Energy Recovery from a Zipline Braking System via Regenerative Braking using Buck-Boost Converter

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***Abstract*—This paper provides the study on the design, construction, and testing of a Regenerative Braking prototype, for zipline rides, that recovers energy upon its activation. The authors of this study wanted to address the energy crisis issue by providing other means for energy generation, which is the innovation of Regenerative Brake. The design of the prototype depends on the operating parameters of the chosen zipline ride. The elements used in the prototype are: geared dc motors, each coupled to the roller of the trolley; capacitors; Buck-Boost converter; and a lead-acid battery. The prototype works by having geared dc motors convert the kinetic energy from the rider to electrical energy. The generated electricity goes through the buck-boost converter to regulate the resulting voltage. This is done to meet the voltage requirement of the lead-acid battery before storing the regulated electricity. After recording the needed data, the resulting currents and battery charging times are averaged to help determine the energy generated. Resulting data showed it would take roughly two years to charge the 4Ah lead acid battery using the prototype for this study. Despite the minimal result, the prototype is proven to be capable of recovering energy from the zipline braking system. This implies that this study can now be an option for energy generation, instead of always resorting to construction of renewable- and coal-fired power plants**

***Index Terms*— Regenerative Braking; Zipline Ride; Buck-Boost Converter; Lead-Acid Battery.**

I. Introduction

Energy crisis has been a major issue despite endeavours on renewable energy to reduce consumption of natural resources. These natural resources are limited in supply, and not all communities are geographically ready for any kind of renewable energy plant. One such study regarding recovery of energy is the innovation by automotive industries through electric vehicles, reducing the dependency of consumers on fuel that contributes largely on carbon emissions. It was also from this vehicle that a braking system able to recuperate energy during deceleration is introduced. Since this recovered energy is of significant value, it has been integrated on a lot of applications such as bikes and trains. It has been the subject of a lot of studies and is continually integrated on different applications wherein it can be proven beneficial to the user [1-10].

Regenerative braking recovers energy by making use of the rotation available during deceleration of the motor. During this time the motor is develops a back electromotive force (back emf), which is fed into a DC-DC converter for rectification. The resulting emf is then stored on supercapacitors for later use. This is widely used on electric vehicles, such as F1 racing cars and trains.

The need for studies regarding innovative ways in recovering energy is a trend nowadays, especially regenerative braking as reported by various previous studies [1-10]. However, most studies regarding the said braking were mostly related to electric vehicles, and only a few talked about its installation on mechanisms that are not entirely operated with an electric source. In addition, those few talked about hybrid cars which still tackled the need for electrical source voltage. Despite these, the sole knowledge that the said braking system harnesses the back emf of the motor implies that it can be used on other motor applications. Such an application is the braking system of a zipline, wherein a motor is used to decelerate the rider as he nears the end of the line.

The main objective of this research is to recover energy from the braking system of a Zipline via regenerative braking using buck-boost converter. The specific objectives are as follows: First is to obtain the measurable parameters of a zipline in operation. Second, is to construct a working regenerative braking mechanism for integration on the Zipline braking system. Third, is to determine how much voltage and current the system generated during braking, as well as the time it took to charge the battery, on all trials of increasing rider weights.

The study is limited to utilization of an already made zipline since a lot of factors, such as line sag, strength of materials, and the like, are to be considered in designing the said cable ride. Also, the parameters generated during braking are determined through prototype testing, whereas the battery charging time is computed.

II. Methodology

A. Location of Implementation

Certain measurable values are considered in determining the testing site of the prototype. The authors chose Adventure Zone: Zipline, located at Star City, Vicente Sotto St., Pasay, Manila, with operating hours of 4:00PM – 10:30PM. The operating parameters of the said Zipline are presented in Table 1. Some of the parameters are given by the zipline operator (horizontal and vertical distances, platform heights.

maximum allowable weight, and cable diameter), whereas other values are solved using trigonometric means (cable length and slope). The remaining parameters, maximum acceleration and maximum velocity, are obtained using equations made by West Virginia University [12].

