Faculty of Applied Sciences
Academic year 2024/2025

ELEC0431
Electromagnetic energy conversion

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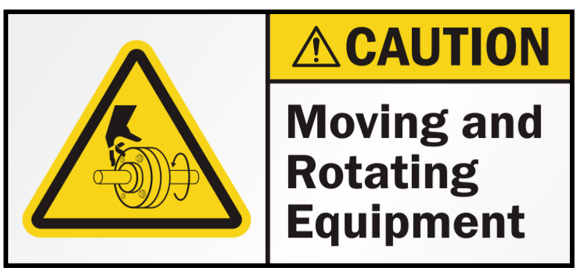
Laboratory 4: DC machines



WARNINGS:

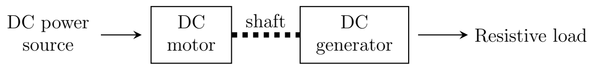
This laboratory involves high currents and voltages, think before acting !

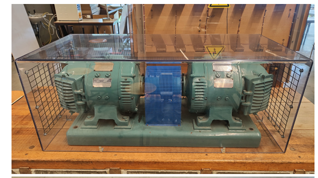
Keep your hands away from the rotating shafts and TIE LONG HAIR !

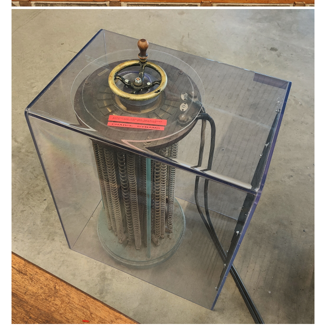
Contents:

1 Components

A DC motor, powered by an external DC power source, brings the rotor of a DC generator to rotate.

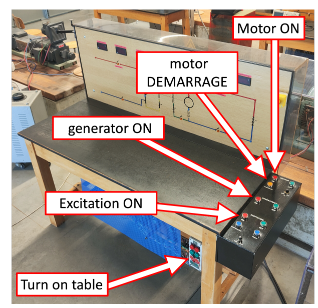






The output of the DC generator is connected to a resistive load. Its resistance can be gradually adjusted from a short-circuit to an open-circuit by rotating clockwise the wheel on top of it.

2 Start-up



1. Turn on the table by pressing the red buttons next to the table right leg.
2. Connect the motor to the power supply by pressing the ON button of the motor.
3. Start the motor by pressing the DEMARRAGE button.
4. Connect the generator to the load by pressing the ON button of the generator.
5. Turn on the excitation current of the generator by pressing the button ”EXCITATION ON”.

Each of the ON buttons (red) is associated with an OFF button (green) you can press to turn off the corresponding part. Two knobs, one for the motor and one for the generator, can be turned clockwise to increase the corresponding excitation current. Finally, one can change the generator configuration (independent excitation or shunt excitation) by pressing the corresponding blue button under the ”Excitation ON” button. Note that the excitation should be turned off to change the configuration. **When changing the generator configuration, make sure to set its excitation current to 0 and to be unloaded.**

3 Questions

3.1 Question 1

A DC generator consists of a rotating armature (rotor) placed within a magnetic flux ϕ. This magnetic flux is generated by the stator, that is an electromagnet crossed by a current I_e. As the armature spins, its windings see a varying magnetic flux $\frac{d\phi}{dt}$, inducing emfs. A commutator, attached to the armature, ensures these emfs are converted into a steady voltage E.

Link together the amplitude E of the total emf, the speed of rotation $\dot{\theta}$, and the total magnetic flux ϕ.

3.2 Question 2

The excitation system and the armature can be connected in four ways:

- Independent configuration → The excitation system and the armature are decoupled.
- Shunt configuration → The excitation system and the armature are placed in parallel.
- Series configuration → The excitation system and the armature are placed in series.
- Compound configuration → Mix between shunt and series configurations.

Give the equivalent model of a DC generator in independent configuration. In this model, represent the emf E, the resistance of the armature windings R_a, the resistance of the stator windings R_e, the current flowing through the armature I_a, the excitation current I_e, the output current I and the output voltage U.

Do the same for a DC generator in shunt configuration.

3.3 Question 3

Based on Questions 1 and 2, how can you increase the output voltage U of an unloaded DC generator, in both independent and shunt configurations?

