Project 2 - IN1080

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Learning outcome

In this project, we will make a simple "do it yourself" (DIY) stepper motor based on 4 inductors, permanent magnets, and a 3D printed frame. The inductors will act as electromagnets, and we will make them by winding copper wire on 4 reels. In this way, we will get experience with inductors, see how the essential details in a stepper motor can be made, and understand and experience how the basic electromagnetic principles of an electric motor work. The labGuide.pdf is now updated to include instruments used in project 2.

Background

A physical inductor is not ideal, and for low frequencies, it can be modelled as a series connection of an ideal inductor L, and a resistor R_W as shown in Fig. 1. The resistor R_W models the resistance of the wire used in the inductor. The voltage over the terminals on the non-ideal inductor is the sum of the voltage over the parasitic resistor R_W and the voltage over the ideal inductor L. For DC currents, there is no voltage over the ideal inductor L, and we can calculate the voltage over the terminals just by finding the voltage over R_W. In other words, if we connect a non-ideal inductor to a DC voltage V, the steady-state DC current is given by Ohm's law $I = V/R_W$.

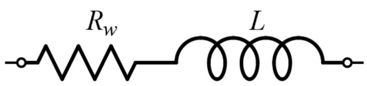

Figure 1: The model of a non ideal inductor with a parasitic resistance R_W. The 2 terminals are symbolized with circles in each end.

An electromagnet is an inductor and can be made by winding copper wire over a reel to make a coil. When current flows in the wire, it will produce a magnetic field where the strength of the field (magnetic flux) is proportional to the current and the number of winding in the coil. In an electric motor, rotational force (torque) is often produced by magnetic forces between electromagnets and permanent magnets. The torque is proportional to the strength of the magnetic field. In Fig. 2, a simplified diagram of a stepper motor is shown. In the center, we have a permanent magnet that can rotate, surrounded by 4 electromagnets that are fixed in space.

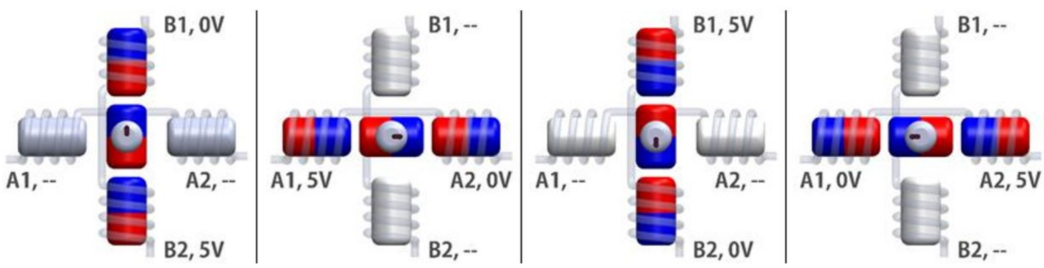

Figure 2: Stepper motor for 4 different voltage configurations and rotor positions (steps).

The electromagnets with the A1 and A2 terminals are connected in series. The two other 2 electromagnets are also connected in series. In the figure, 4 different configurations of voltages are applied to the outer terminals A1/A2/B1/B2 of the electromagnets. To the left, a voltage of 5V is connected over B1/B2 with the highest potential on the bottom terminal. No voltage is applied to A1/A2. The free rotating permanent magnet in the rotor in the centre will now rotate so that it aligns it's north pole (blue) with the south pole (red) of the top electromagnet, and it's south pole with the north pole of the bottom electromagnet. In the next sections of Fig. 2, other voltage configurations are shown, and the rotor will align at different angles (steps).

In Fig. 3 left, we see how the electromagnets (inductors) are connected. If we apply a sequence of voltages over the electromagnets as illustrated in Fig. 3 right, the rotor will rotate as shown in Fig. 2. This is called wave commutation. "Commutation" is the name of the act of changing a voltage configuration so that the rotor rotates either to a specified angle or with a specified force (not relevant here).

