ENERGY CONVERSION AND ROTATIONAL MECHANIC MEASUREMENTS WITH A COMMON DC MOTOR

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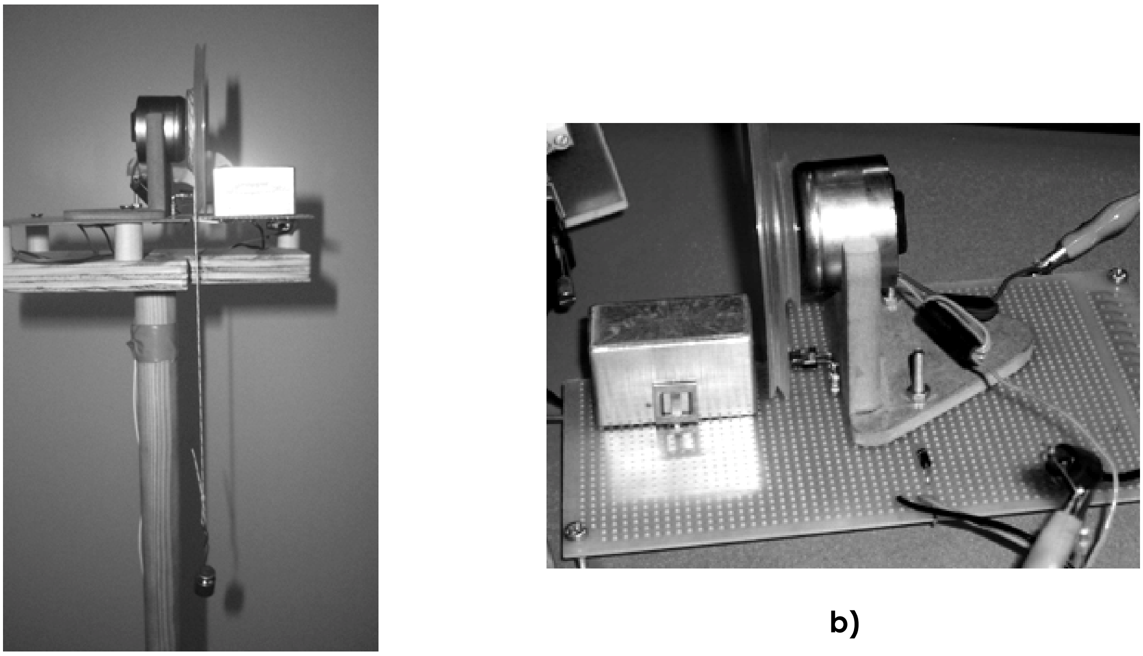
Abstract
A good opportunity for hands-on activities, both at school and at home, is represented through experiments conducted by means of easy to find materials or devices recycled from old and no more working household appliance (as a dc motor can be). These kinds of activities keep a special appeal and attractiveness together with a great teaching value, because pupils can repeat experiments at home proving to their parents their new acquired skills and competencies. In this work a dc motor, derived from an old video recorder, is interfaced with a PC to measure efficiency in conversion from electrical to mechanical energy.

1. Introduction
The use of easily to find materials, as for example devices obtained from an old and no more working domestic machine, represents a good occasion to build up and to conduct hands-on activities.
Even in schools well furnished with technological and advanced instrumentations, this kind of activities play an important role in all teaching strategies devoted to generate interest and enthusiasm for scientific topics.
Moreover, didactical experiments based on everyday materials allows students to contextualize in a concrete way the physical laws and phenomena.



b)

a)

Figure 1: a) The electric dc motor, mounted on a support, is employed to lift small weights through a pulley. b) Detail of the electric motor circuitry: the box on the left is the revolution counter.

However, to obtain the best results it is necessary to use a well designed didactical pattern so that child's attention can be focused on the correct cognitive knots in physics learning (Maloney 2001, Stefanel 2008). Moreover, the production of acquisition systems (progressively cheaper and easier to be used) allows a large diffusion of the on-line experimental activities, allowing quantitative measurements and data analysis discussion (Gervasio 2009, Michelini 2009). In this work a dc motor, derived from an old video recorder, is interfaced with a PC to measure efficiency in conversion from electrical to mechanical energy. Proposed experimental activity is addressed to teachers, in order to illustrate how many crucial conceptual knots (such as, for example, energy conversion processes and electromagnetic induction) may be highlighted through homemade experimental apparatuses. This activity is based on teaching procedures and experiment documentation designed in the context of MOSEM[2] European project.

