Cortex-M0 and DAVE programming environment which contains already implemented modules for a variety of operations, like PWM configuration and generation, UART configuration ,etc.

A secondary goal of the project was the realization of a fluid with magnetic proprieties – a so called ferrofluid. Because the market options on this product are limited and quite expensive (approximately 90 lei for 10 ml of fluid), we decided to create our own liquid, using cheap and easily available resources.

Overview

Electromagnetism represents the study of electromagnetic force, a type of physical interaction that occurs between electrically charged particles. It plays a huge role in our daily lives because it is responsible for all phenomena above the nuclear scale that we encounter, with the exception of gravity. Whatever powered devices we use, from table clocks to microwave ovens, have some form of electromagnetic principle involved in their functioning. It is electromagnetism which has given the flexibility for switching off/on electricity as required. A few applications of electromagnetism include: home appliances – the loudspeaker whose coil movement under the electromagnetic force produces audible vibrations, power circuits – relays – which have the potential to cut down large current to the load with the application of a small current, medical imaging – MRI – which provides a picture of the anatomy and physiological processes of the human body, control of electrical motors – which operate through the interaction between motor's magnetic field and winding currents to generate force – and many more other applications.

To generate the electromagnetic force required for our project we chose to build two electromagnets from materials that are cheap and easily attainable: a conductive wire of 0.8 mm thickness and two metal rods. The construction principle is simple: the wire is wound around the metal rod and is connected to a current source. Before the wire is electrified, the atoms in the metal core are arranged randomly, not pointing to any particular direction. When the current is introduced, the magnetic field penetrates the rod and realigns the atoms. With these atoms in motion, and all in the same direction, the magnetic field grows. The alignment of the atoms, small regions of magnetized atoms called domains, increases and decreases with the level of current, so by controlling the flow of electricity, you can control the strength of the magnet. When the current is turned off, the atoms return to their natural, random state and the rod loses its magnetism. In this project, the current source is an 12V - 15Amps computer source and the control of the current has been realized with the platform XMC1100 and some transistors.



Now that we have the means to create an electromagnetic force, we turn our attention to the material that the force is applied to: the ferrofluid. A ferrofluid is a liquid that becomes strongly magnetized in the presence of a magnetic field. Ferrofluids are liquids made of, usually, nanoscale ferromagnetic, or ferromagnetic, particles suspended in a carrier fluid(an organic solvent or water). Ferrofluids usually do not retain magnetization in the absence of an externally applied field and thus are classified as "superparamagnets" rather than ferromagnets. To make the ferrofluid we used ordinary cooking oil and laser ink toner. Five parts of toner and three parts of oil were stirred in a small jar for approximately five minutes; the solution has to be as homogenous as possible. After that, the resulting solution magnetic proprieties were tested using a permanent magnet. We have to mention the fact that the resulting ferrofluid doesn't have the best quality and proprieties. This is due to the fact that the particles are too big. In a high quality ferrofluid, there are nanoparticles which are suspended by Brownian motion and generally don't settle under normal conditions. In our case, the toner was constituted of micrometer-scale particles which are too heavy for Brownian motion to keep them suspended, and thus will settle over time because of the inherent density difference between the particle and its carrier fluid.

A ferrofluid has many applications in today's world: in electronic drives are used to form liquid seals around the spinning drive shafts in hard disks. The rotating shaft is surrounded by magnets. A small amount of ferrofluid, placed in the gap between the magnet and the shaft, will be held in place by its attraction to the magnet. The fluid of magnetic particles forms a barrier which prevents debris from entering the interior of the hard drive. A new and innovative use of this liquid is in medical field: magnetic drug targeting. In this process the drugs would be attached to or enclosed within a ferrofluid and could be targeted and selectively released using magnetic fields. Also, it has been proposed in a form of nanosurgery to separate one tissue from another – for example, a tumor from the tissue it has grown.

Resources

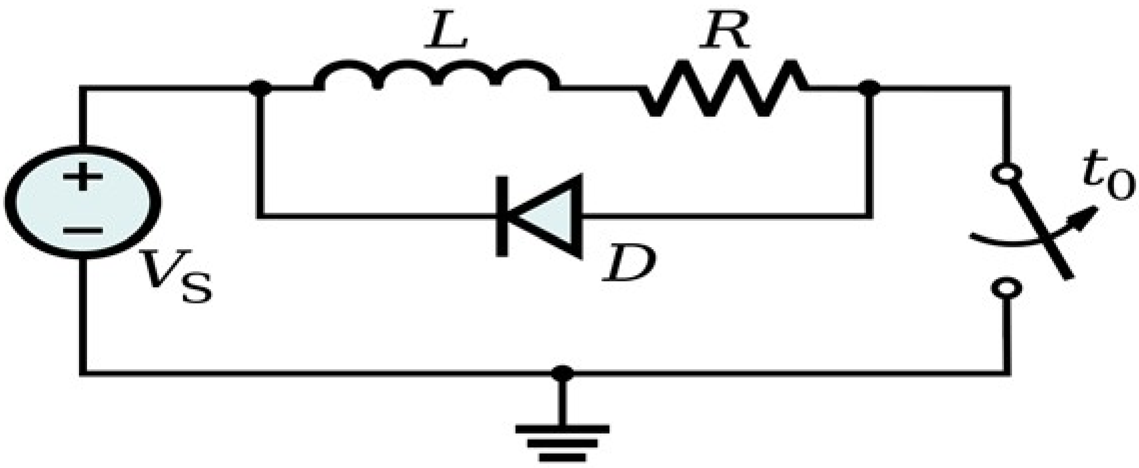
For our project we used the following resources:

