Rope Brake Dynamometer: Methodology, Results, Discussion

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1.0 Design and Methodology

The chosen rope brake dynamometer in Figure 1 was created using the motor of a remote controlled toy car. The purpose of the dynamometer is to measure the torque and speed of an electric motor for various masses applied using the shrink of an elastic. This design was chosen for its safety, stability, and simple set up. The outer tire of one of the back wheels was removed to provide a ridge for the string to wrap onto, and the car was secured on top of a chair and book with rope. One end of the string was tied to an elastic band anchored to the ground by another book, and the other end was tied to a water bottle. Rice was used as a variable mass by filling the water bottle. When the motor was turned on, the wheel spun counterclockwise toward the elastic band, causing the elastic to shrink to various lengths for each mass measured. This is the safest design, as it has no modified or exposed wires, and does not need to be connected to a power outlet. This device was used for all results recorded, and the method of obtaining the data is outlined below.

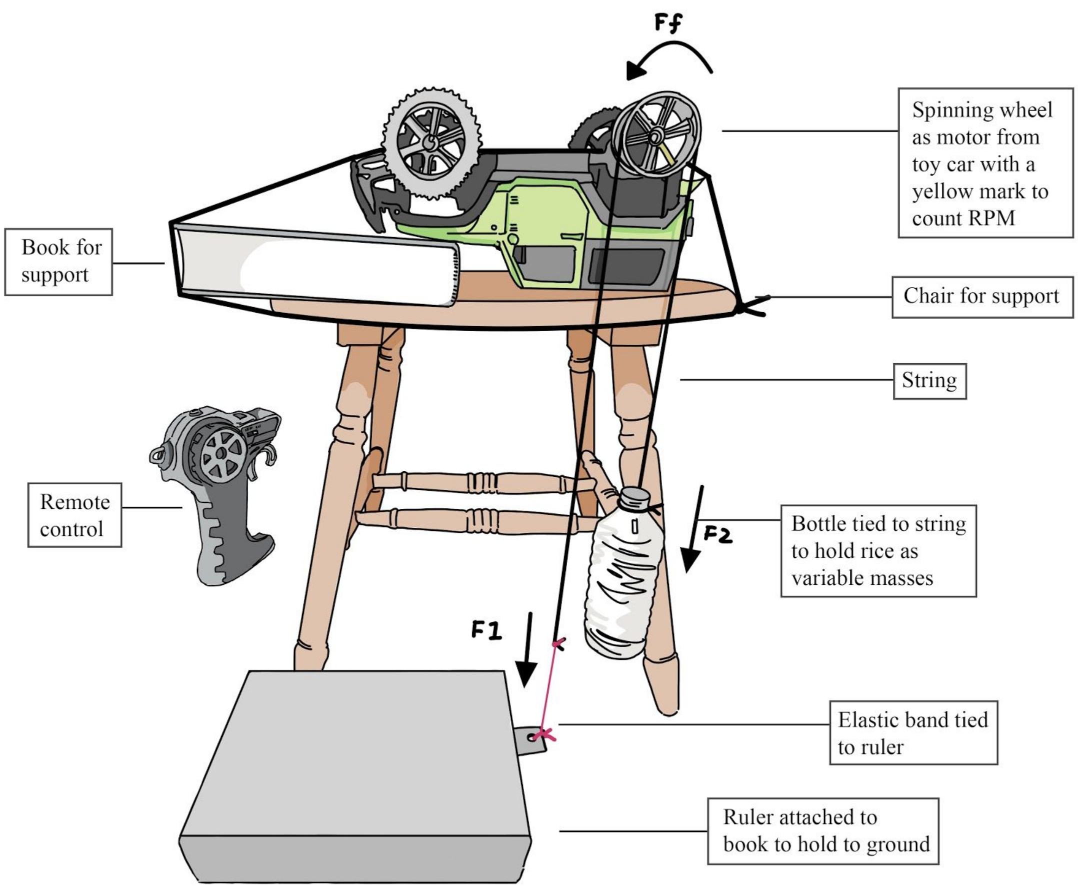

Figure 1: A rope brake dynamometer made using the wheel from a toy car, designed by Kais, drawn by Joyce.

Figure 2: Additional images of the dynamometer are shown.

Method for generating results:

1. The device was set up according to Figure 1 above.
2. The original length of the elastic was measured using a ruler and recorded to be 0.100 m.
3. The wheel was marked with a yellow marker to aid in counting RPM.
4. A slow motion camera was turned on to begin recording.
5. With no mass on the string, the motor was turned on in the counterclockwise direction for at least 2 seconds.
6. The bottle was filled with 0.100 kg of rice and attached to the string hanging from the wheel.
7. The motor was turned on using the remote control for at least two seconds.
8. While the motor was on, the displacement of the elastic was measured using a ruler and recorded in the Table 1 below.
9. Steps 6-8 were repeated for 0.150 kg, 0.200 kg and 0.250 kg of rice.
10. More rice was added to the bottle until it reached 0.440 kg and the motor's rotational speed was zero.
11. The device was turned off and placed in a safe place.
12. The slow motion video from the camera was replayed and the number of rotations of the wheel for each mass was counted for 2 seconds of the recording. This number was then multiplied by 30 to get the value of RPM for each variable mass, and was recorded in Table 1.
13. All data was recorded and noted as shown in Table 1, Table 2, Figure 3 and Figure 4.