2. Didactic goal and experimental setup

The proposed learning path is aimed both to address some conceptual knots and to teach methodologies typical of scientific approach in practical problem solution. In particular the focused learning knots are relative to: Electromagnetic induction, rotational motion and energy transformation/dissipation (Maloney 2001, Stefanel 2008). Regarding the methodologies, the addressed topics are:

- To discern among different contribution and their relative weight in a physical phenomenon.
- To distinguish between transient and stationary state.
- To single out the more convenient strategies to obtain data needed for device characterization.

The proposed experimental activity consists in the determination of the energy conversion efficiency of a dc motor lifting a small weight. To get such a determination, the circuital electric model of a motor is put forward and is applied to the experimental apparatus shown in Figure 1. The apparatus consists in a motor mounted on a support, holding a small pulley on which an inextensible thread may be wrapped (when the pulley is turning), so that a weight fixed on its end may be lifted. The electric power is determined by measuring the current flowing in the circuit and the potential difference at the motor ends. The system is equipped with a sensor (the box appearing in the bottom left part of Figure 1) allowing to count the pulley turns for its angular velocity determination. All interesting parameters (current intensity, electric tension and angular velocity) are acquired on a PC interfaced to sensors through a Kethley acquisition card.

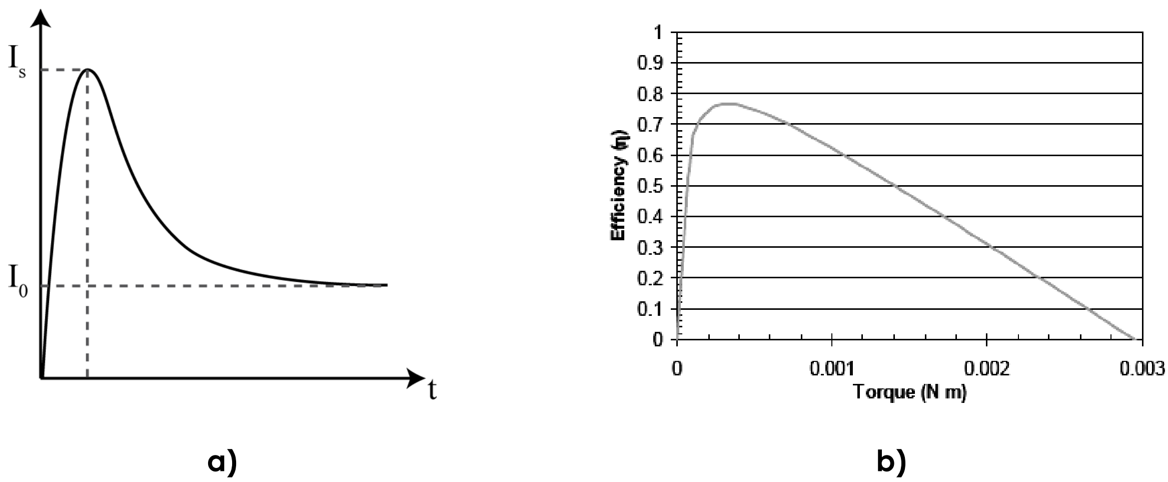


Figure 2: Theoretical predictions: a) The transient current, immediately after the motor is switched on. b) A regime property: the efficiency as a function of the load torque.

3. Modeling of the dc motor

In order to determine efficiency in conversion from electrical to mechanical energy, system modeling should take into account both the electric and the mechanical behavior (Ayasun 2005, YAP 2006).

As regards the former, a dc electric motor may be modeled by a series circuit consisting of:

i) A resistor R_a (rotor's armature resistance);
ii) An inductance L_a (rotor's armature inductance);
iii) Two counter-electromotive force (CEMF) generators.

Regarding the two CEMFs, the first one is due to the rotor spinning in the magnetic field generated by the stator (and consequently will be present throughout the motion and will remain proportional

