MICROPUMP VALVE ACTUATION SYSTEM FOR CONTROLLING NON-MAGNETIC FLUID CIRCUITS

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The project envisages the realization of a magnetically actuated micropump. The electromagnetic (EM) micropump system consists of three main components: 2 valves and a magneto mechanic actuator. The control of the pumping mechanism is ensured by an embedded microelectronic system. This ensures proper control of both the inlet and outlet microvalves and the pump diaphragm. A control circuit was designed using microcontroller ATMEGA2560 to produce square waves that controls coil actuator and the 2 valves. The system is designed to be used in many applications especially in medical drug delivery system.

Keywords: Magnetically actuated micropump, medical drug delivery application

1. Introduction

Electromagnetic micropumps typically consist of a housing with inlet and outlet valves through which the fluid flows, a flexible diaphragm that changes the pressure inside the housing, a permanent magnet placed over the flexible diaphragm, and a coil that generates an electromagnetic field. In general, either the magnet or the coil must be attached to the flexible membrane.

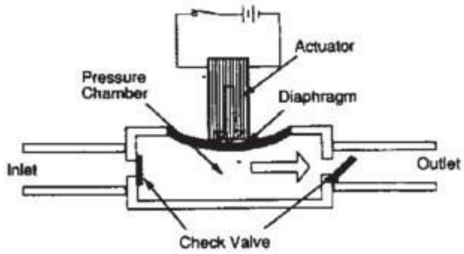

Fig. 1 Principle of magnetically actuated valve of a micropump

When electric current is applied to the coil, the resulting magnetic field creates attraction or repulsion between the permanent magnet and the inductor. In contrast

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to the electrostatic principle, electromagnetic actuation delivers force over longer distances at much lower control voltages.

2. Micropump actuation system

In order to magnetically actuate the micropump, an elastic membrane is used for the actuator and flexible membranes for valves ,and also permanent magnetic material is needed,in our case magnetite. The micropump will control the flow of the fluid,closing and opening the valves and actionate the actuator in a specific order, in order to obtain the peristaltic effect.

A microcontroller polarize the inductor of the target valve or actuator using a H-bridge. The H-bridge is used to polarize the inductor in both ways, in one way is to close the valve/actuator by pulling the magnetic material using electromagnetic force and on the other way, to push the magnetic material. Te block diagram of the actuation system of the micropump is present in the next figure.

The electrical circuit is designed to control the current through the inductor and, by implication, the intensity of the magnetic field generated. This is used: the ATMEGA2560 microcontroller, 3 H-bridges, a H-bridge consisting of 4 transistors and two drivers to control the bridge.

The 5V power supply is powering the microcontroller, the H-Bridges and drive controllers for H bidges. Also, the inductors are polarized through H bridges form an external power source.

The drivers that switch the gates of the transistors are controlled by the microcontroller via 4 PWM signals.

In order to be able to provide a pulsating current and implicitly an electromagnetic field with variable polarity, we used 2 half Bridges , which allows us to control the direction of the field but also the frequency with which it changes. This Half Bridges has in its composition 4 NMOS transistors, which act as a switch and their position determines the direction in which the current flows. and also , we add an intrinsic Schottky diode connected anti-parallel to one of the

transistors. This diode provides a return path for the current when we have an inductive load, avoiding possible destruction of the devices. The bridge is fed by the external power source and the gates of the transistors are controlled via the two drivers controlled by the microcontroller with the 4 PWM signals. The inductor is polarized by an alternating current whose change is set by the frequency at which the gates of the transistors switch. At any point in time on either arm of the H-bridge we have a single transistor open diametrically opposite to the other arm.

