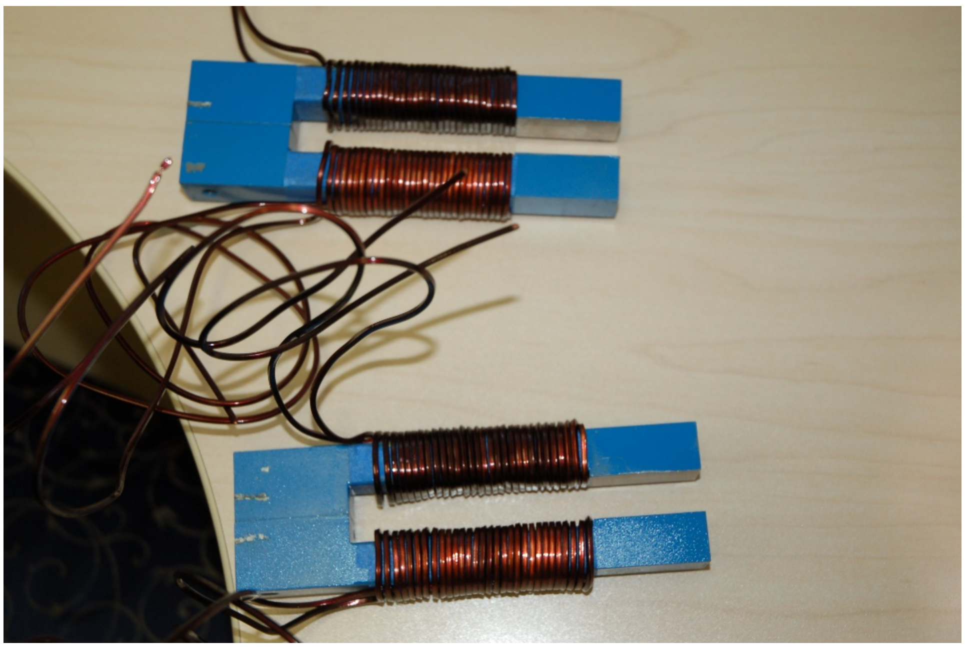
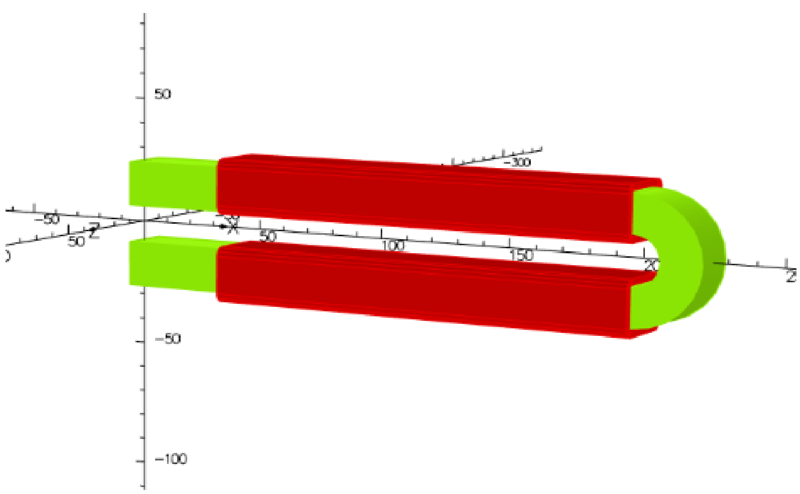
I2 Steerer magnetic calculation and realization report





Nathan Simon - 2019/08/09

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1) Context

Magnetic steerers are used to modify the trajectory of the particle beam in laboratories along a direction. This project requires two steerers to steer the beam in both directions of the transverse plane with a weak magnetic energy. Those magnets will be placed in a restricted space, and they will be close. The magnetic field from a magnet can be perturbated by the presence of the steel of the other magnet nearby. The aim of this study is to show the influence of a magnet near another magnet and to identify how close those steerers could be positioned. In a second time, the goal is to design and make the magnets.