3.4 Question 4

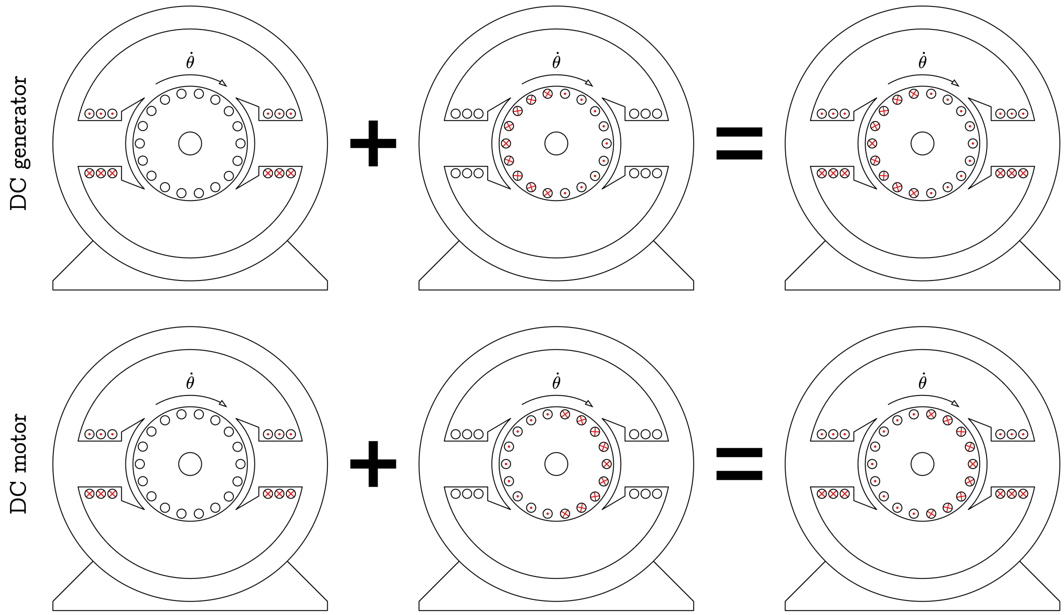
The design of a DC motor is very similar to the design of a DC generator. A steady magnetic field is generated by the stator, that is an electromagnet crossed by a current I_e. When a current is injected in the armature windings, a torque appears due to the Laplace force.

Give the equivalent model of a DC motor in shunt configuration. In this model, represent the emf E, the resistance of the armature windings R_a, the resistance of the stator windings R_e, the current flowing through the armature I_a, the excitation current I_e, the input current I and the input voltage U.

Hint: DC generators and DC motors share the same equivalent models, only the direction of some currents changes.

3.5 Question 5

The hereunder figure shows the schematic of a DC generator and of a DC motor. The first column shows the direction of the currents in the stator only, the second shows the direction of the currents in the armature only, and the last shows the two together. On this figure, for all the cases, draw the appropriate neutral magnetic field lines.



You observe that the current in the armature impacts the neutral magnetic field lines, so that they do not remain horizontal in the armature. This is the "armature reaction", it impacts the emf E. Deduce the difference in construction between the DC generator and the DC motor?

3.6 Question 6

Based on the equivalent model derived at question 4, and neglecting the armature reaction and armature resistance R_a, how does the speed of rotation $\dot{\theta}$ should vary with the excitation current in a DC motor in shunt configuration?

3.7 Question 7

What are the current, voltage and power ratings for both the DC motor and generator?

Hint: You will find all the information written on the nameplate of the machines.

You should not exceed these ratings for the rest of the lab.

In which fixed configuration is the motor wired?

Hint: Have a look at the board drawings.

3.8 Question 8

Why does the motor start in 4 audible steps?

Hint: Use the equivalent model developed in Question 4 to support your explanation.

3.9 Question 9

Setting the DC generator in independent configuration and keeping its output in open-circuit, bring its rotor to its nominal speed of rotation. Measure, draw and explain the no-load characteristic.

Hint: Starting with a zero excitation current, gradually increase it by steps of 0.1 A until reaching the nominal output voltage, and decrease it back to zero. Plot how the output voltage varies with the excitation current. What do you observe (3 things) ?