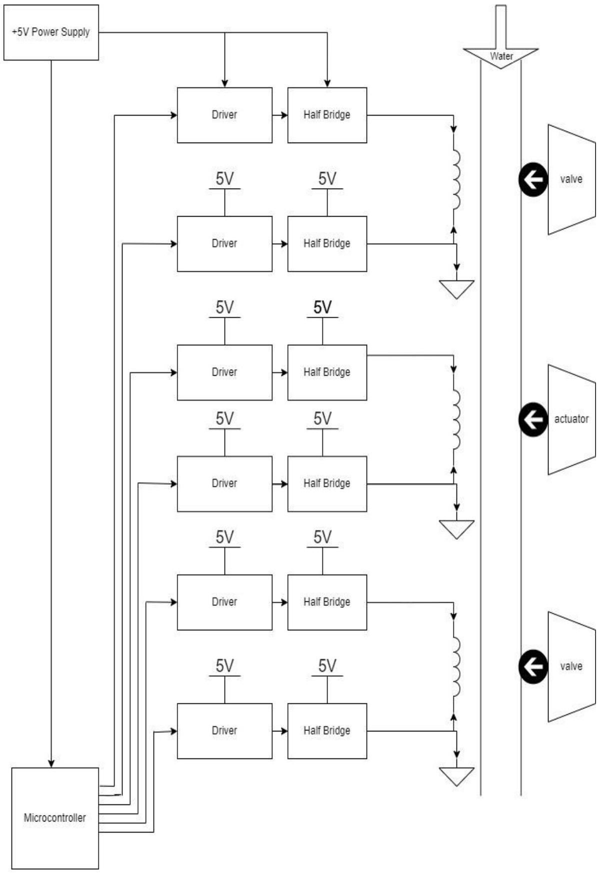

Fig. 2 Block Diagram of the actuation system

Two MCP14700 synchronous 2-input MOSFET drivers are used to control the two pairs of transistors that make up the H-bridge. They are designed to control both the top and bottom bridge transistors and have two PWM inputs that allow independent control of N-channel MOSFETs. The transition thresholds for the PWM inputs are 1.6V for rising signals and 1.2 V for descending. The threshold levels of the PWM inputs tolerate 3V logic and have a 400mV hysteresis curve for over-temperature protection.

The drivers are supplied with a voltage of +5 V via the voltage regulator. They implemented the bootstrap circuitry for the top transistor internally, allowing for low complexity and low cost for systems using these drivers.

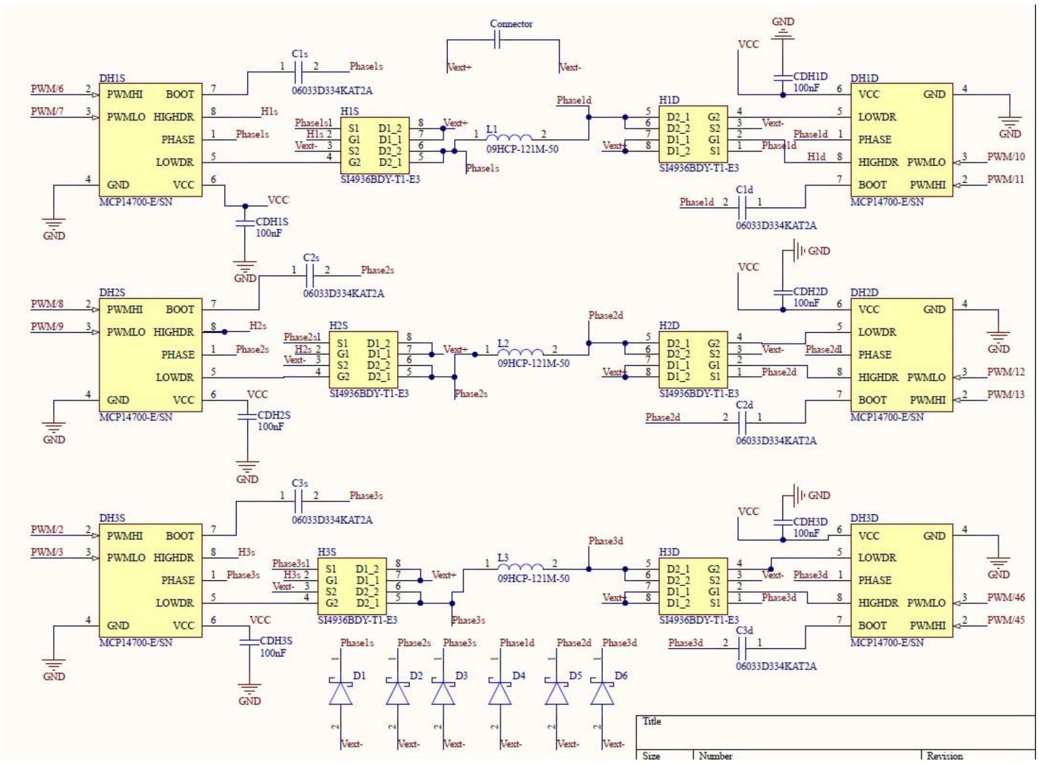

Fig. 3 Electrical scheme for the micropump actuation system

For this application, a two-phase control configuration was used and each gate of the two pairs of transistors was connected to the control pins of the drivers (HIGHDR and LOWDR, respectively). With the exception of the capacitors, all circuits for controlling the transistors are integrated in the chip. The PWM pins are internally connected to the ground plane to ensure that no signal is present at the transistor gates when left floating.

A transition from "0" to "1" or vice versa, from "0" to "1" of the PWM pins ,also shows the behavior of the control states of the LOWDR and HIGHDR pins, on which a the signal is applied to the gates of the transistors in the composition of the H-bridge.

