Regenerative Braking System

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Introduction

Project Objective

To design a procedure that compares the input and output energy of a regenerative brushless dc motor, and optimize the efficiency with varying conditions, such as the weight applied for the motor to brake and the resistive load on the motor. This will allow us to identify the condition at which the motor will recover the most energy.

Benefits of Regenerative Braking

- Reduced wear on vehicle components, specifically brake pads
- Increase in range due to longer battery life
- Energy recovery process increases system's energy efficiency

Testing Procedure

Before Testing

1) Weight is attached to the cord which is coiled around the hub motor.
2) Power the motor controller with a power supply of at least 30V to enable regen braking as shown in Figure. 1.
3) Set the motor controller to maximum regen braking by connecting throttle signal pin to the ground.

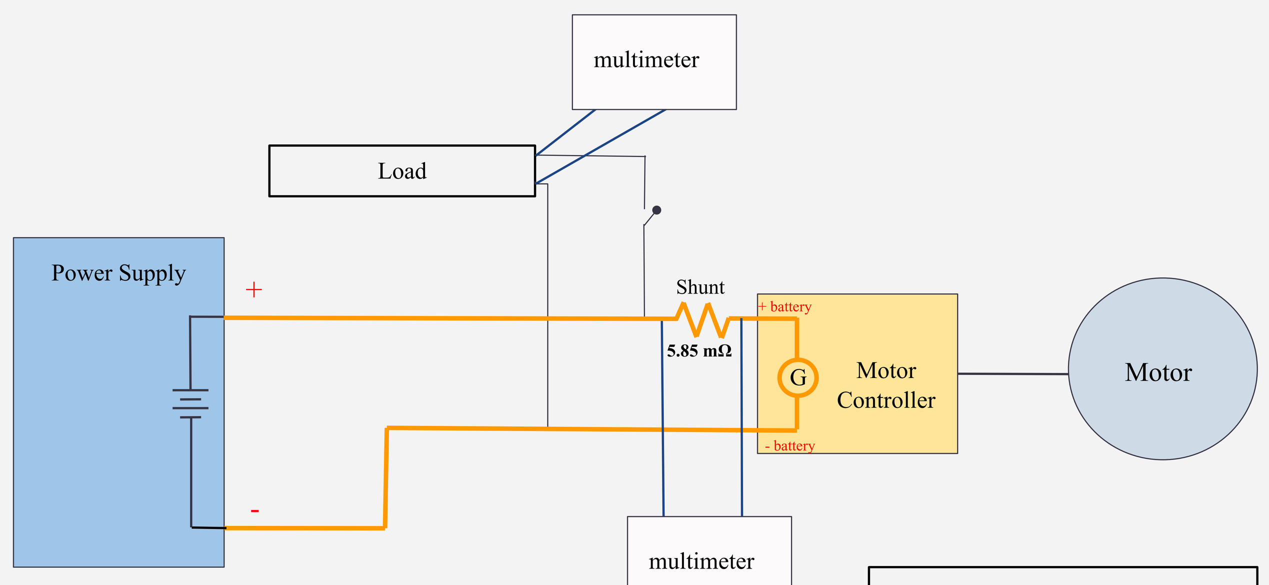

Figure 1. Before Testing

During Test

1) Release the weight so it begins to free fall.
2) Immediately after, turn off the power supply and allow the regenerated energy to power its own motor controller to further enable regen braking to get the circuit shown in Figure. 2
3) Measure the voltage across the load resistor and shunt over time.