2) Simulation on Opera

A) Specifications of the magnet:

Characteristics used in the model for the first design of the magnet:

Pole inner gap (g1): 7.5mm

Pole outer gap (g2): 7.4mm

Pole height (a): 10mm

Yoke transverse thickness (t): 15mm

Longitudinal half thickness (h): 10mm

Steerer length (l): 200mm

Pole width (w): 40mm

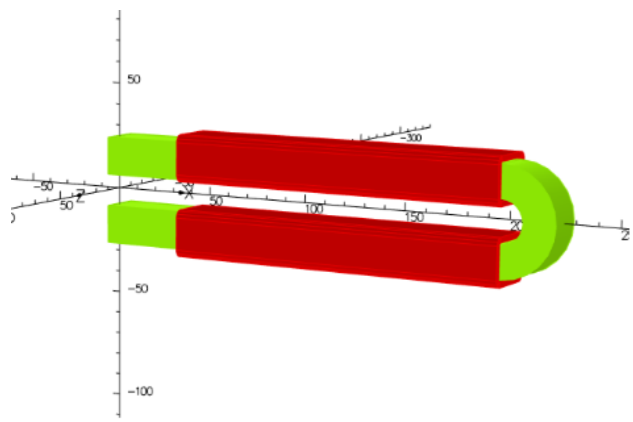

Fig 1: Model for the simulation on Opera

Coil transverse width (cw): a/4

Coil minimum radius of curvature (cr): 1 degree

Minimum clearance between the coil and the end of the reduce potential region: 2mm

Current power supply (ci): 1 A

Coil number of turns (ct): 200 turns

Current density (cd): (ci*ct)/((1-w)*cw

B) Placement of the steerers:

We can only use the yoke of the second magnet for our simulation because we are only interested in the influence of the steel. The influence of the coil is negligible against the steel one.

The two steerers are placed perpendicularly to have a correction of the beam in two directions.

The simulation is conceived to scan the field from the origin to 50 mm.

Several simulations were made with different spacing between the middles of the steerers (50mm, 60mm, 75mm, 90mm, 100mm, 125mm and 150mm) to check its impact on the magnetic field.

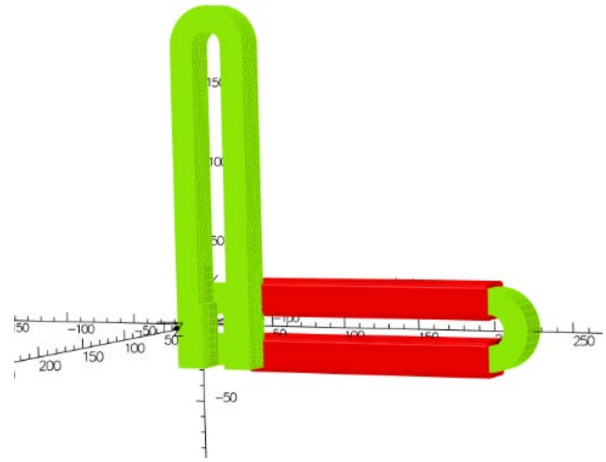

Fig 2: Two steerers models placed closed

3) Exploitation of the results

A matrix was created with the data supplied by Opera, then to process the data, Gnuplot was used to generate the plot underneath. We can clearly see the presence of the steel between 0 and 17.5mm and between 32.5 and 50 mm because the magnetic field integral between those data ranges is lower is the magnets are closer.

The closer the steerers are, the greater the variations of the magnetic field. Starting from approximately 125mm (we can't see the 125mm plot because it is superposed with the infinite one) there is no perturbations between the steerers.