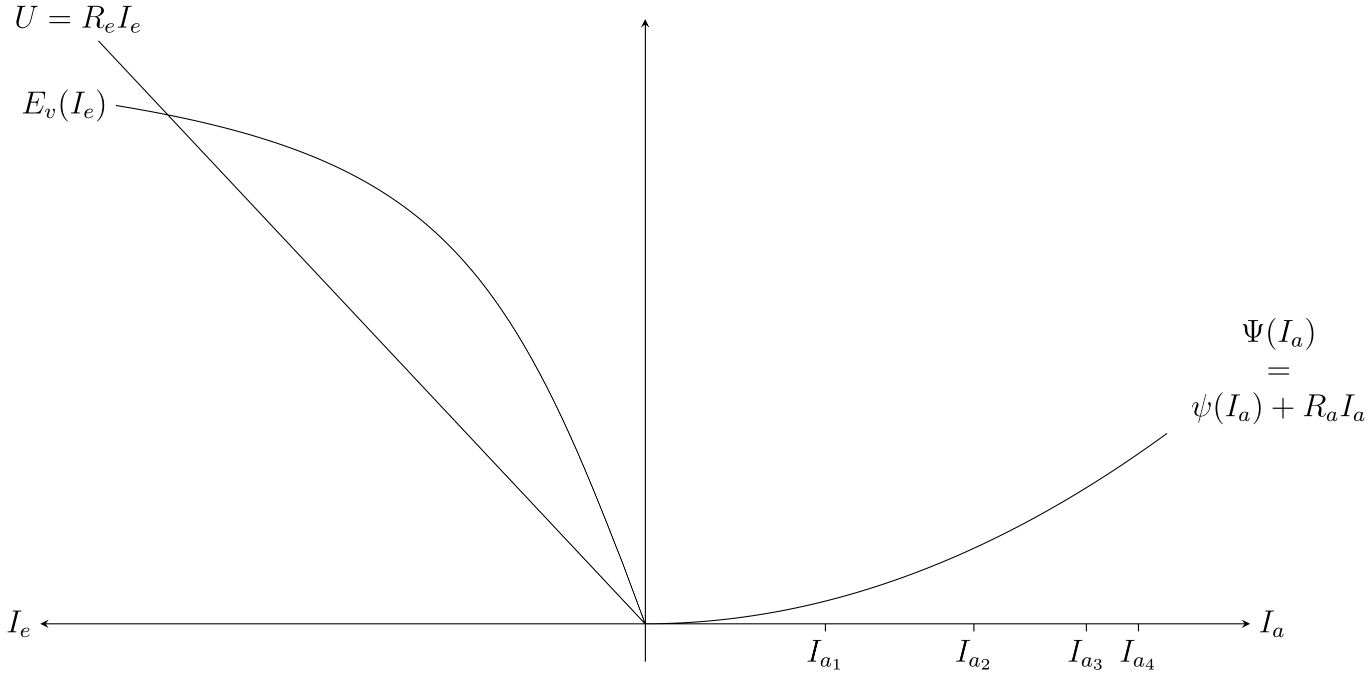
3.10 Question 10

Using the DC generator in independent configuration as a variable mechanical load, how can you vary the torque it applies on the DC motor?

Starting with a speed of rotation of 1500 RPM at no load (no torque), measure and explain how the speed of rotation varies when increasing the torque.

Make sure not to exceed the ratings of the machines.

3.11 Question 11



For a DC generator in shunt configuration, the output voltage U is equal to the excitation current I_e multiplied by the resistance of the excitation system R_e. It is also equal to the no-load emf $E_v(I_e)$, minus the armature reaction $\psi(I_a)$ and minus the voltage drop due to resistance of the armature R_a. These two taken together are denoted $\Psi(I_a) = \psi(I_a) + R_a I_a$. It results the equation

$$E_v(I_e) = \Psi(I_a) + \underbrace{R_e I_e}_{U}$$

that is used in the Picou construction to determine the U-I output characteristic of the DC generator in shunt configuration. Based on the curves $E_v(I_e)$, $R_e I_e$ and $\Psi(I_a)$:

1. Select an armature current I_a, find the corresponding $\Psi(I_a)$ and report it on the y axis.
2. From it, draw a line parallel to the line "$R_e I_e$". The intersections with the curve $E_v(I_e)$ represent the points satisfying $E_v(I_e) = \Psi(I_a) + R_e I_e$.
3. Draw vertical lines from these intersections, down to the curve "$R_e I_e$", this provides U.
4. Eventually, plot the $U(I_a)$ points obtained.

Perform the Picou construction on the above figure, for the four armature currents I_{a_1} to I_{a_4}, and for a zero armature current. Deduce the U-I output characteristic.

3.12 Question 12

Swap the DC generator configuration to shunt, reach a speed of rotation of 1500 RPM and adjust the generator excitation current to reach an output voltage of 100 V at no-load.

Before changing the configuration, make sure the generator excitation current is null.

Using the DC motor to maintain a speed of rotation of 1500 RPM, gradually decrease the load resistance to measure the U-I output characteristic of the DC generator in shunt configuration. Do the measurements fit the theoretical curve developed at the previous question?