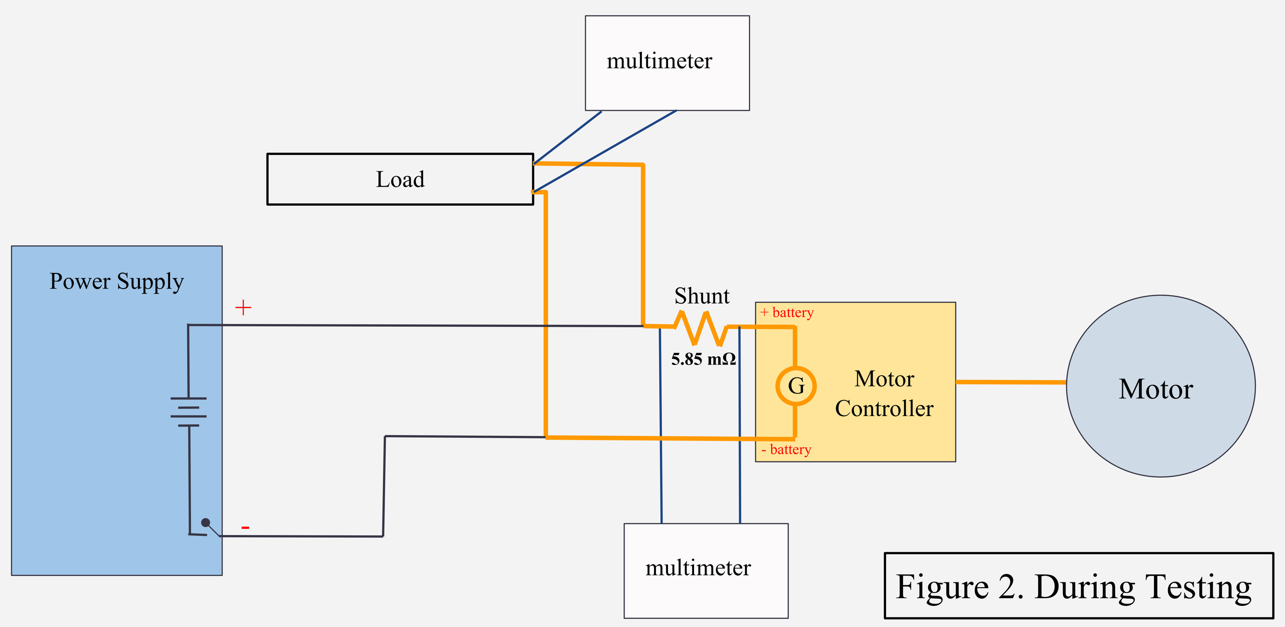

Figure 2. During Testing

Results

Calculations for voltage, current and power were repeated for all the tests with varying conditions to obtain the output energy recovered through the regenerative brake.

$$E_{in} = mgh \qquad I = \frac{V_{shunt}}{R_{shunt}} \qquad P_{instant} = V_{load} I \qquad E_{out} = \int P_{instant}\, dt$$

Time since regen starts (s)	Voltage across the load (V)	Voltage across the shunt (V)	Current through the shunt (A)	Power through shunt (W)	Power through the load (W)	Instantaneous Output Power (W)
0	1.1	0	0	0	0	0
0.23	8.8	0.008	1.65	0.013	14.52	14.53
0.45	6.6	0.018	3.71	0.069	24.49	24.56
0.68	7.6	0.013	2.68	0.035	20.37	20.41
0.91	7.6	0.013	2.68	0.035	20.37	20.41
1.14	7.7	0.013	2.68	0.035	20.64	20.67
1.37	7.7	0.014	2.88	0.040	22.23	22.27
1.6	7.7	0.014	2.88	0.040	22.23	22.27
1.82	7.7	0.014	2.88	0.040	22.23	22.27
2.05	7.7	0.014	2.88	0.040	22.23	22.27
2.28	7.7	0.014	2.88	0.040	22..23	22.27
2.51	4.9	0.014	2.88	0.040	14.14	14.18

Figure 3. Test 3.2

Load (Ω)	3
Weight (kg)	4
Height (m)	2.67
Total Time (s)	2.51
Energy input (J)	104.8