In order to obtain a robust PCB, we have developed 2 boards ,one contains the Atmega 2560 and one contains the actuation system coupled by board to board connectors and inductors are located on bottom side of actuation system CB. Also, we add an potentiometer to control the frequency manually of the bridges that polarize the inductors

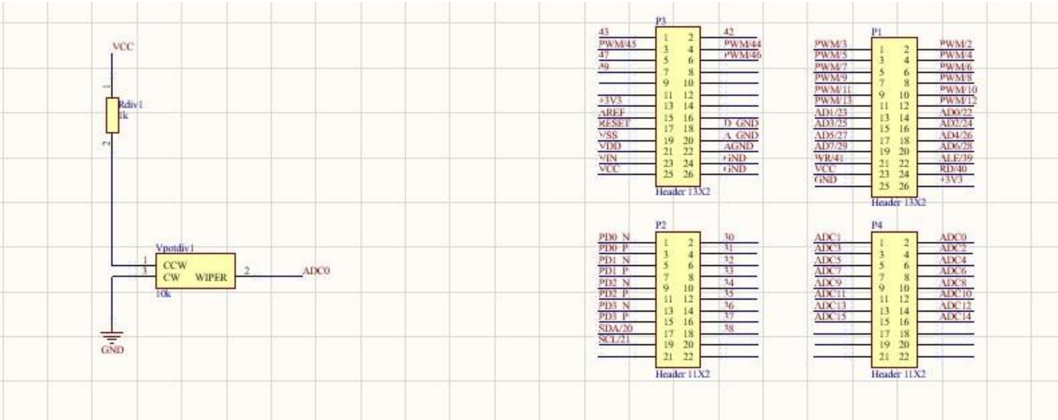

Fig. 4 Potentiometer to control de frequencyof the actuating system

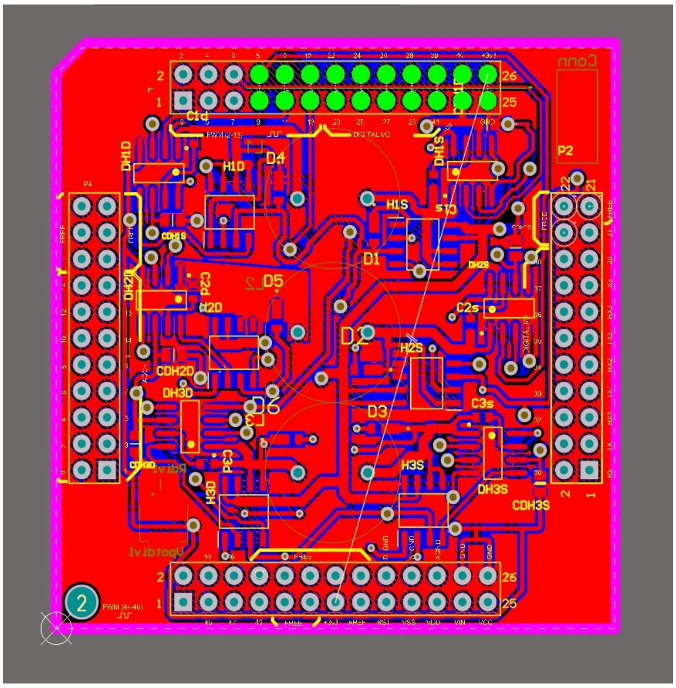

Fig. 5 Actuating system PCB Layout

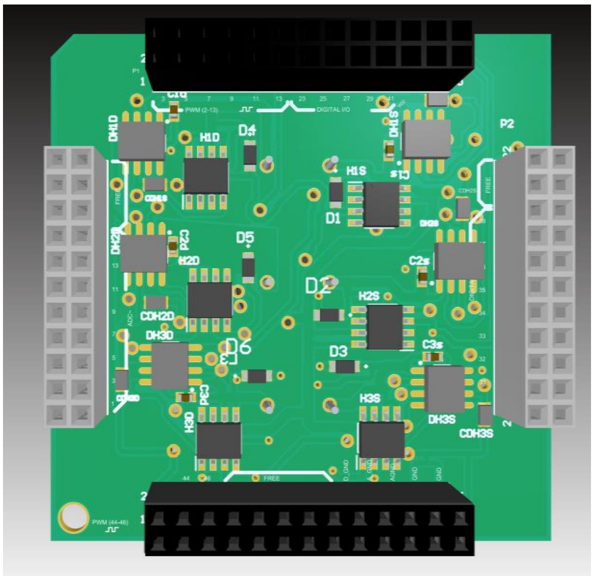

Fig. 6 Actuating system PCB 3D Layout

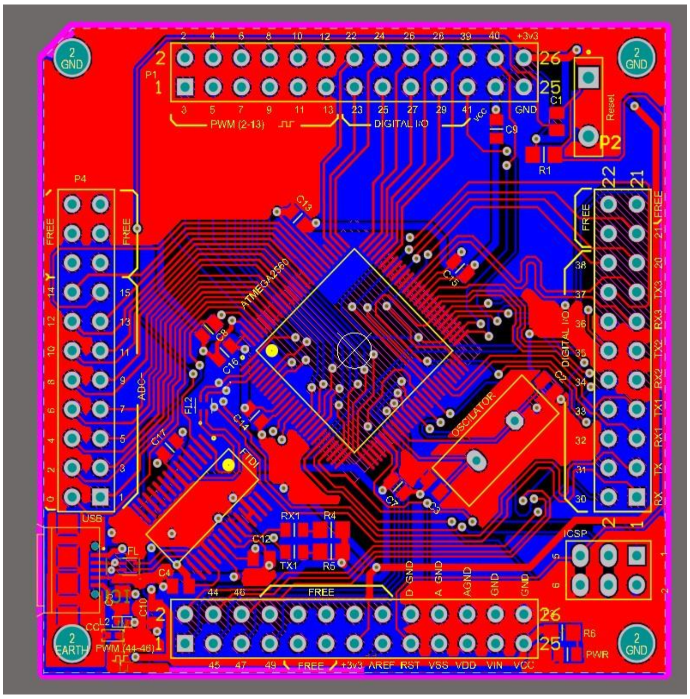

Fig. 7 Atmega2560 PCB Layout

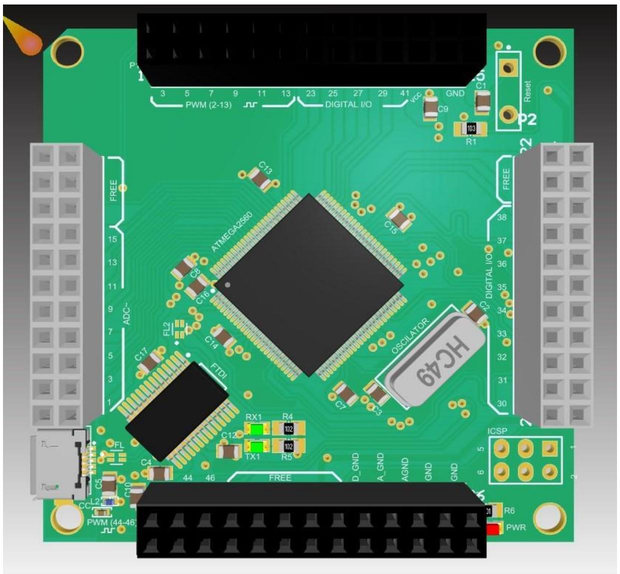

Fig. 8 Atmega2560 3D Layout

4. Valve control unit. Modeling and Simulations

After measures, the Inductor is heating to approximately 100 °C on constant current of 1A, so we make the model of the inductor in Ansys, in order to simulate the behave and intensity of the magnetic field in different configuration of the inductor. In the next picture is shown the real inductor of which we make a model in ANSYS.

Fig. 9 The inductor which is modeled

In the next photos there are pictures with modeled inductors with different number of turns and at different currents. In the photos it is measured the variation of the intensity of the magnetic field, according to the number of turns and the current through the inductor:

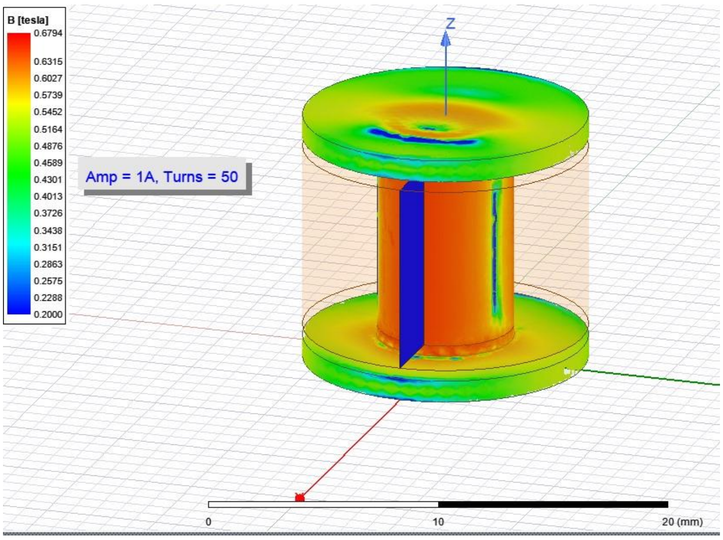

Fig. 10 Intensity of the magnetic field 1A 50 turns

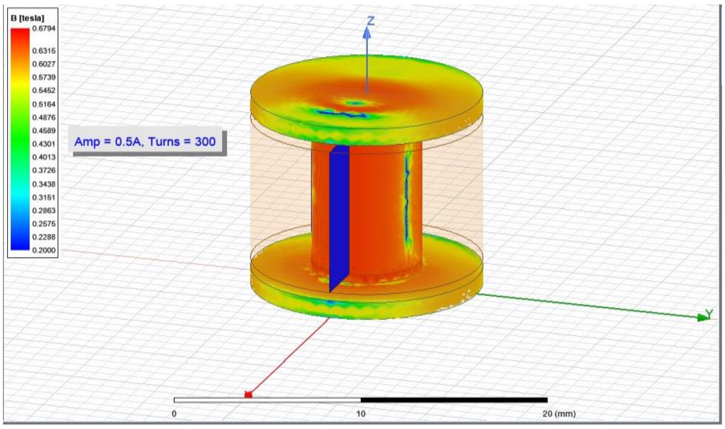

Fig. 11 Intensity of the magnetic field 0.5A 300 Turns

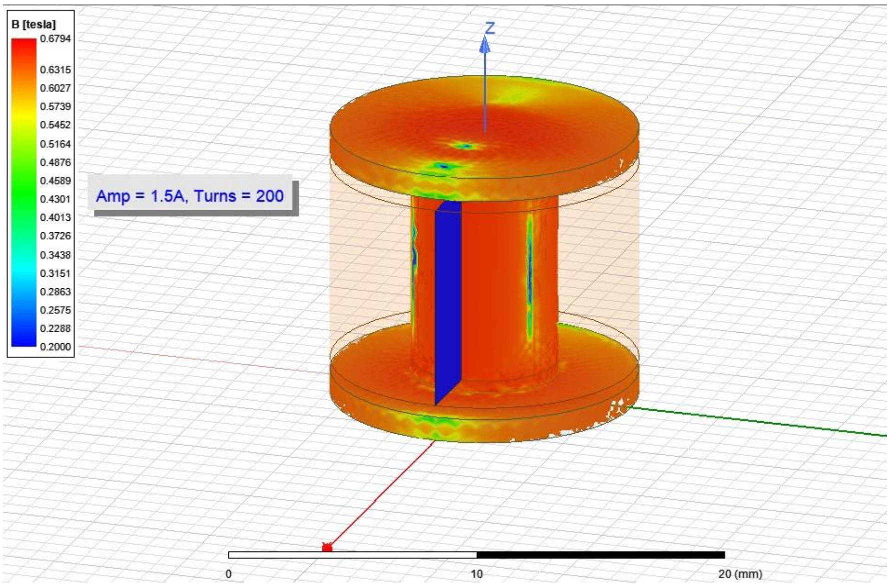

Fig. 12 Intensity of the magnetic field 1A 300 turns

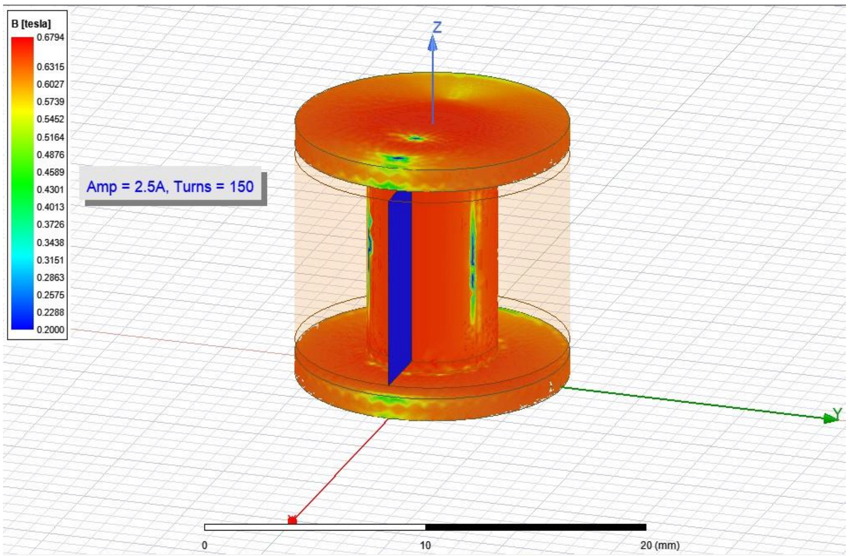

Fig. 13 Intensity of the magnetic field 1.5A 200 turns

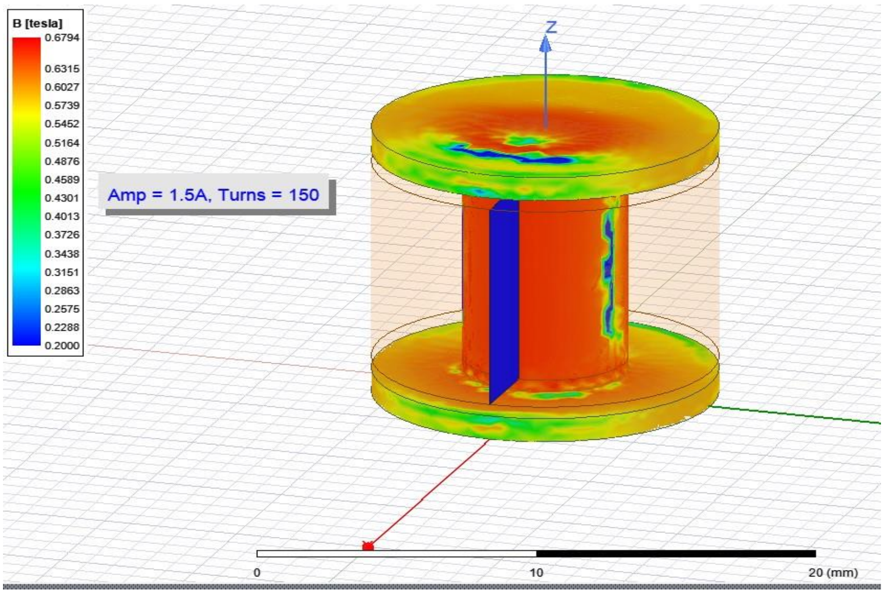

Fig. 14 Intensity of the magnetic field 1.5A 150 turns