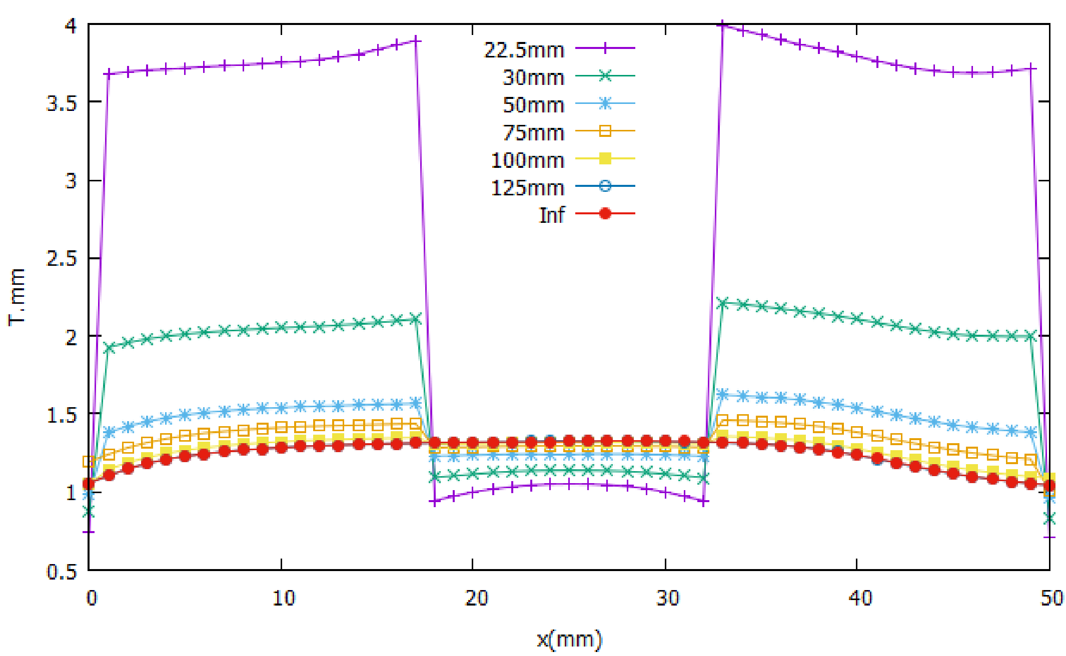

Fig 3: Influence of the distance between the steerers on the magnetic field integral

4) Dimensioning of the magnet

To dimension this magnet, we choose the worst case with 22.5mm between the middles of the two steerers. We need to have a magnetic field integral under 0.5 T.mm in the gap and an electric power smaller than 3W. To set those parameters we are using this equation below:

$$P = R\,I^2 = \frac{L\rho}{S}\,(N\,I)^2$$

Where L is the coil "one-turn" length, S is the coil cross section, ρ the Electrical resistivity (16.8nΩ.m for copper at 20◦C), and NI the total amount of current (Ampère × turn). This is coupled with the Ohm's law.

We have researched standard power supplies used in TRIUMF, the one with the lower current and voltage is a 5A and 15V.

Therefore, we have adapted the magnets to this power supply. To manufacture this magnet, we will use the smallest insulated copper we have (2.15mm x 2.15 mm). With this copper we must do 30 turns to have the desired characteristics, so a length of coil of 64.5 mm is needed.

We can reduce the length of the yoke by approximately 75 mm, because the steel is not saturated so we can reduce the quantity of material. We updated the model of the magnet to make it realistic with the hole for the screw and the new specifications.