Calculations made for *k,* F1, F2, Ff, and Torque are described below.

2.0 Results

The analysis of the dynamometer is displayed in a graph and table.

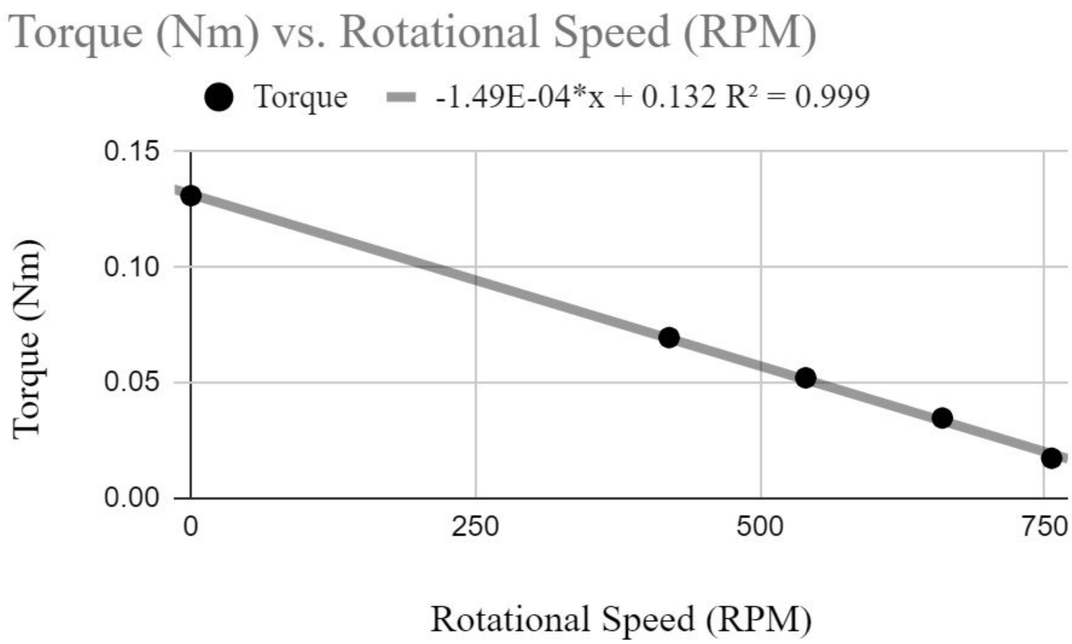

Figure 3: This graph shows the relationship between the rotational speed and the torque. The data measured is accurate, as it follows an inverse linear relationship closely with an R^2 value of 0.999.

Mass (kg)	*Shrink (m)*	*RPM*	*Friction (N)*	*Radius (m)*	*Spring constant, k (N/m)*	*Torque (Nm)*
0.000	N/A	930	N/A			0
0.100	0.040	756	0.58			0.0174
0.150	0.080	660	1.16			0.0348
0.200	0.120	540	1.74			0.0522
0.250	0.160	420	2.32			0.0696
0.440	0.300	0	4.35	0.0300	14.5	0.131

Table 1: The data for the most successful dynamometer is recorded in this table. The accuracy of the data for torque was estimated to be ± 0.0001. The stall torque is 0.131, at 0.440 kg of mass.

The measurements of the mass (kg) and shrink (m) in Table 1 were obtained using instruments with up to 3 decimals of precision. This meant the numbers may be ± 0.0005 of the actual value, which accounts for the small error in the torque calculation. The equation, $T = Ff * r$ was used to calculate torque, where T is the torque (Nm), *Ff* is friction (N), and *r* is the radius of the wheel (m). *Ff* was obtained through arranging the sum of forces equation. Since the system is not accelerating, $\Sigma F = 0$. $\Sigma F = F2 - F1 - Ff$ could be rearranged to $Ff = F2 - F1$. *F1* is the force from the elastic, and *F2* is the force from the mass. $F1 = k * x$, where *k* is the spring constant (N/m) and *x* is the displacement of shrink from the elastic (m). $F2 = m * g$, where *m* is the mass of rice (kg), and *g* is the acceleration of gravity (9.81 m/s^2). *Ff, F1,* and *F2* are shown as labelled in Figure 1.

To calculate *k*, the elastic band was removed from the device and analyzed separately. Various masses were hung on the band so that the applied force was equal to the force of gravity on the mass alone. The equation of the forces in the system would then be *F1=F2,* which simplifies the calculation to $m * g = k * x$. When plotting *m*g* (N) vs. *x* (m) on a graph, *k* is determined through the slope of the trendline.