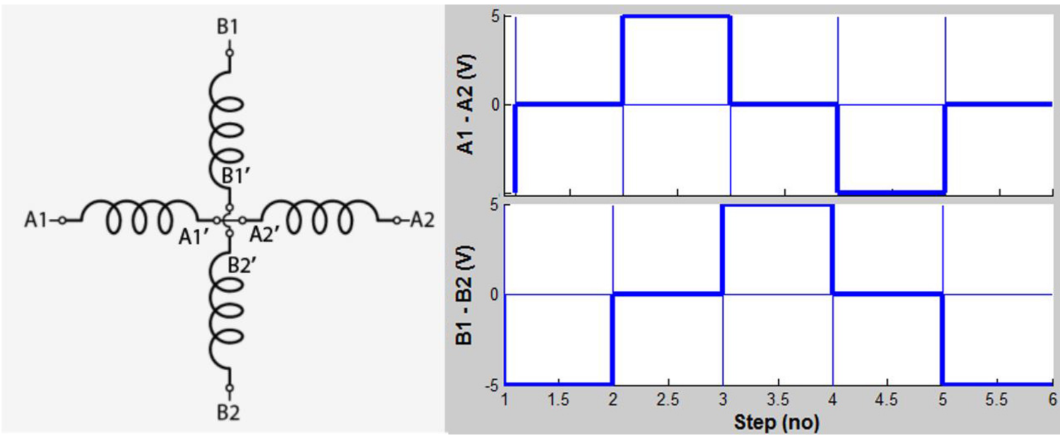

Figure 3: Left: how the electromagnets (inductors) are connected. Current can flow between B1 and B2, and between A1 and A2. Right: The sequence of voltage configurations that produces "wave step" motion.

What to do

We will now make a stepper motor based on winding copper wire on 4 reels, connecting 2 and 2 coils in series, assembling the coils in a 3D printed frame, and manually applying (commutating) voltages over the resulting terminals to produce "wave step" motion. To reduce the air gap between the electromagnets and the permanent magnets, the rotor is located on top of the electromagnets.

Make sure to read the "tips"/"important info" section at the end of this document during the assembly process.

Coil winding: We have available lacquer insulated copper wire with a diameter of 0.4mm, with resistance R_W that can be calculated from the length and cross-sectional area of the wire, together with the resistivity of copper ρ. Since the wire is insulated, coiling the wire will not affect the resistance from end to end. We want to commutate the motor with a voltage of 5V. 5V is chosen because it is easy to make a motor driver for this motor in a later project in IN1080. We want the current in each coil to be somewhere in the range 1.0A-1.3A. 1.5A-2A may be an upper limit to avoid overheating the wires.

1. Calculate the required parasitic resistance R_W in one inductor (corresponding to the wire resistance between A1 and A1' in Fig. 3, so that 2 inductors in series draws 1.2A from a single 5V voltage source.

2. Calculate the required length of copper wire in one inductor to get the resistance found in question 1 for a 0.4mm diam (AWG26) copper wire when the resistivity of copper is $\rho = 1.7 \cdot 10^{-8}\Omega m$

3. Use the drill and fill one reel with copper wire, as shown in Fig. 4. Grind the lacquer insulation off the ends (Fig.5 left). Measure the resistance R_W of your new inductor with RS-12. Assume that the length of the wire in the coil is 15m. Does this resistance correspond well with the value calculated in question 2? You can not expect a perfect match, but make sure that the value is greater than about 2Ω; otherwise the current and the heat will be too high.

4. Use the drill and fill 3 more reels. Grind off the lacquer insulation of all ends and connect the inductors, as illustrated in Fig. 3 left, Fig. 4 right, and Fig. 6/7. The direction of the magnetic field is found by

using the right-hand rule, as illustrated in Fig. 5 right. If your inductors are coiled in other directions, you may have to connect them in a different way than shown in the example.