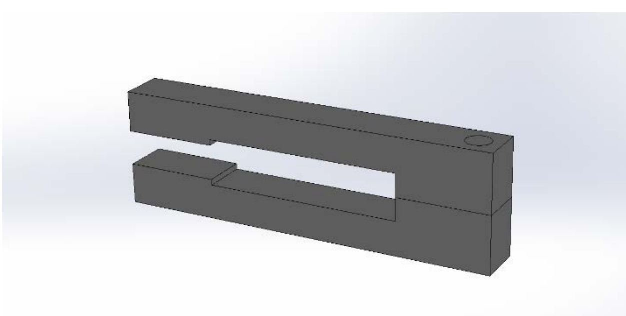

Fig 4: Steerer 3D model in Solidworks

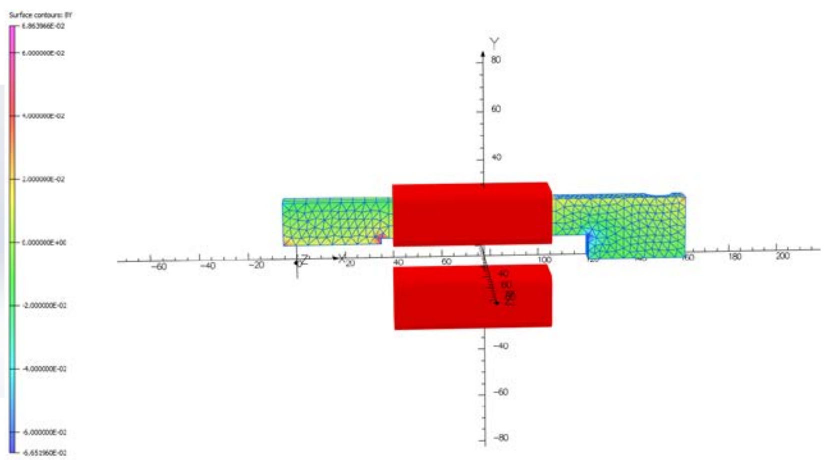

Fig 5: Saturation of the steel after reducing the length of the yoke

The reaction of the realistic design of the magnet in the worst case (d=22.5mm) is the same as the original model so the modification doesn't influenced the phenomenon of two close magnets.

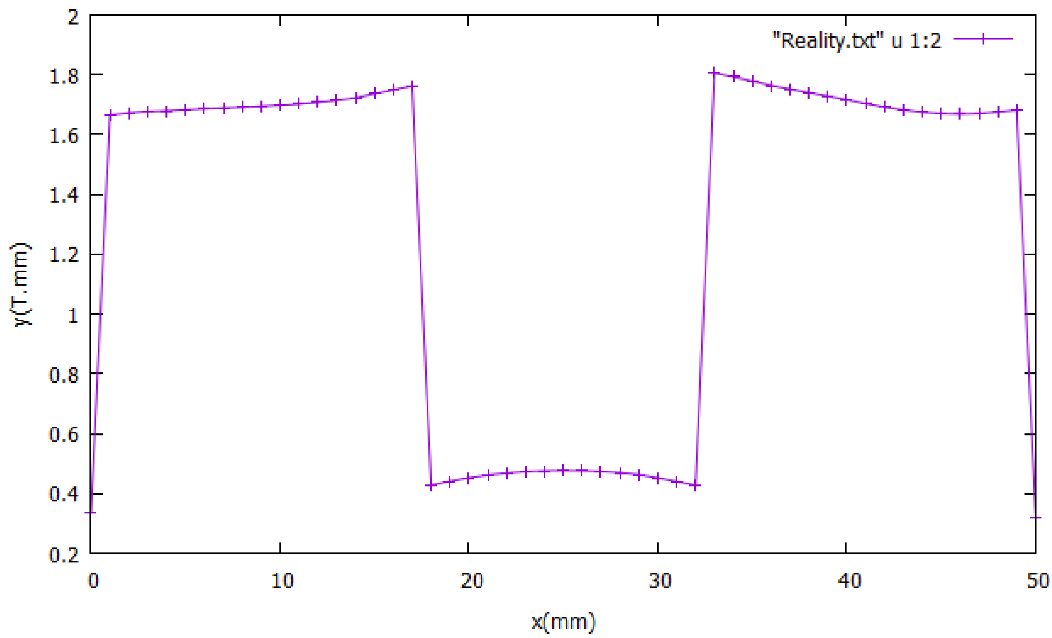

Fig 6: Reaction of the new model in the worst case (d=22.5mm)

The Figure 7 is extracted from a simulation destinated to show if the hole through the magnet is not perturbating so much the magnetic field. We can see that there are no big pikes or variation on the plot.