- XMC1100 microcontroller with USB cable;
- 12V – 15 Amps computer source;
- Two electromagnets constructed in the manner explained above;
- A bowl with a thin membrane of ferrofluid;
- 4 transistors BD911(two for each electromagnet);
- 2 diodes 1N4007(one for each electromagnet);
- Resistors with various values(100 ohms, 3.3 ohms at 20 Watts);
- HC05 Bluetooth module;

The connections between the components have been realized with jumper wires on a solderless breadboard.

Solution description

For controlling the current which flow through the electromagnets we used a pair of transistors. With the platform XMC1100 we emitted a small current which was connected to the base of the first transistor through a 100 ohms resistor. The collector was connected at the current source through the 3.3 ohms, 20 Watts resistor. Because we needed a current of approximately 1.5 - 2 Amps to detect a small movement of the ferrofluid, we decided to use a second transistor. Therefore, the emitter of the first transistor was connected to the base of second transistor. The collector was also connected to the power source, with the emitter going to ground. An essential part of the circuit is the flyback diode. This has the role of protecting the circuit against the flyback voltage. When the circuit is powered, voltage(electromotive force) is applied to the ends of the coil. As the electrons travel, they put energy into creating a magnetic field. After we cut the power, the electrons don't just stop: the collapsing magnetic field puts its energy back into an effort to keep the electrons moving. It generates electromotive force in the coil. The resulting voltage is going to be passed through the circuit to whatever is stopping the current. This has the potential to damage the transistors. To avoid the damage we placed a diode. By shunting the current back to the coil the diode shorts out the voltage spike.



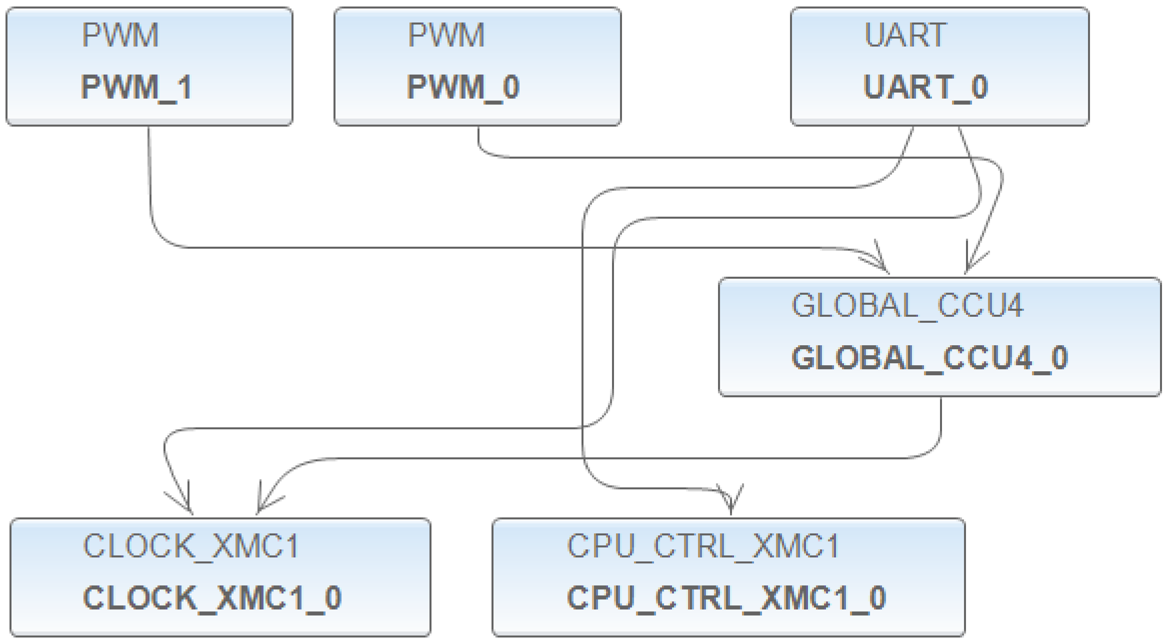
After the rigging was repeated for the second transistor, we connected the Bluetooth module to the XMC1100. The Bluetooth connection has been used to send a number to the microcontroller which is mapped to a certain duty cycle of a PWM signal. The PWM signal is used as the signal which goes in the base of the first transistor. In total, there are three levels of duty cycles implemented in software. The bowl with ferrofluid has been placed between the two transistors and the source was turned on. After sending each level through Bluetooth we could see, on the edges of the bowl, the liquid rising according to the duty cycle imposed by the level that has been sent.