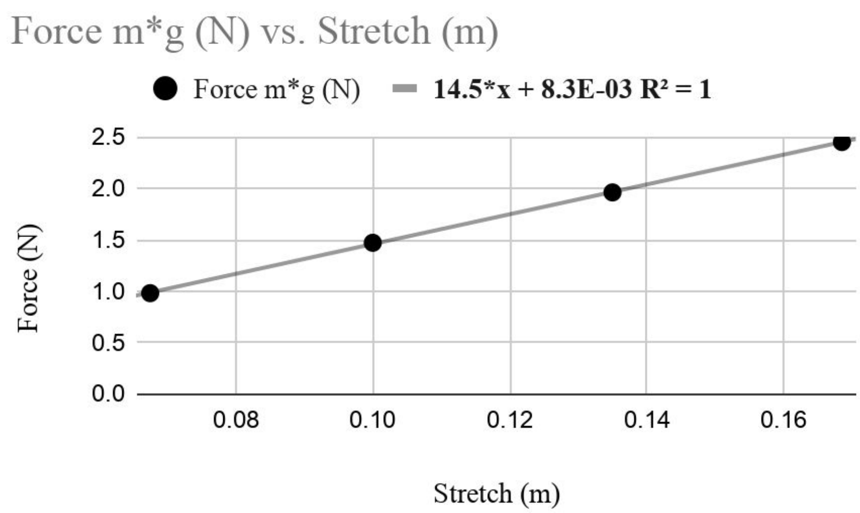

Figure 4: This graph plots the relationship between the force of the hanging mass and the stretch of the elastic. *k* was determined to be the slope of the trendline.

Mass (kg)	Force *m*g* (N)	Stretch (m)
0.250	2.45	0.1685
0.200	1.96	0.1350
0.150	1.47	0.1000
0.100	0.981	0.06750
		k = 14.5

Table 2: The data used to calculate *k* of the elastic band in Figure 4 is shown.

3.0 Discussion

The close observation and analysis of the electric motor rope brake dynamometer provided important insight regarding efficiency, safety, and possible improvements. Although this design was chosen as the highest performing dynamometer, it is still crucial to examine the data critically.

Is the data good? Does it display the expected trend (inverse linear torque-speed)? If not, what do you think is going wrong?

The data collected from this device was good, as it displayed the expected inverse linear torque-speed trend when graphed. As seen in Figure 3, data points followed the trendline closely with an R^2 value of 0.999.

What's good about your design (things to keep)? Why?

Safety, inexpensiveness, and stability are the best features of this design. The device had no exposed wires, eliminating the danger of a short circuit or an electric shock. It was easy and quick to step up, as the motor was secured safely and controlled by a remote, which made it simple to switch on and off. All of the parts of this design were household items, and therefore the construction was low cost. The motor was securely placed on the chair and supported by books and ropes to allow for accurate measurements to be taken. The device was also durable; it could run for hours before the battery died and thus enabled it to perform more experiments without break. Additionally, the motor was powerful enough to lift a mass of up to 0.3 kg, which allowed for measurements of greater accuracy, as smaller masses tended to be more affected by the friction and the swinging of the rope than heavier masses.

What's bad about your design (up to three things to improve/design out)? What's wrong with it? Why?

One problem was the difficulty of the process of measuring the rotational speed of the motor. The RPM was determined from counting the revolutions when playing back a slow motion video recording. This was time-consuming and imprecise. Accuracy could be improved by counting revolutions in 15 second increments and multiplying the result by 4, instead of only 2 seconds and multiplying by 30. An alternate solution could be to use an audio queue for each revolution instead of video. Another problem with collecting data was determining an exact stretch value, as the motor would not run smoothly during the addition of more mass. This caused the elastic to fluctuate in length and made it challenging to measure an accurate value. A solution to this problem could be to use masses that do not disrupt the system when being added, such as solid weights instead of grains of rice. Additionally, using a container for the mass that has a larger opening than a water bottle would help with the disruptions.

Do you have any safety concerns with your designs/plans?

The motor was tested for safety before the start of the test. Originally, water was to be used as the variable mass but it was determined to be unsafe around electric components. Fixing this was the priority as it poses immediate risk to the user. Additionally, the device was resting on one textbook for support but was later tied down with ropes to ensure the motor did not fall off the stool due to vibration. This was less of a priority but also important as it makes the system user-friendly.