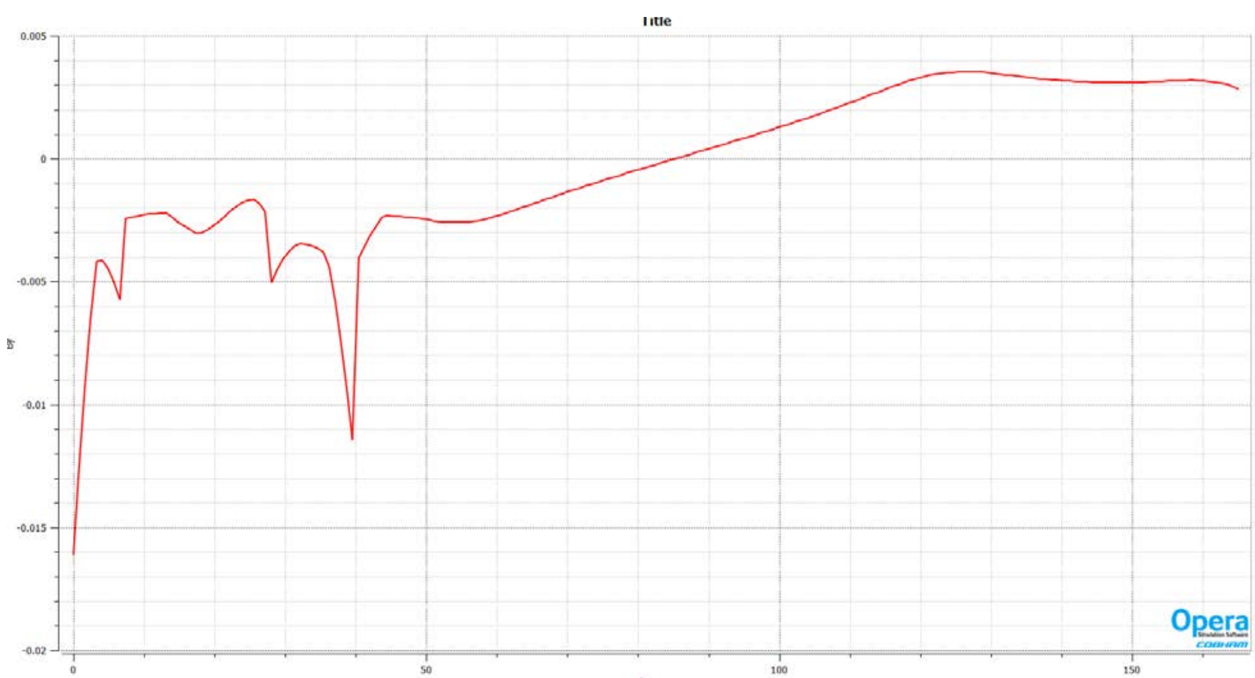

Fig 7: Influence of the hole through the magnet on the magnetic field

5) Winding work station

To do some winding you need an unwinder to dispense the conductor. You also need a brake to generate a tension on the wire to make it easy to deform with the winding machine (see Fig 9). The alignment should be kept between the unwinder, the brake and the winding machine (see Fig 8).