Figure 4. Test 3.2

$$\text{Efficiency} = \frac{E_{out}}{E_{in}}$$

Efficiency at varied resistance load for a 4kg mass

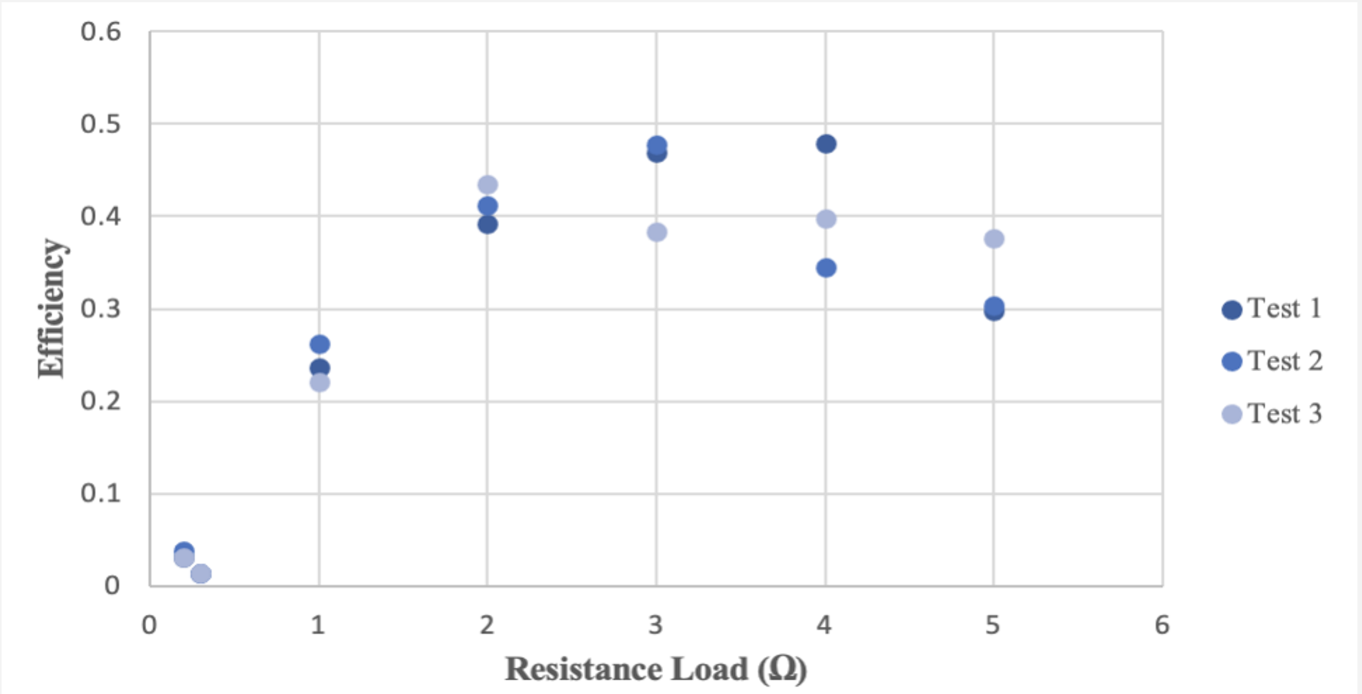

Figure 5. Efficiency

Energy Output

1) Motor generates voltage by rotation once weight is dropped
2) Measure voltage across the **shunt**, which has precise known resistance to get current
3) Circuit in series so same current everywhere in circuit, thus we can measure voltage across **load**
4) Calculate power dissipated by load ≈ power motor is generating

Sources of Error

Considered Uncertainties	Unconsidered Uncertainties
• Instrumental: multimeter voltage readings, shunt resistance • Observational: The system's mass, time of regenerative braking, height at which the braking was activated	• Air resistance on falling mass • Internal friction of motor • Weight of metal wire • Operation temperature of system

Using uncertainty propagation, the experiment yielded an average efficiency at optimal conditions of 40% with 3.62% confidence in the results or **40% efficiency +/- 1.13%.**

Conclusions

Average efficiency of 40%

Across all of our tests, we observed an average efficiency of approximately 40% as seen in Figure 5. Understanding this efficiency number allows us to further estimate the increase in range and reduction in wear that the friction brakes will experience.

Determined Most Efficient Load of 3Ω

We saw a peak in efficiency that corresponded with a load resistance of 3 ohms. It is unknown how applicable this result would be for different types of motor and motor controllers. We hypothesize similar medium-sized motors will be most efficient at a 3Ω load resistance however, future testing with different motor setups is necessary.

Correlation Between Potential Energy and Efficiency

Since the change in mass had no significant difference in efficiency, we can determine that the total energy input into the system does not impact the efficiency of recovering that energy. We would like to conduct additional experiments with more varying weights to better confirm this conclusion.

Applications

The ideal application of our testing result will be for elevators since it has the strongest correlation to our test involving the conversion of vertical mass drop's potential into electrical energy. Found in our tests, the mass has less to no effect on the efficiency itself. However, the velocity of an elevator is a crucial factor when considering safety. To maximize efficiency while being safe, we can apply our result for an application involving an elevator with a weight sensor that could adjust the amount of load for an ideal efficiency at a safe enough speed going down.

Future testing

With additional funding and from what we have learnt throughout the process of this project, future testing can be done for a more accurate and applicable result. Uses of regenerative brakes are mostly found in the transportation field for vehicles. Thus, testing horizontal and more precise movements such as a peloton for the input energy will yield a much more confident result instead of using just vertical potential energy. Additionally, the implementation of software to plot the voltage overtime should be used instead of readings from the multimeter for more precise measurements.