UNIVERSITY OF Waterloo

Department of Mechanical and Mechatronics Engineering

Dynamometer Project

A Report Prepared For:
ME100 At The University of Waterloo

Prepared By:
Ryan Groot, Bill Pan, Daniel Moorthy

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Design Decisions

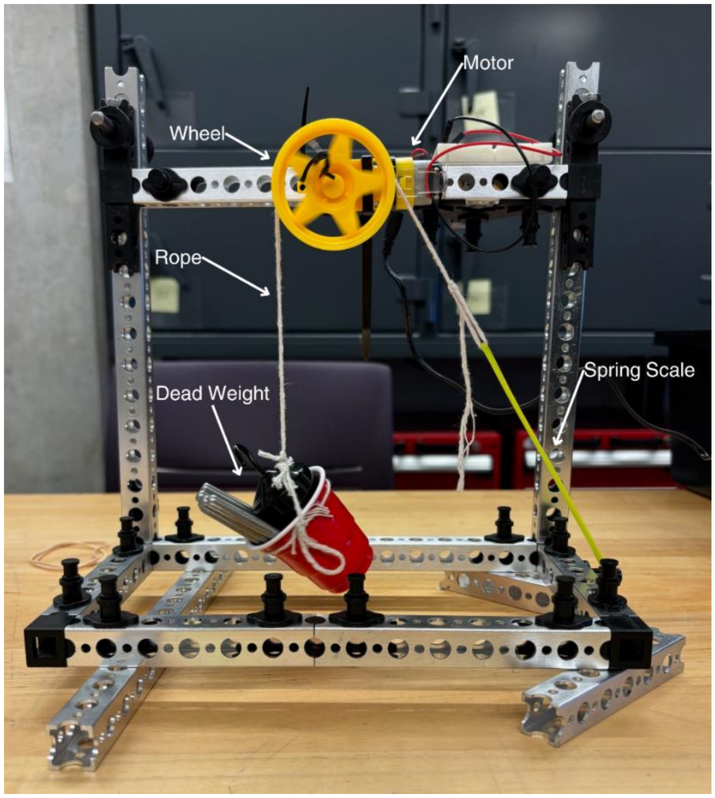

Figure 1. Labeled Diagram of Dynamometer Set-up

Figure 1 depicts our rope-brake dynamometer design. The design includes the following key components: a frame, a weight, an elastic spring scale, a rope, and a wheel. The frame design primarily focuses on stability. The width of the base minimizes potential errors that arise from unsteadiness and shaking. The wide, hollow base also considers the height needed for the dead weight to hang. The dynamometer can span across two tables and allows the dead weight to drop freely as far as necessary.

The dead weight is designed to be easily changeable. With minimal restrictions, the mass can be adjusted quickly. A weight can easily be determined by multiplying the mass by the acceleration due to gravity, g. The red bucket is straightforward, holding weight well without interfering with the sides of the base.

On the other side of the wheel was the rope, tied to a doubled-up elastic hooked onto a peg. This elastic acted as a spring scale by utilizing the value of elastic force. It was attached to a peg for the purpose of easily hooking it on and off. This design allows testing the spring constant, k, and transferring the free weight to be more accessible than a permanent attachment. Doubling up the elastic allowed us to keep the total stretch and drop off the weight to lower values. The rope, attached to both the free weight and the elastic, distributes friction caused by both forces across the wheel at the points in which it makes contact. Therefore, the rope was crucial in connecting the known forces to the slowing of the motor.

Finally, designs regarding the wheel were included for a simpler and more accurate experiment process. Removing the tire around the wheel provided an indented surface where the rope could securely sit. With the addition of a marking (a twist tie on a spoke of the wheel), each rotation became clearer when counted. All these design decisions contributed to an accurate and efficient experiment.