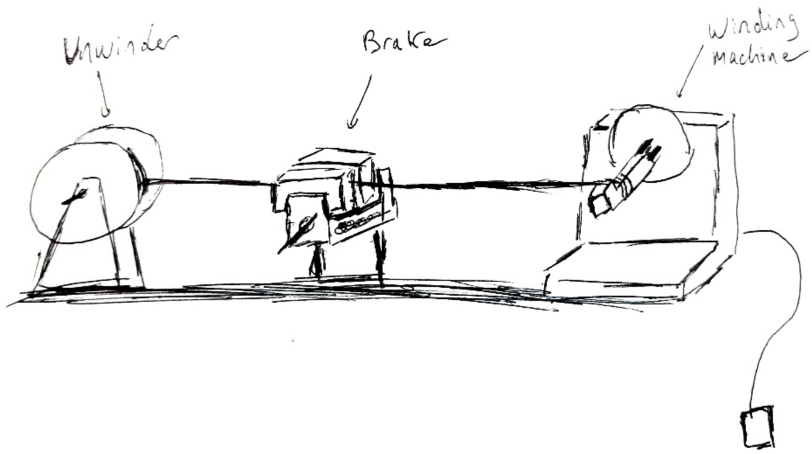

Fig 8: Schema of the winding workstation

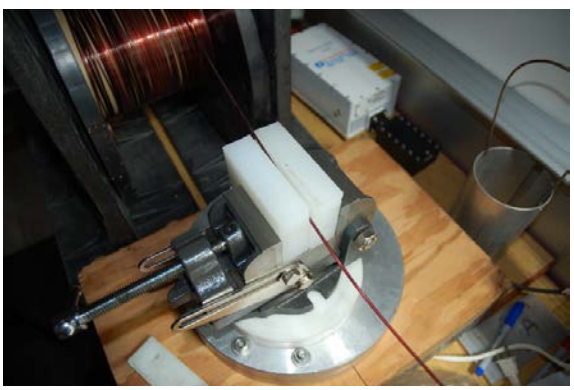

Fig 9: Picture of the brake

The yoke needs to be fastened on the winding machine. To make it turns press the pedal. You can adjust the rotating speed and the direction.

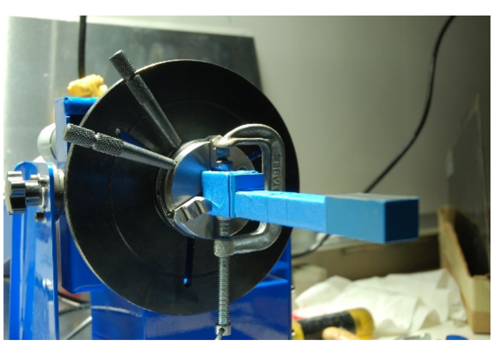

Fig 10: Yoke fastened on the winding machine

6) How to wind a coil

On the Figure 11 below we can see that there is a small thickness of insulation around the yoke. Then you must make a reserve of copper for the output. The output should be formed and fasten to the yoke like on the Figure 12 (do not hesitate to put more wire than necessary for the output). After two turns you can remove the plastic plier, then after six turns you can also remove the metallic plier which is keeping the output on the yoke.