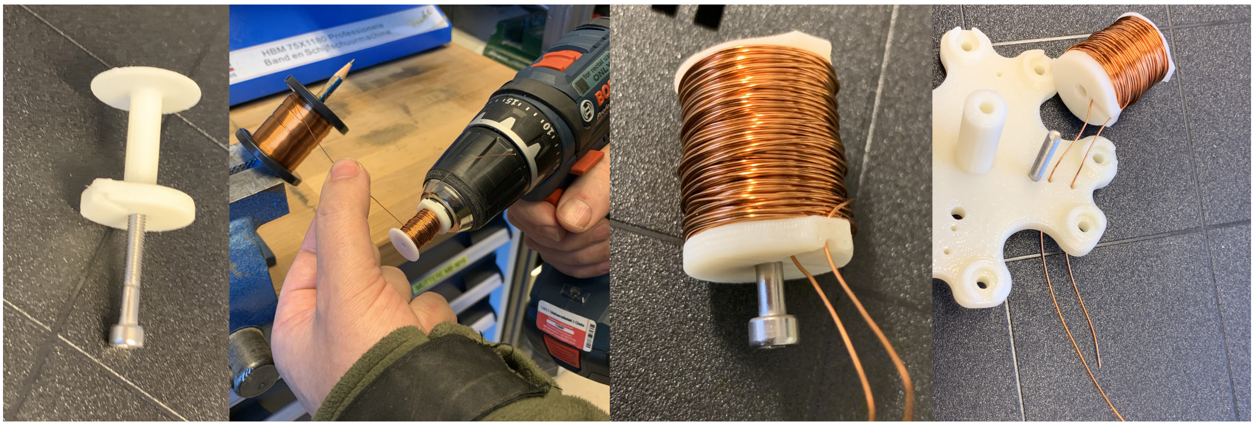

Figure 4: Making of an inductor. Left: Insert the screw into the reel. Let the head stick out about 10mm. Middle: Let the short end of the wire follow the hole and the slot in the reel, tighten the drill chuck over the screw head, and fill the reel with wire. Make sure that the reel is full. Right: assemble the inductor in the frame as shown.

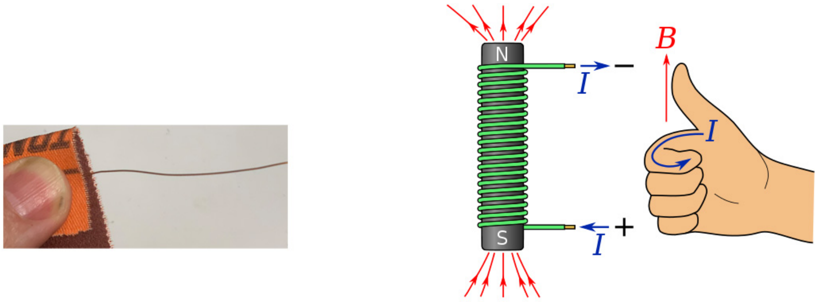

Figure 5: Left: Grinding off copper wire lacquer insulation by dragging the wire between 2 sandpapers. Right: Right-hand rule for finding the direction of the magnetic field. Put your fingers in the direction of the current flow. Current is here defined to flow from the positive to the negative terminal.

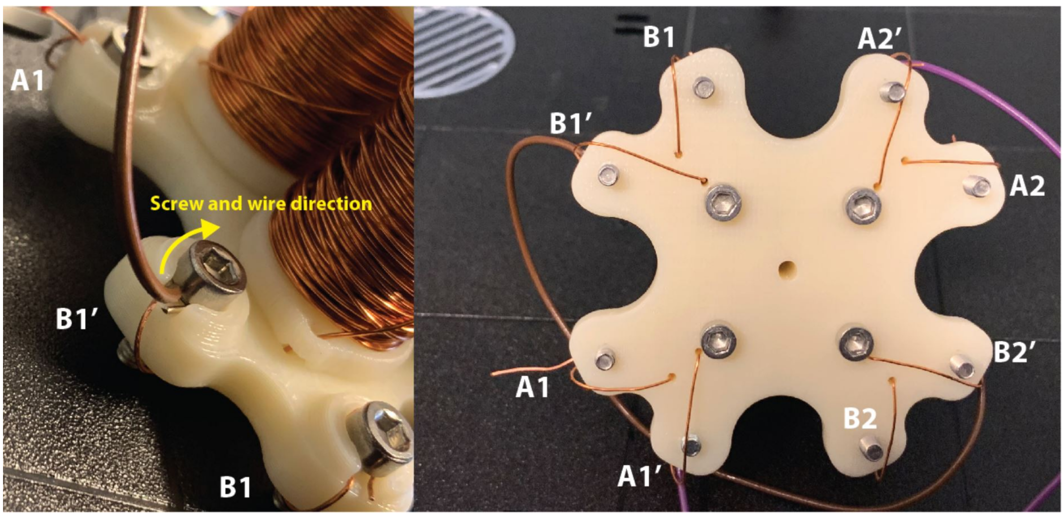

Figure 6: Terminals with preferred wire direction (clockwise), and wiring on the underside.