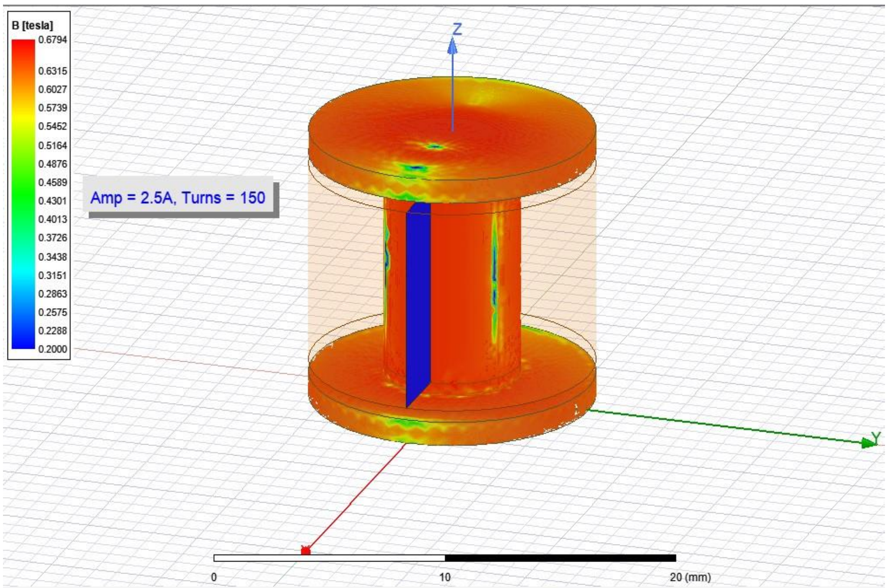

Fig. 15 Intensity of the magnetic field 2.5A turns 150

In the modeling phase of the inductor, we decided that we have to use more turns in order to use a lower current, because a high current value through the inductor will result in getting the inductor hotter. In Fig. 17. it is shown that intensity of the magnetic field is getting stronger due to increasing the number of turns than increasing the value of the current through the inductor.