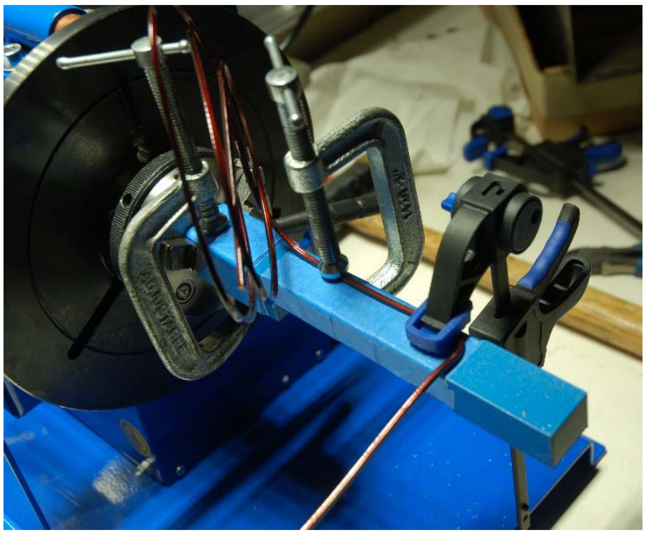

Fig 11: Fastened output and insulation of the yoke

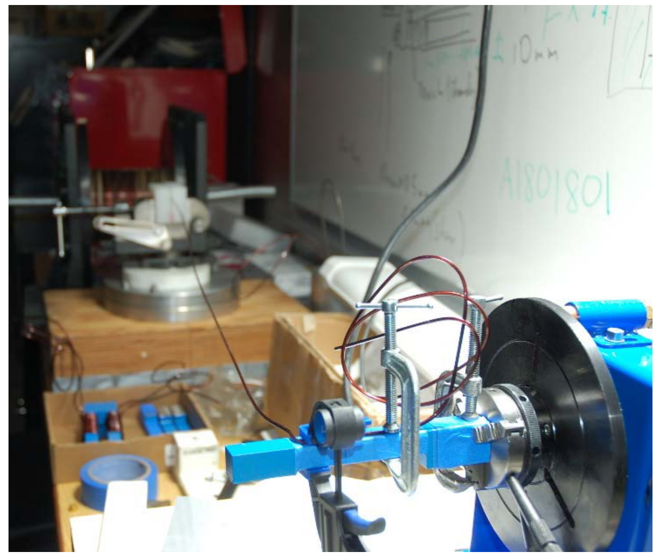

Fig 12: Reserve of copper

The wire is inclined to twist, you can use a wrench to choose the orientation of the wire. If you let the wire turn the geometry of the coil will not be good. The wrench is also useful to adjust the tension. You can push on the wire with your thumb but it's less precise.

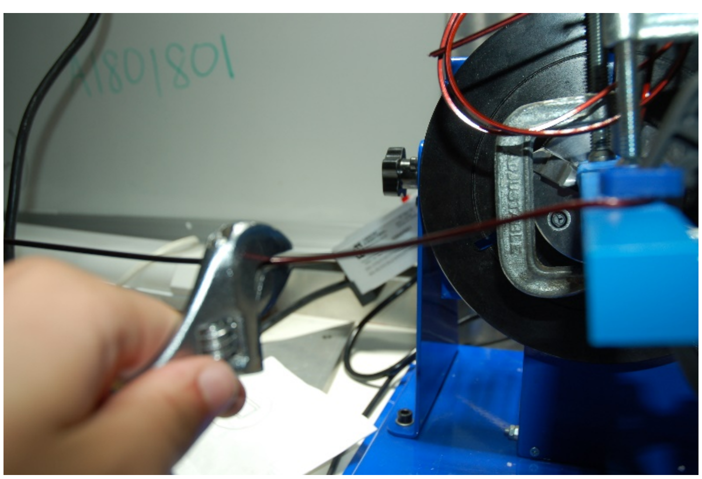

Fig 13: Wrench for keeping the wire straight

You must hit the copper with a soft mallet through a block of plastic to not damaged the conductor. The aim is to tighten the wire around the yoke and to keep the geometry of the coil. You can hit the wire after 3 or 4 turns.

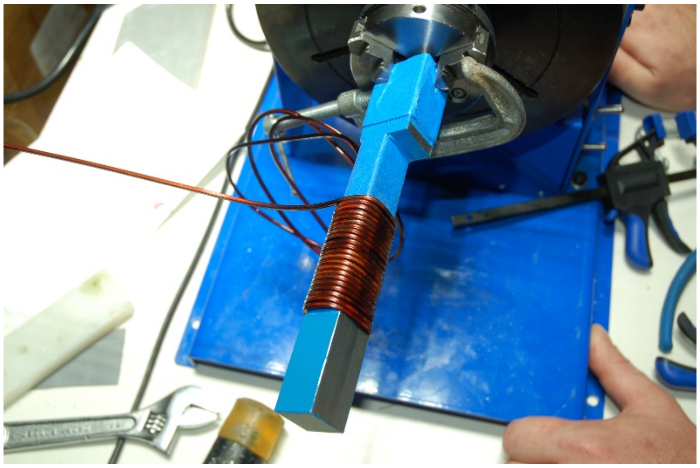

Fig 14: Coil fastened to the yoke

Fig 15: Soft mallet and block of plastic

When the required number of turns is done you will have to give a shape to the output (see Fig 15). Do not hesitate to put more wire than necessary for the output.