Appendices

- Video of all the designs working: https://youtu.be/uy4TcKKHLhI

Design 2 (Joyce):

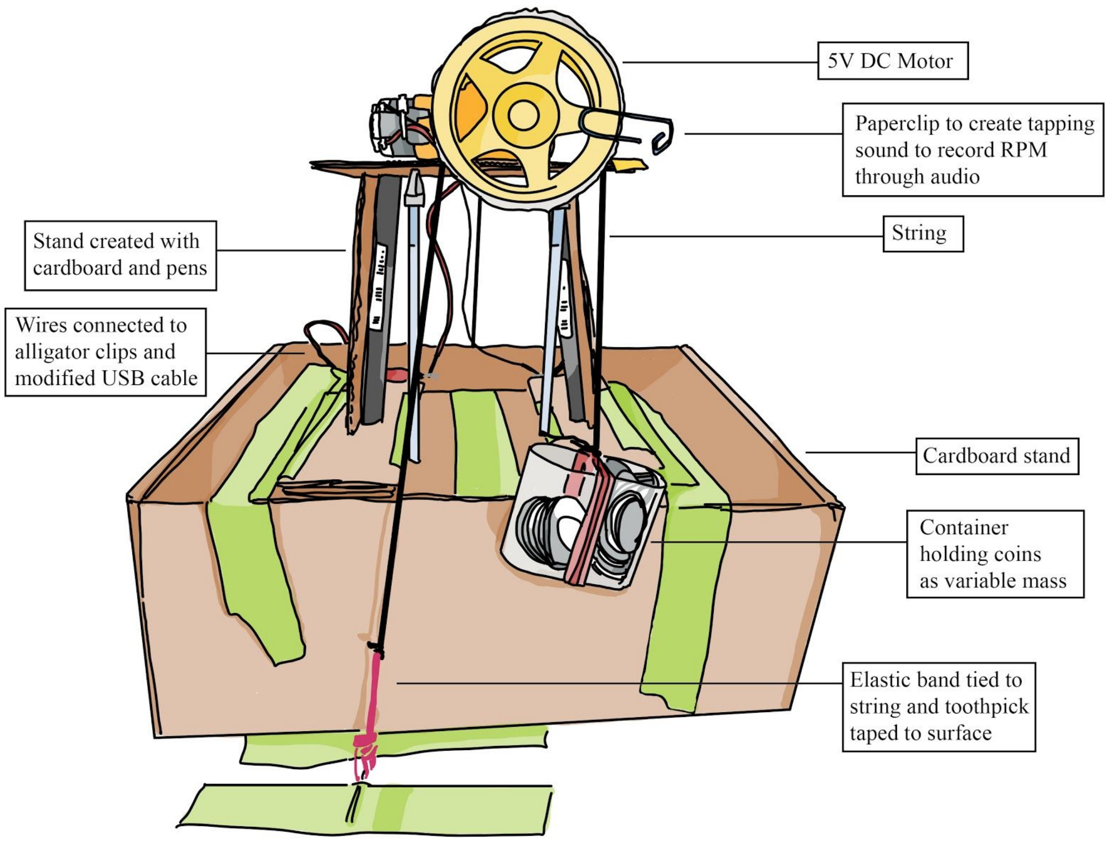

Figure 5: This diagram outlines the key features of design 2.

Photos:

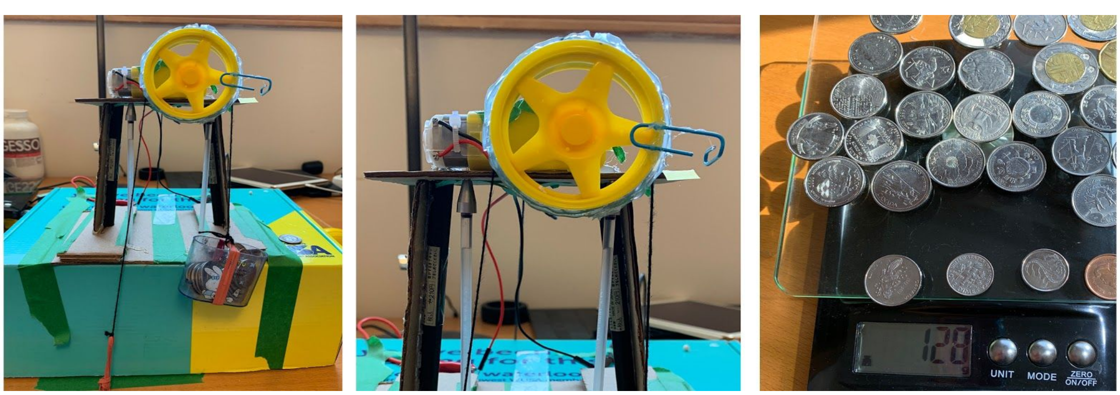

Figure 6: Images of design 2 are shown.