Scale Calibration Curve

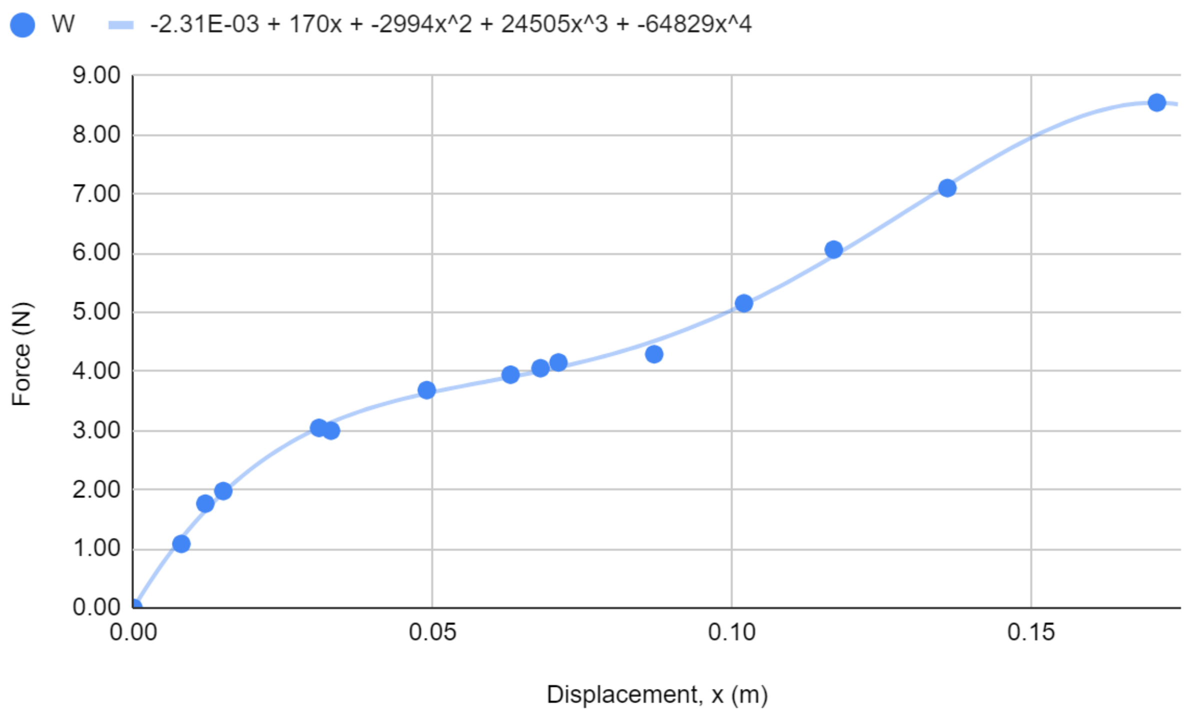

Figure 2. Graph of weight force (N) against elastic band stretch displacement (m)

Figure 2 shows the graph of the calibration curve of our elastic band. The stretch distance of the elastic is on the x-axis, and the force exerted by the attached weight at that distance is on the y-axis. To obtain these data points, the elastic band was held so that there was no stretch or slack, and that length was measured and recorded as the initial length using a metric ruler. Then, a scale was used to measure the mass of objects hung on the elastic; the mass multiplied by the acceleration due to gravity provided the weight force acting on the elastic. The elastic band was then hung from a fixed peg, and the weight was hung from the elastic band. Once the weight was steady at equilibrium, the length of the elastic band was measured. Subtracting the initial length from the new length gives us the displacement the elastic band was stretched. Since the system is in equilibrium, the force exerted by the elastic band is equal to the force of gravity acting on the mass. The stretch displacement and the force from the spring provide a data point to plot. Repeating this process with different weights generates a curve of best fit. The function of that curve is used to relate the stretch distance to an expected force, which is required for calculating the torque of the motor.

An elastic band was chosen as the scale because it is the most appropriate option for this project. It is simple, reliable, easy to attach to objects, and provides sufficient accuracy. Unlike other methods, such as a metal spring, which can get deformed and permanently stretched, the elastic band provides a more consistent force. These factors make the elastic band the best option, considering that this project requires the scale to be consistent for all its readings and stretched for long periods.