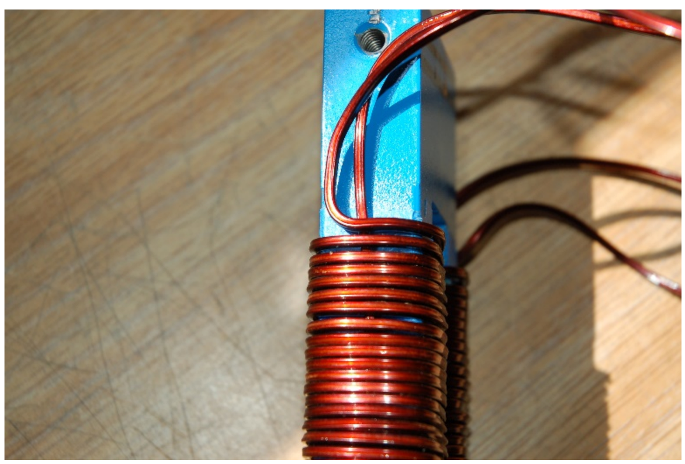

Fig 15: Output forming

The magnet should look like the ones below. The coil must be tightened on the yoke and the wire should be as straight as possible around the yoke.

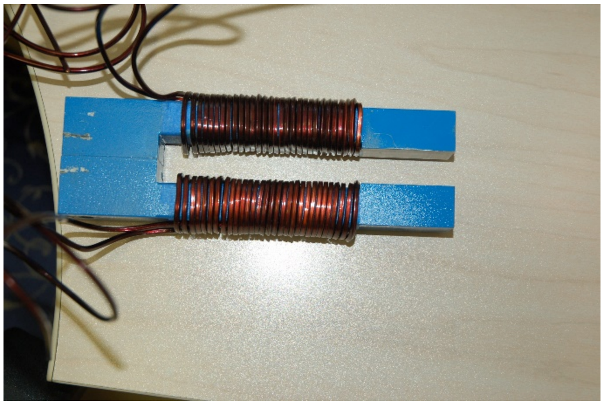

Fig 16: Finished steerer

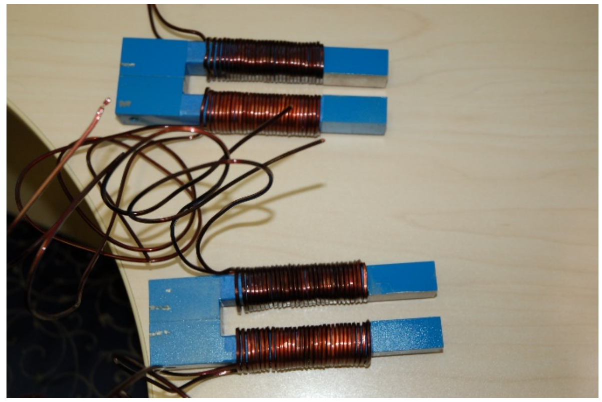

Fig 17: The two I2 steerers

7) Conclusion

During this project the magnetic calculations and simulations have permitted to find the design and choose the specifications of the magnets. With the specifications we have updated the model and checked the performances of the steerer. The yokes were made by the diagnostic division. We had to create a winding workstation with the available elements. The winding requires to be precise and to proceed carefully.

There are remaining tasks: do the magnetic measurement to check the performances of the magnets and install the prototypes.