From the software point of view application gets commands through the UART serial interface from a Bluetooth module, HC-05. Supported commands are, the following numbers represent levels of power:

1 – for a power level of 40 per cent;
2 – power level of 65 per cent;
3 – is the command for a 100 per cent level of power.

This power levels are some PWMs which are connected to the two transistors bases responsible for opening the power part of the application. PWMs are generated with a small frequency, 500Hz. UART serial interface is configured in FullDuplex mode with a 19200bps Baudrate, 8 bits of data, one stop bit and no parity. This is strongly related to the Bluetooth module configuration, which have to match.

Software modules are illustrated in the next scheme from Dave:



Application code:

```
#include <DAVE.h>
#include "xmc_gpio.h"
void delay(){
        int i;
        for(i = 0;i<0x2fffff;i++); // 2 sec
}
int main(void)
{
  DAVE_STATUS_t status;
  uint32_t i; // pt delay
  uint8_t ch;  // cararacter receptionat

  PWM_Init (&PWM_0);       // initializare modul PWM
  PWM_Init (&PWM_1);
  //PWM_SetFreq(&PWM_0,1500);  // perioada 20 milisecunde
  PWM_SetDutyCycle(&PWM_0,0); // nu genereaza semnal
  PWM_Start(&PWM_0);
  PWM_Start(&PWM_1);
  PWM_SetDutyCycle(&PWM_0,0); // nu genereaza semnal

  status = DAVE_Init();          /* Initialization of DAVE APPs  */
  XMC_GPIO_Init( P2_11, XMC_GPIO_MODE_OUTPUT_PUSH_PULL );
  XMC_GPIO_Init( P2_10, XMC_GPIO_MODE_OUTPUT_PUSH_PULL );

  UART_Init(&UART_0);
  UART_SetRXFIFOTriggerLimit(&UART_0, 0); // buffer 1 caracter

  while(1){
                if(UART_Receive(&UART_0,&ch,1)){
               if(ch=='1'){
                        PWM_SetDutyCycle(&PWM_0,4000);
                        delay();
```

```
			PWM_SetDutyCycle(&PWM_0,0);
			PWM_SetDutyCycle(&PWM_1,4000);
			delay();
		}
		if (ch=='2') // comanda 2
		{
			PWM_SetDutyCycle(&PWM_0,6500);
			delay();

			PWM_SetDutyCycle(&PWM_0, 0);
			PWM_SetDutyCycle(&PWM_1,6500);
			delay();
		}
		if (ch=='3') // comanda 2
		{
			PWM_SetDutyCycle(&PWM_0,10000);
			delay();

			PWM_SetDutyCycle(&PWM_0,0);
			PWM_SetDutyCycle(&PWM_1,10000);
			delay();
		}
		ch='0';
		PWM_SetDutyCycle(&PWM_0,0);
		PWM_SetDutyCycle(&PWM_1,0);
		}
	}
  return (1);
}
```

Results

As we mentioned, the electric current flowing through a conductive wire produces a magnetic field. But how strong is the magnetic field generated? The strength of the magnetic field(formally named magnetic flux density) is measured in Tesla[T]. Its formula is:

$$B=ur*N/L*I$$

where:

ur – is the magnetic permeability;

N – is the number of turns of the conductor ;

L – is the length of the portion of core where conductor was wrapped around;

I - is the intensity of electric current;

L and N were easily obtained using measurement and counting J. L has a value of 7 centimeters and the number of turns is approximately 188 for each electromagnet. Also, for each of the three levels, the electric current(I) was measured with a multimeter which gave readings of: 0.9 Amps, 1.72. Amps and 3.07 Amps.

Determining an approximate value for ur has proven to be the most difficult step. Because we didn’t have the exact chemical composition of the core, we couldn’t calculate a reliable relative permeability – we only know that the core was some kind of alloy composed mainly of steel, but which also had iron. After some internet research, we settled on a value of 300 for ur(the relative permeability is the material permeability against the air permeability).

Considering the above we arrived at the following values:

1st level – B = 0.865 Tesla

2nd level – B = 1.468 Tesla

3rd level - B = 2.718 Tesla

Bibliography

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