Design 3 (Emily):

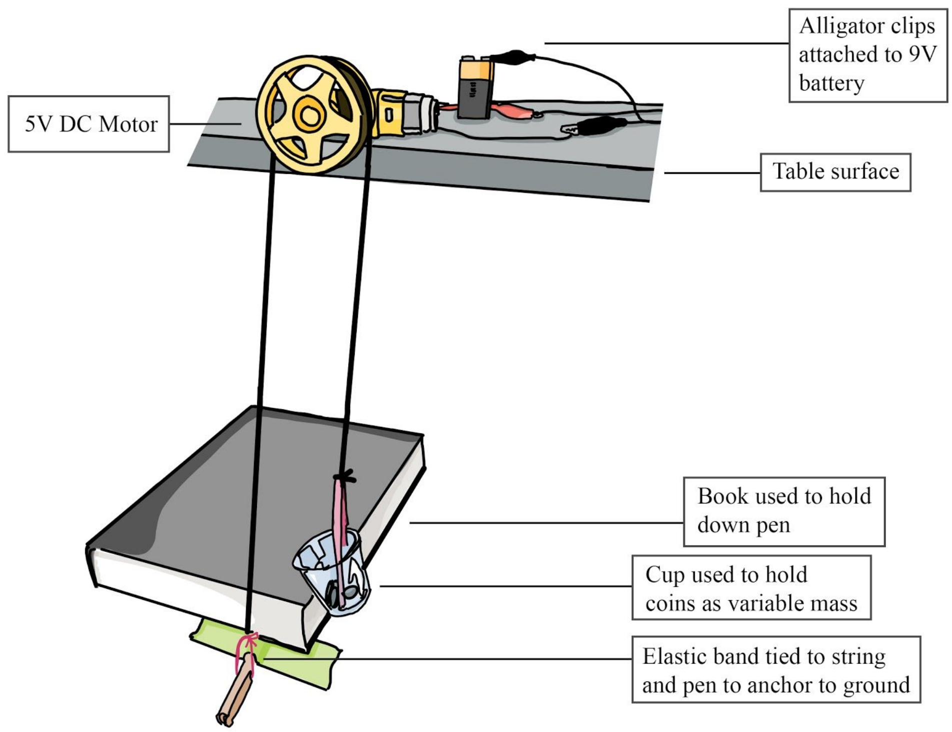

Figure 7: This diagram outlines the key features of design 3.

Photos:

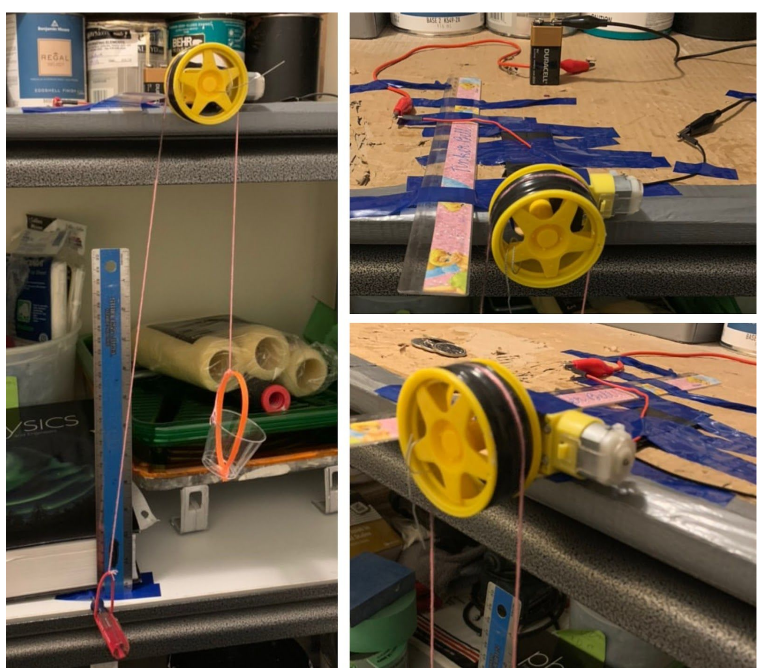

Figure 8: Images of design 3 are shown.

Design 4 (Brendan):