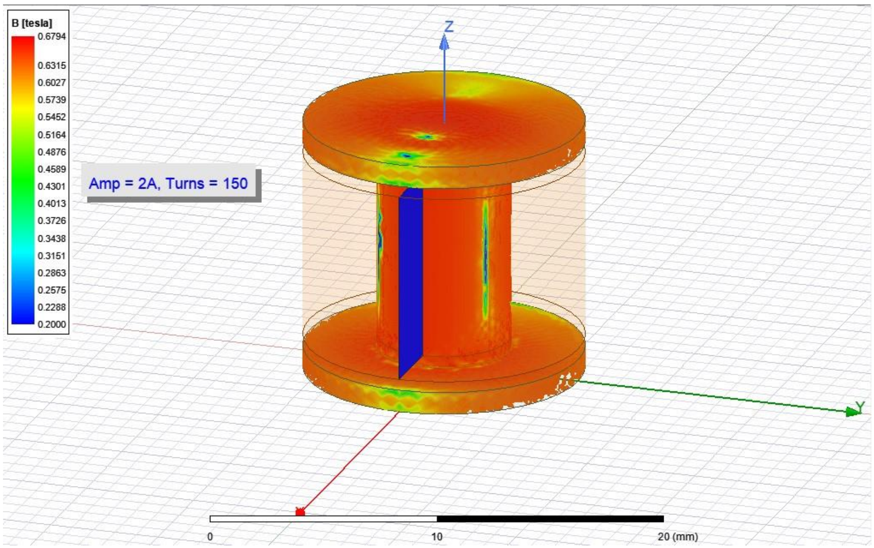

Fig. 16 Intensity of the magnetic field 2A 150 turns

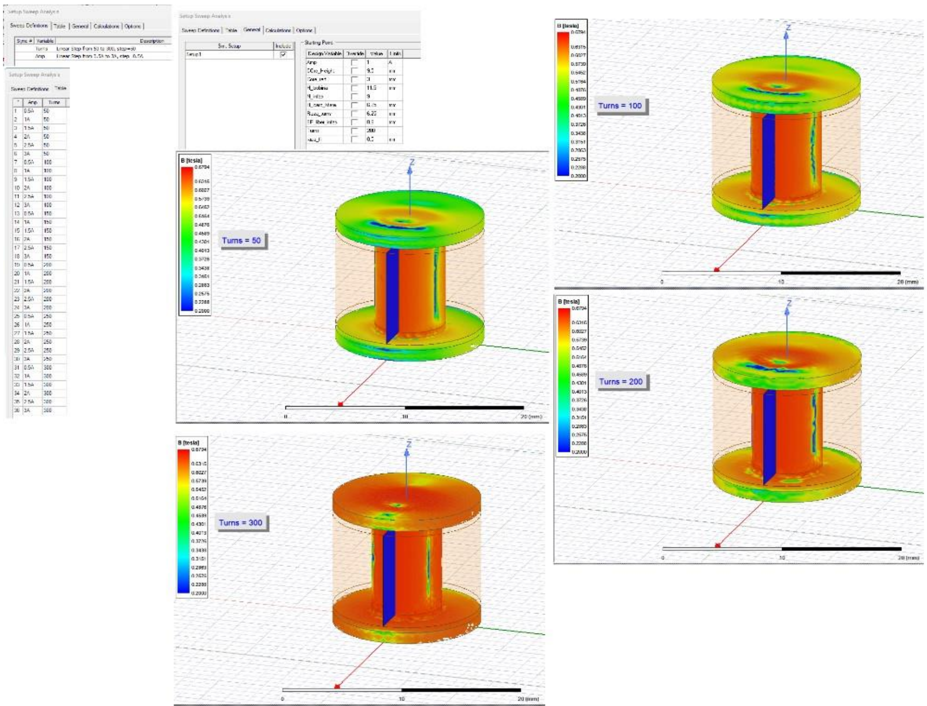

Fig. 17 Intensity of magnetic field according to the number of turns

5. Command algorithm of the micropump system

For a continuous flow of a fluid through the micropump, we have to create the peristaltic effect using the valves and actuator. The peristaltic effect is created if we have a controlled flow of the fluid by closing and opening valves and actuator in a specific sequence which is described in the next picture

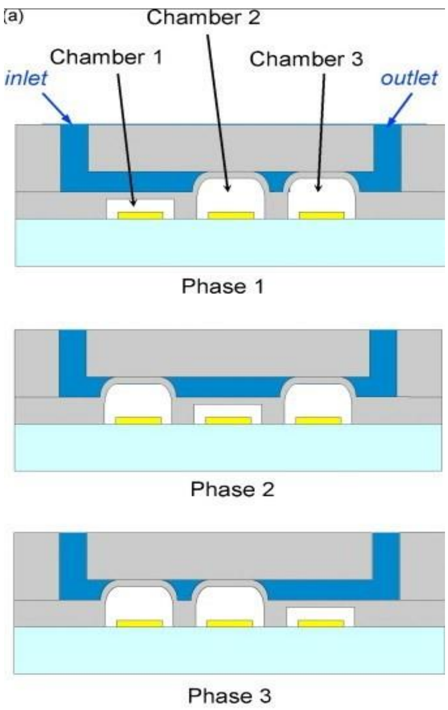

Fig. 18 Peristaltic effect

In order to have a good flow of fluid, the microcontroller will command the valves and actuators on a repetitive sequence, the frequency of the closing and opening of the valves will be controlled by a variable resistor from 0 to 200 Hz.

Functional Diagram

Step	Time(ms)	Valve 1	Actuator	Valve 2
0	0	1	1	1
1	5	0	1	1
2	10	0	0	1
3	15	1	0	1
4	20	1	0	0
5	25	1	1	0
6=1	30	0	1	1

0-open valve

1-close valve

Fig. 19 Functional Diagram

6. Results

To test the functionality of the board, before doing the final board, we made a prototype board in which we have built the command circuit for only one inductor powered with +5V from a source. Thanks to the iterations performed when analyzing the parameters of the Inductor, we were able to accurately determine the value of the current required for each coil. For this reason, I have chosen to power the H-bridge and implicitly the inductor with a current of 1A.