Torque-Speed Relation

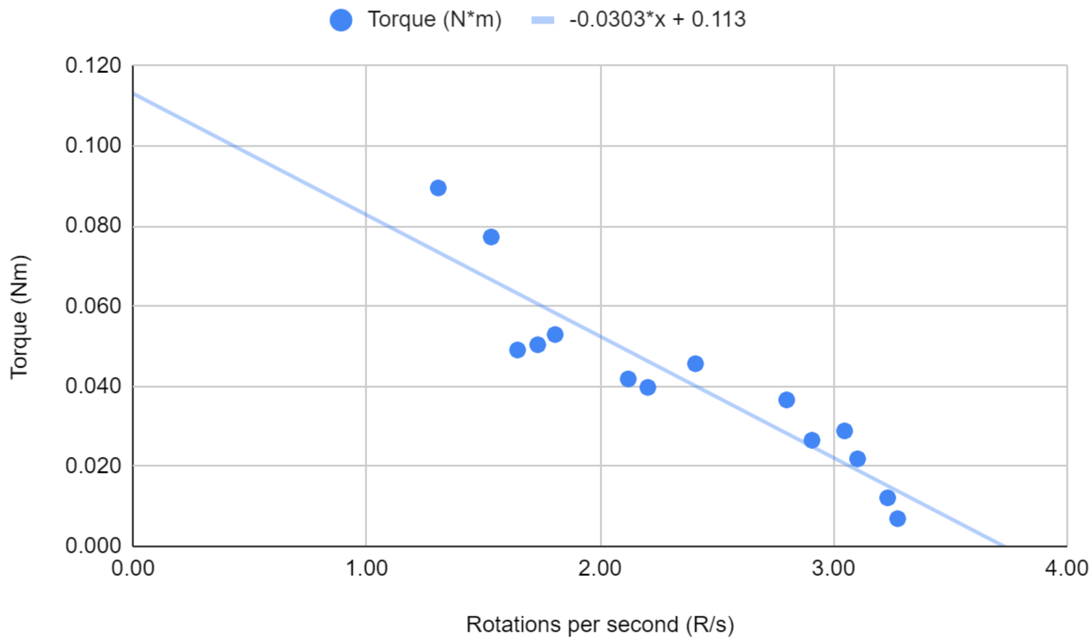

Figure 3. Graph of motor's torque (Nm) against its rotations per second speed (R/s)

Figure 3 shows the torque-speed graph of our motor. The speed of the motor in RPS is on the x-axis, and the torque of the motor in N*m is on the y-axis. The experiment was set up as shown in Figure 1 to obtain the data points. Then, when the motor is started, it turns counter-clockwise so that the force output from the motor is pulling against the scale. The force of the motor plus the gravitational force of the weight is equal to the force of the elastic band. The gravitational force of the weight is equal to its mass multiplied by gravitational acceleration. The force of the elastic band is found by measuring its stretch and using the instantaneous slope at that stretch point in the function in Figure 2; by taking the derivative of the function in Figure 2 and using the stretch value as the input, an instantaneous k value can be used in F = -kx. The force exerted by the motor is found by subtracting the gravitational force of the weight from the force of the elastic band. To find the torque of the motor, we multiply the force of the motor by the radius of the wheel.

To determine the motor's rotation per second (RPS) with each attached weight, the wheel was recorded for about 10 seconds using an iPhone 14 camera. The number of rotations and the time taken in seconds were counted from the video. Dividing the number of rotations by the seconds provided the motor's RPS.

To plot Figure 3, we plotted the RPS value on the x-axis and the torque on the y-axis. This process was repeated with a range of weights to get more data points. The trend indicated a line of best fit. The line shows that the torque-speed data for the motor follows a negative linear relationship, with the torque and speed being inversely proportional to one another. This is consistent with MIT research on the expected torque-speed relation of DC motors [1]. The data we collected is of good quality relative to the quality of equipment we had available. The experiment could be improved using analogue devices, such as an actual spring scale, to measure the force readings. Still, this experiment's numerous data points justify the best-fit line over a larger range.

References:

[1] M. Page, "D.C. Motor Torque/Speed Curve Tutorial: Understanding Motor Characteristics," *Mit.edu*, 2019. Available: http://lancet.mit.edu/motors/motors3.html