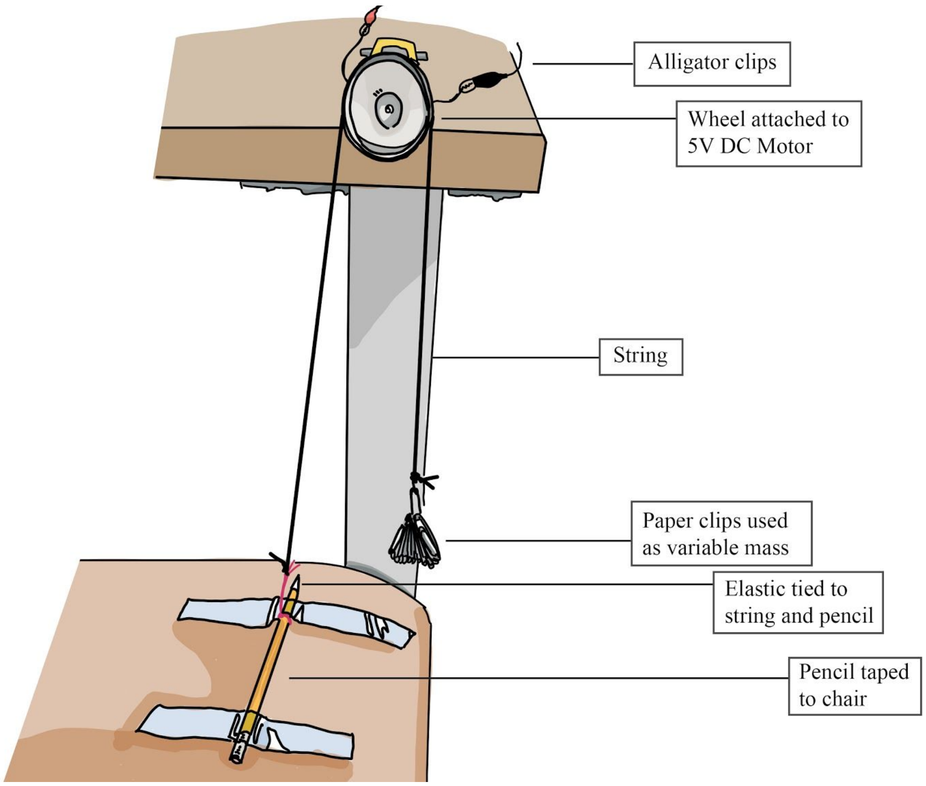

Figure 9: This diagram outlines the key features of design 3.

Photos:

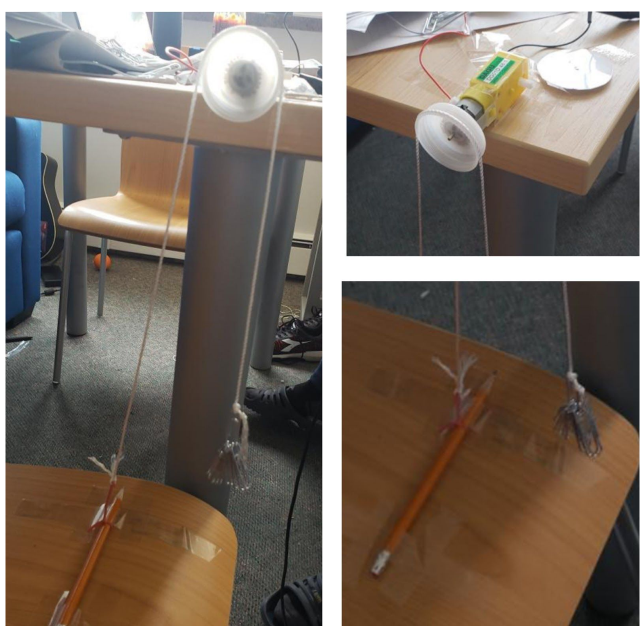

Figure 10: Images of design 4 are shown.

Data:

Design 2:

Mass (kg)	*Stretch (m)*	*RPM*	*Friction (N)*	*Radius (m)*	*Spring constant, k (N/m)*	*Torque (Nm)*
0	0.050	234	0			0
0.009	0.053	186	0.092			0.0023
0.036	0.060	138	0.25			0.0062
0.049	0.065	132	0.42			0.011
0.069	0.071	114	0.59			0.015
0.087	0.082	78	1.1			0.027
0.107	0.093	60	1.5			0.038
0.126	0.104	42	2.0			0.050
0.137	0.105	Stall	2.0	0.025	60.1	0.050

Table 3: The data for design 2 is recorded in this table.