We analyzed the current through the inductor connecting an oscilloscope to the output of the circuit and analyzed the waveforms obtained according to the Fig.s below. The PWM control signals have been programmed to switch at a frequency of approximately 3 kHz. . Using an oscilloscope, we obtained the following waveform, showing that for a current of 1.011 Arms, a peak-to-peak value of 2.252 A is obtained. In the next Fig. the current through the coil is shown in yellow.

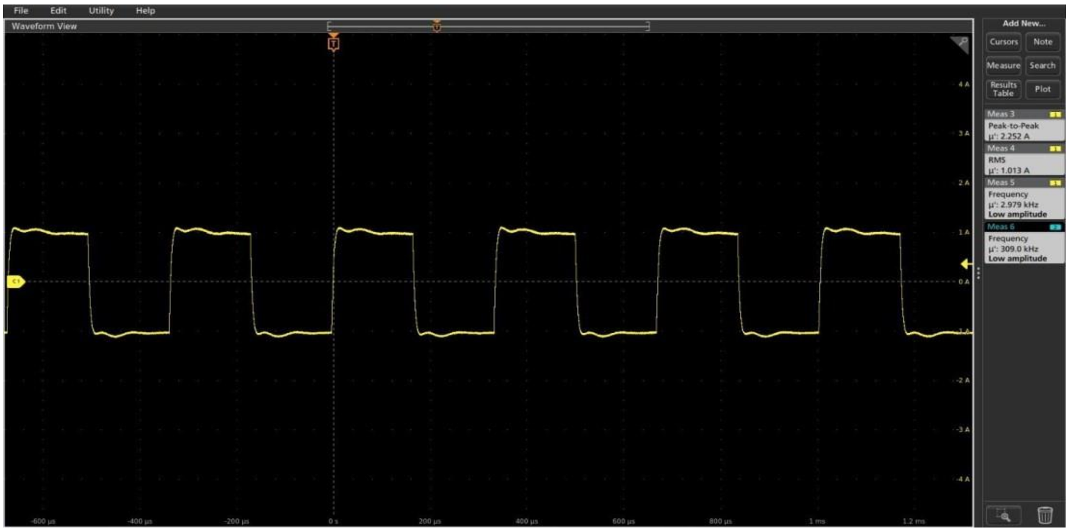

Fig. 20 Waveform of the current through the inductor

After this result, we multiplied this command circuit for one inductor 3 times and created the final command board.

7.Conclusion

After this research, it was tested and confirm that the designed and manufactured electronic system is capable of controlling valves and actuator using electromagnetic field in a specific sequence in order to create a controlled regular flow of the fluid through the micropump. Using Ansys platform, it was modeled and simulated the inductors used in the project in order to determine the right amount of turns and the current through the inductor, in order to have enough intensity of the magnetic field to push and pull the magnetic material on top of the flexible/elastic material and also to manage in keeping the inductor temperature at safe values (under 80 °C).

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REFERENCES

[1] *D. J. Laser and J. G. Santiago*, "A review of micropumps," Journal of Micromechanics and Microengineering, vol. 14, no. 6, pp. R35–R64, Jun. 2004.

[2] *C. Yamahata, F. Lacharme, Y. Burri, and M. A. M. Gijs*, "A ball valve micropump in glass fabricated by powder blasting," Sensors and Actuators B: Chemical, vol. 110, no. 1, pp. 1–7, Sep. 2005.

[3] *B. Wagner, W. Benecke*, Microfabricated actuator with moving permanent magnet, IEEE Proc. 1991, pp. 27–32.

[4] *F. M. White*, Fluid Mechanics. New York: McGraw-Hill, 1986

[5] *Carrozza, M. C., Croce, N., Magnani, B., & Dario, P*. (1995). A piezoelectricdriven stereolithography-fabricated micropump. Journal of Micromechanics and Microengineering, 5(2), 177–179. doi:10.1088/0960-1317/5/2/032

[6] *Yamahata, C., Lacharme, F., Matter, J., Schnydrig, S., Burri, Y. and Gijs, M.A.*, 2005, June. Electromagnetically actuated ball valve micropumps. In The 13th International Conference on Solid-State Sensors, Actuators and Microsystems, 2005. Digest of Technical Papers. TRANSDUCERS'05. (Vol. 1, pp. 192-196). IEEE.

[7] *Arcire A., Olaru R., Petrescu C.*, Study of The Influence of Ferromagnetic Material on the Characteristics of an Actuator Based on Ferrofluid and Permanent Magnets, 2012 International Conference and Exposition on Electrical and Power Engineering (EPE 2012), 25-27 October, Iasi, Romania, pag. 776-780.

[8] *N. Bencheikh*. Conception et réalisation d'un conveyour électromagnétique planaire miniature. PhD thesis, Université de Technologé de Compiègne, France, 2006.