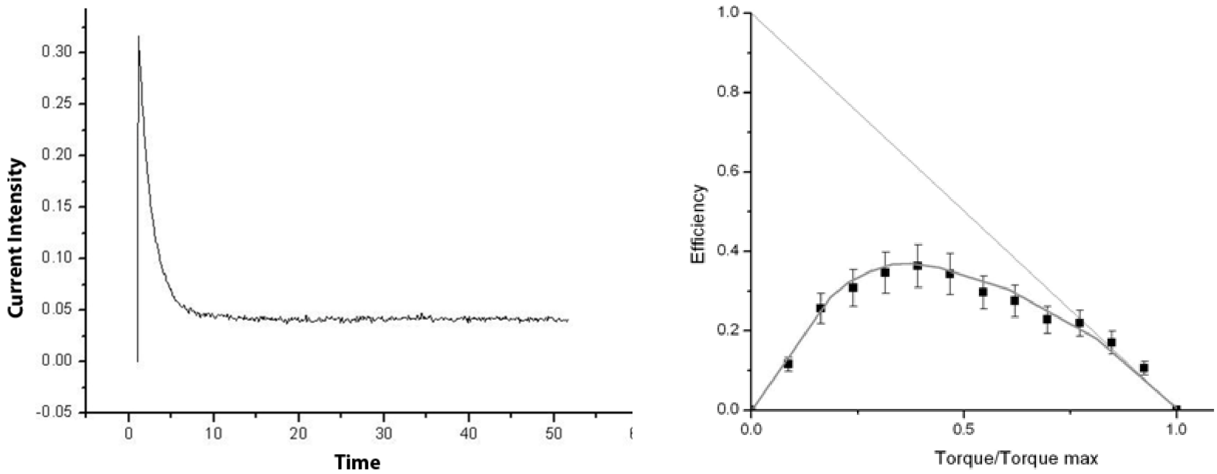
to the angular velocity ω of the motor) while the second one is a transitory CEMF appearing when the switch is turned on to feed the rotor's inductance. In this way, only in the transitory phase, there will be a CEMF proportional to the rate of the armature current variation.
The mechanical behavior should take into account the electromechanical torque **T** developed by the rotor (proportional to the armature current $i_a(t)$). Opposing to it, there are: the external load torque $\mathbf{M_{ext}}$, the rotational inertia of the rotor (which appears only in the transitory phase and is proportional to the rotor's moment of inertia), and finally the torque due to the dissipative viscous forces which is proportional to the angular velocity **ω**.
Taking into account all these torques, theoretical predictions may be made on the current absorption either in the transient or in the regime state. In particular, for this last, the efficiency of energy conversion can be defined as:

$$\eta = \frac{P_m}{P_e}$$

(where P_m and P_e denotes respectively the mechanical delivered power and the electric absorbed power). In Figure 2 the theoretically predicted current (flowing in the motor in the transient and stationary regime) and the stationary efficiency (as a function of the load torque) are shown.
In this context students have to acquire experimental data, to represent graphically them and to discuss results in the context of theoretical predictions.

4. Experimental results

By employing the experimental device shown in Figure 1 we have measured the current absorbed by a dc electric motor obtained from an old video recorder. The data were collected as the motor was raising a little weight. In Figure 3 we show the measured current absorbed by the motor as a function of time (immediately after it has been turned on i.e. starting from the transient state – Figure 3a) and the experimentally determined conversion efficiency as a function of the load torque (figure 3b).



a) b)

Figure 3: Experimental results: a) The transient current, immediately after the motor is switched on. b) A regime property: the efficiency as a function of the load torque.

As we can see by comparing Figures 2 and 3 (showing respectively theoretical predictions and corresponding experimental findings) the model reproduces the main features of the motor energetic behavior. In particular we should observe (Figure 2a and 3a) that in the transitory regime, after the (very short) time interval needed to reach the current value I_S, the rotor will begin to spin giving rise to a CEMF proportional to ω. As a consequence, the net EMF at the motor's terminals will progressively reduce until the regime value is reached (simultaneously, the angular velocity will increase to a constant regime value). As regards the conversion efficiency, we need to point out that the mechanical friction can be neglected only at high load torque when the angular speed is very low (in this conditions only electrical dissipation by Joule Effect on motor windings are relevant). In fact, as angular speed increases the dissipative torque will be progressively more important lowering until zero the conversion efficiency.

5. Conclusions

Dc electrical motor, with suitable data acquisition, is an effective tool to investigate a number of conceptual nodes. In particular the different role and relative weight of mechanical and electrical losses can be efficiently investigated and experimentally shown.

Real time graphs of either time depending or stationary phenomena play a central role in this didactical activity, leading students to distinguish between transient and stationary state, and to discern among the relative weight of different contribution in a physical phenomenon.

The proposed learning path constitutes also a good training in order to choose the more convenient strategies to obtain data needed for device characterization.

Furthermore, employed devices allow pupils to repeat some activities at home, so that they can both consolidate practical concepts acquired (such as the motor transient phase before reaching stationary functioning conditions, or maximum load torque permitted) and reach a better awareness of gained competences.

The described experimental activity leads students not only to obtain graphical representation of phenomena, but also to theoretically interpret the procedural path for obtaining them.

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