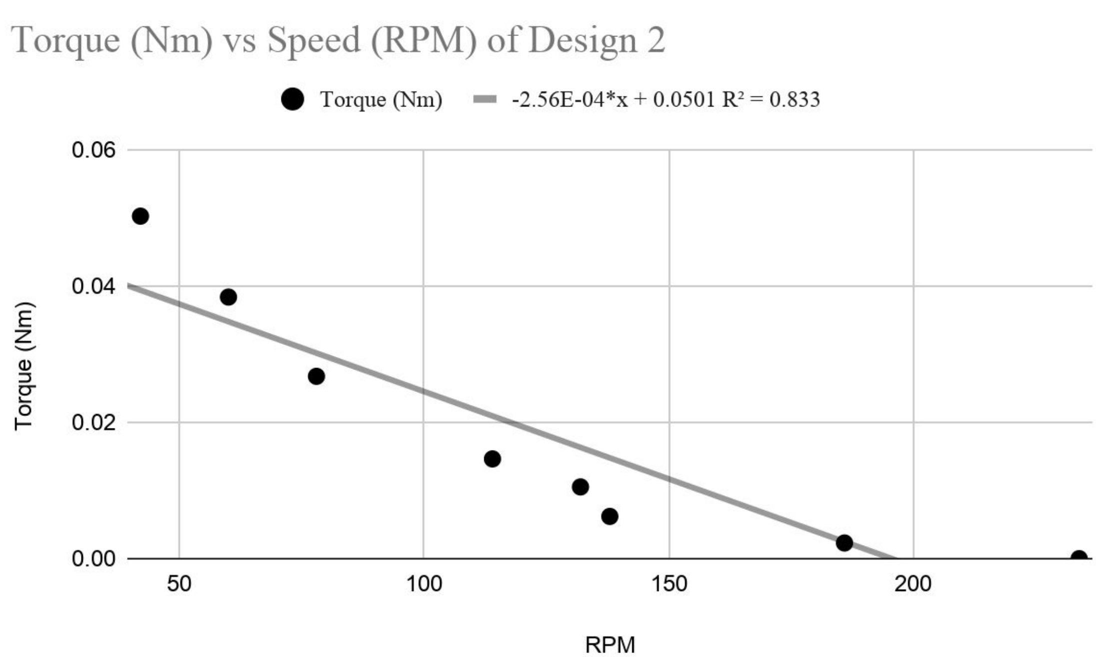

Figure 11: This graph shows the relationship between the rotational speed and the torque for design 2.

Design 3:

Mass (kg)	*Stretch (m)*	*RPM*	*Friction (N)*	*Radius (m)*	*Spring constant, k (N/m)*	*Torque (Nm)*
0	0.030	280	0			0
0.02268	0.049	204	0.828			0.0207
0.04536	0.061	100	1.274			0.0317
0.06804	0.069	92	1.49			0.0372
0.09072	0.085	80	2.15			0.0538
0.1134	0.091	60	2.26			0.0565
0.13608	0.0999	Stall	2.53	0.025	55.3	0.0633

Table 4: The data for design 3 is recorded in this table.

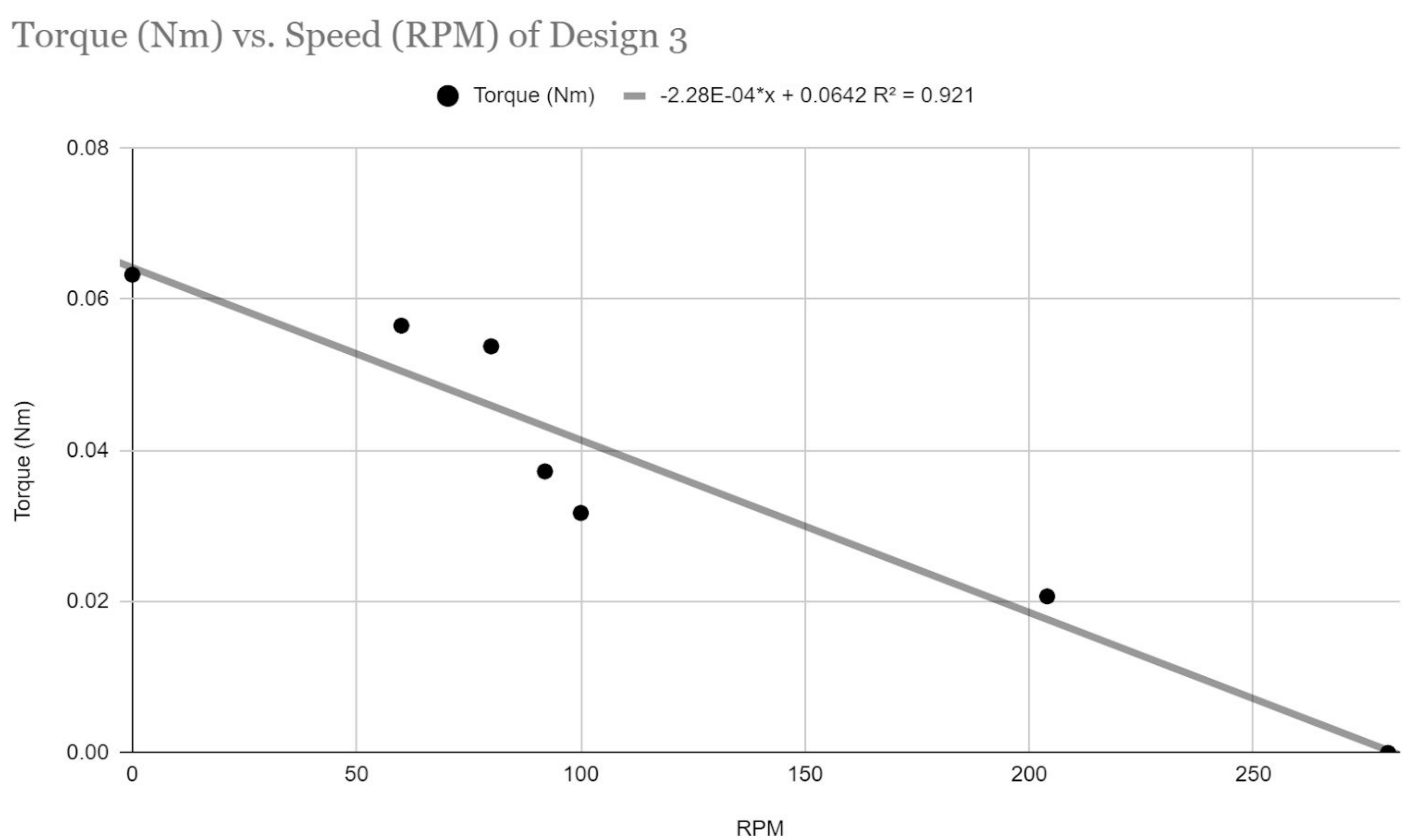

Figure 12: This graph shows the relationship between the rotational speed and the torque for design 3.