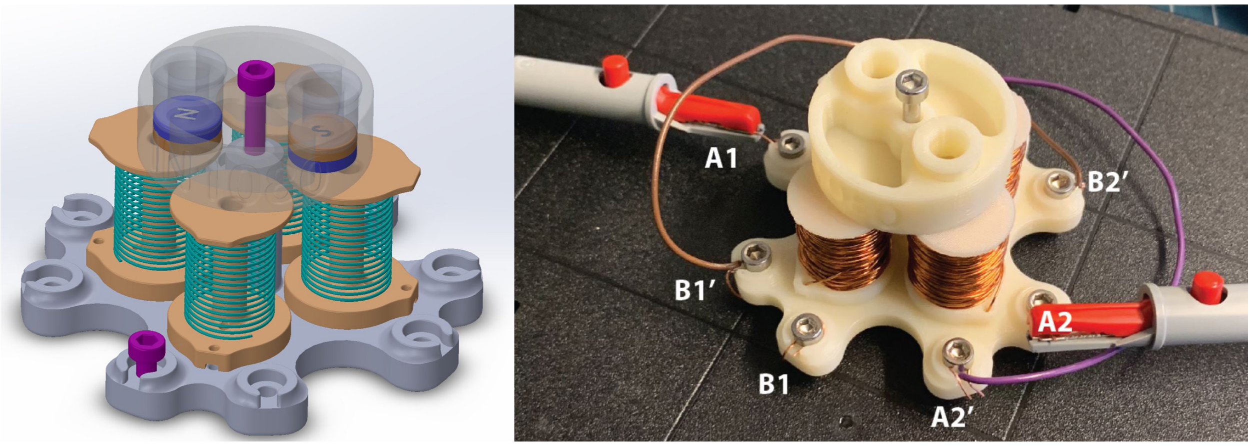

Figure 7: Right: fully assembled motor. The 2 external wires are used to connect the inductors in series. Left: the single permanent magnet in the rotor illustrated in Fig. 2, is split into 2 separate magnets that are aligned in the vertical direction to minimize the air gap to the vertically aligned electromagnets in the underlying frame.

Running the motor: We now want to manually commutate the motor

5. Manually connect the 5V from the RS3005D DC Power Supply (not ELVIS) to the terminals A1, A2, B1, B2 such that the rotor rotates according to wave commutation.

Tips

- When you wind the wire on the reels (Fig. 4), make sure each end is long enough to reach to the corresponding terminal screws.
- The wire is not so strong so try to avoid bending it more than necessary.
- Do not reuse wire that have already been winded, as it will easily break.
- Remember to grind off the lacquer insulation on the terminal ends of the wire before you connect them to the terminal screws.
- It is ok to wind the wire in all 4 reels in the same direction (for example, clockwise).
- Make sure that all 4 the small reels are full of wire; otherwise, the resistance will be to low, and the current/heat will be too high. If it is not enough wire left on the large source reel to fill a new small reel, the wire left on the source reel must be discarded.
- Make sure that the current is not higher than ≈1.5A.
- In the terminals, it is best to feed all wires around the screws in the clockwise direction (Fig. 6 left), otherwise tightening the screws may push the wires back and out of the screw area.

Important info

Do not use a higher supply voltage than 5V

Always enable over current protection (OCP) on the power supply. The OCP LED must always be on (see the labGuide). 2A is ok.

The inductors may be hot - be careful when touching them

Disconnect the inductors from the power supply when not in use

Submission requirements

The project report must be in the form of a single PDF document.

- The report must have your name, and the name of the person you collaborate with in the title. Your name first.
- The report must contain 3 numbered answers corresponding to questions 1, 2, 3.
- The motor must be demonstrated running wave commutation for a teaching assistant in IN1080.
- Each group will use the motor in a later IN1080 project, so when you leave the lab, bring the motor with you and store it somewhere for later use.

Deadline:

- 21. February

Final comments

The stepper motor you just have made is probably as simple as it can be. Stepper motors are normally used for rotating wheels to specific angular positions. By adding more electromagnets (refereed to as poles), and using toothed iron cores, a higher angular position resolution can be achieved as you can see in the videos in the reference chapter. Another way to increase the angular resolution is to use half or micro step commutation. However, this often requires a more advanced physical design of the magnets and cores (see the link in the reference). Stepper motors can also be made without permanent magnets. It should also be mentioned that when the rotor of an electric motor rotates, it generates a voltage (EMF) that should be included in the electrical model of the inductor.

Making DIY electric motors can be interesting and fun, and if you have time, tools, and skills, you can make strong, fast, high-quality motors yourself. There are many examples on YouTube.

References

1. LabGuide.pdf
2. Permanent magnet.pdf (In our rotor we use We use 2 * 4 of these in series)
3. DIY stepperMotor1, (YouTube)
4. DIY stepperMotor2, (YouTube)
5. Other types of stepper motors, (YouTube)

Have fun!