The Energy Principle in a Model of Electric Braking of a Flywheel

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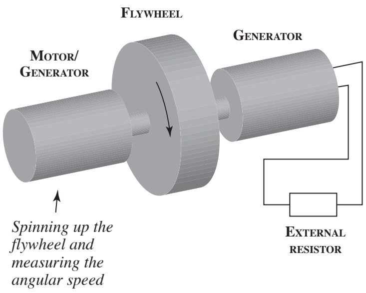
Introduction

In many cases in typical school physics problems, using energy considerations is nothing more than a convenient shortcut that yields partial answers rather than a complete description of a phenomenon. Examples are collisions whose dynamics is determined fully by the balance of momentum and proper constitutive relations for the interactions during collisions. Using the balance of energy—alongside that of momentum—in integrated form, we are able to find final velocities in an elastic binary collision but we cannot say anything about the collision proper. For this reason, such applications do not provide us with a sense of meaning and importance of the energy principle—using energy considerations is unnecessary.

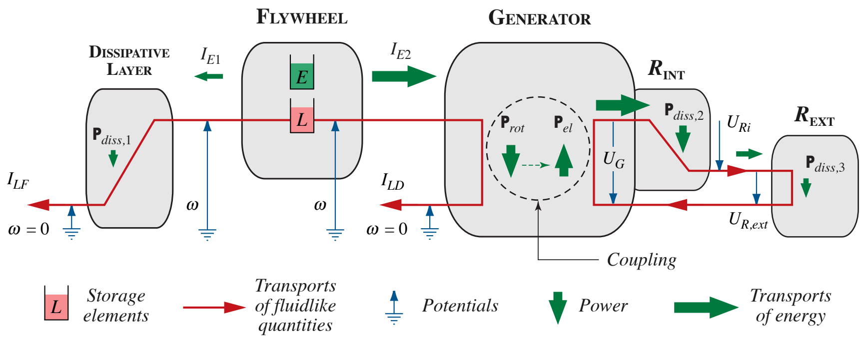
In this paper, we present an experimental and modeling investigation of a ***system*** where the ***coupling of mechanical and electric processes*** can be observed and where a simple model ***requires the use of the energy principle*** if we wish to obtain a complete description.

Experimental Setup



An electric DC motor/generator (on the right) is attached to a flywheel. The spinning wheel drives the device as a generator that is connected to an external electric resistor to form a single-loop circuit. As the flywheel spins down, voltages and angular velocities are measured with the help of the motors/generators on the left and on the right.

Process Diagram

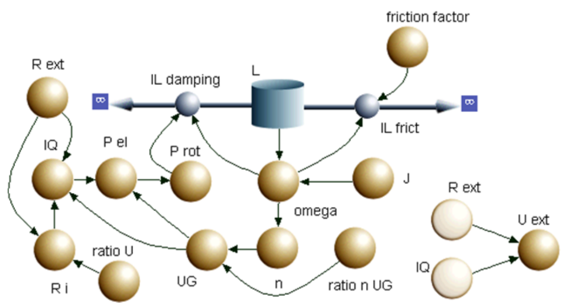


Process diagrams visualize explanations of physical processes—they show ***storage*** and ***flow*** of ***fluidlike quantities*** and ***energy*** and introduce ***power*** as the measure used in the coupling of processes. Here, the generator ***couples mechanical and electric processes***.

$\mathbf{P}_{rot}$ is the rate at which the mechanical process releases energy. The energy ***released*** is ***used*** at the rate $\mathbf{P}_{el}$ by the electric process. Importantly:

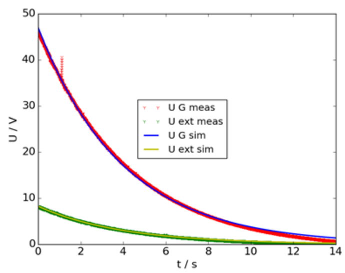
$$\mathbf{P}_{rot} = \mathbf{P}_{el}$$

Dynamical Model



A dynamical model based upon the balance of angular momentum (L) of the wheel. The braking moment (I L damping) of the motor/generator is calculated indirectly via the electric power (P el) of the generator leading to an ***electro-mechanical feedback loop*** in the model: We use the notion of ***power of processes and its balance*** in the coupling of different types of processes. This constitutes a ***direct and indispensable application of the energy principle***.

Comparison of Data and Simulation



During breaking, ***the first motor on the left is disengaged***. Its voltage (UG) serves as a measure of the angular velocity of the wheel. ***The second motor is engaged***: it acts as a generator whose voltage (Uext) is measured across the external load resistor; it drives the flow of electric charge. ***Fitting simulation results to dynamical data*** yields values of missing parameters.