Design 4:

Mass (kg)	*Stretch (m)*	*RPM*	*Friction (N)*	*Radius (m)*	*Spring constant*	*Torque (Nm)*
0.00566	0.0057	Stall	0.0927			0.00205
0.00501	0.0053	11s	0.0887			0.00194
0.00433	0.0042	13.2.	0.0667			0.00147
0.00366	0.0035	26.2	0.0551			0.00122
0.00301	0.0025	36.8	0.0355	0.0221	26	0.000784

Table 5: The data for design 4 is recorded in this table.

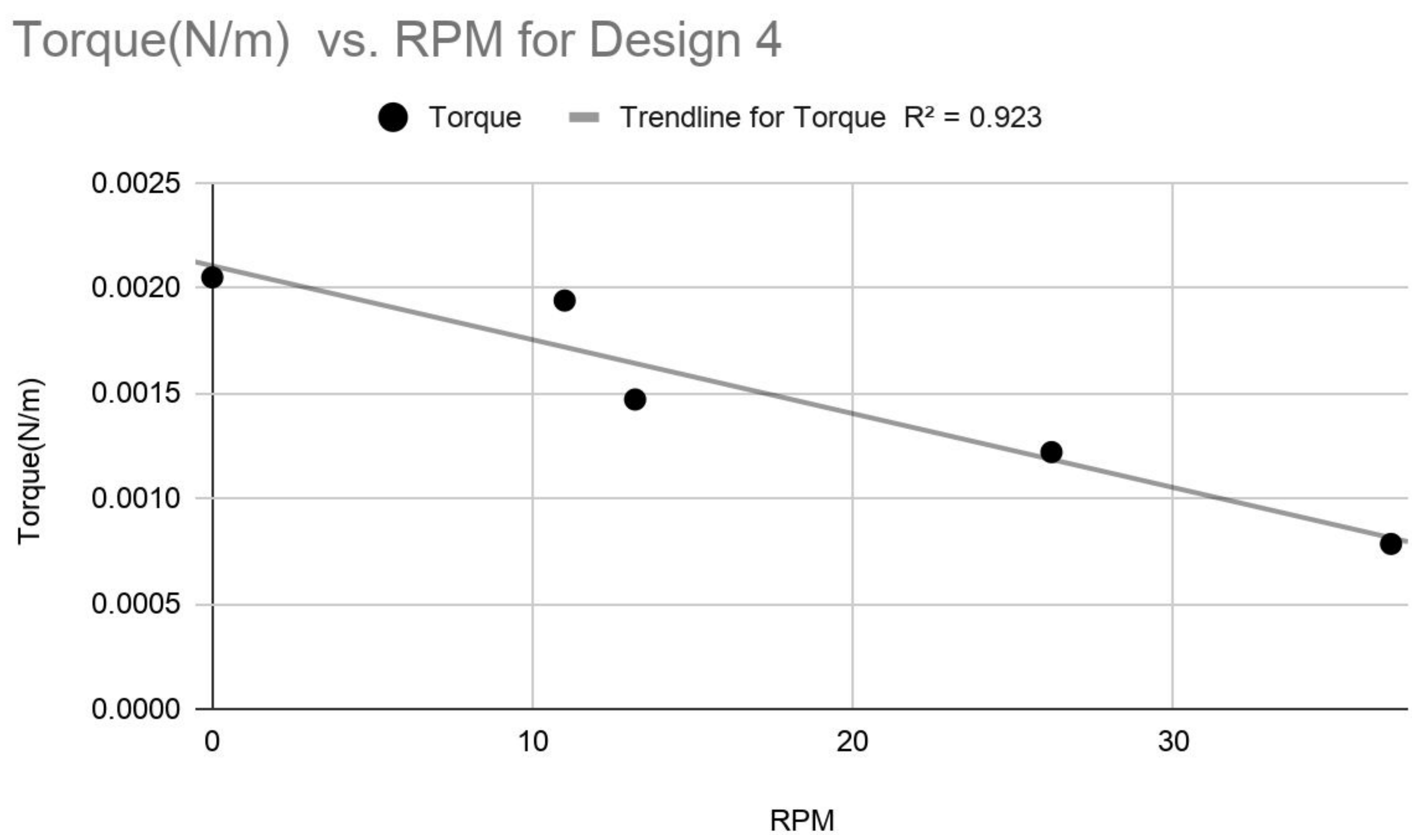

Figure 13: This graph shows the relationship between the rotational speed and the torque for design 4.