Table 1
Zipline Operating Parameters

Operating Parameters	Values Obtained
Horizontal Distance (x)	50 m
Height of Platform 1 (y1)	6.1 m (20 ft)

B. Design of Prototype

The design of the regenerative braking prototype, or ReGen in the succeeding texts, is based on the operating parameters of the zipline. It is divided into two parts: the trolley and circuit design. The authors adopted the already present trolley design of Adventure Zone and made some modifications, as seen on Figure 1.

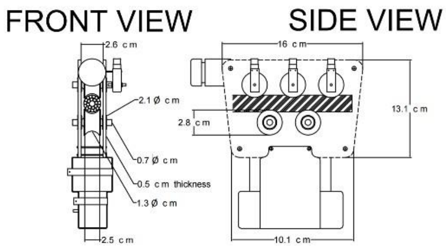

Figure 1: Trolley Design

As for the schematic diagram, the usual schematic of regenerative braking, consists of motors connected to capacitors, which is then connected to a buck-boost converter, and lastly to the battery. For this study, a switch is placed between the buck-boost and the battery for measurement purposes during testing. This can be seen in Figure 2.

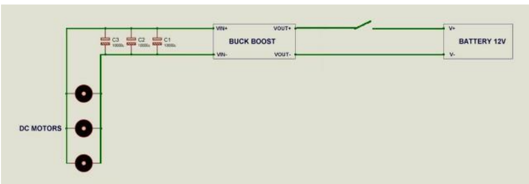

Figure 2: ReGen Schematic Diagram

C. Construction of Prototype

For the trolley, the authors brought the proposed trolley design to a machine shop to produce the desired metal assembly. Three of the five rollers have its shafts cut, where the shaft of the geared DC motors will be connected. Figure 3 shows the assembled trolley with the geared dc motors.

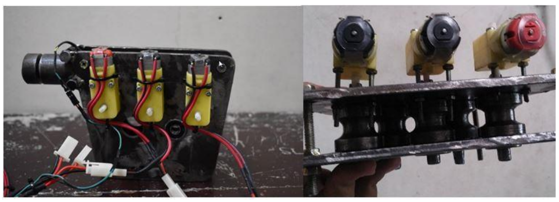

Figure 3: Trolley Assembly

For the circuit board, the regenerative braking circuitry does not require the placement on the PCB, as it is able to function on its own. The circuit components, such as the capacitors, buck- boost, dc motors, switch, and battery are connected as seen on the schematic at Figure 2. These two major parts are fastened using nuts and bolts to create the ReGen prototype. Figure 4 shows the entirety of the ReGen prototype.

Figure 4: ReGen Prototype.

D. Simulation

In this part, the authors assumed speed in rpm, applied that speed to the geared dc motor using a hand drill, and measured the generated voltage from the terminals of the motor. Upon reaching the desired speed, the leads of the DMM are placed on the common nodes of the capacitor bank to measure generated voltage. The voltage at the output terminals of the buck-boost converter is then measured to see if the generated voltage is boosted. This voltage at the output terminals of the converter is now called the boosted voltage. Open circuit test, as well as other parameters needed or this test, are done using a load of 20Ω and results are recorded on Table II which will be discussed in the result section.

E. Prototype On-Site Testing

Now that the prototype is deemed working, it is ready for actual testing at Adventure Zone. This is further divided into two parts: Trolley-Zipline Assembly and Actual Testing. For the trolley zipline assembly, prior to the actual testing, the trolley should be clamped on the cable. Upon loosening bolts and screws, the metal plates are separated so that the rollers can be placed along the line of the cable. After this, the trolley is locked at the braking point. The plugs are connected and ReGen is now prepared for testing, positioned behind the brake block as seen on Fig. 5. The positioning of the brake block is predetermined by the zipline owner.

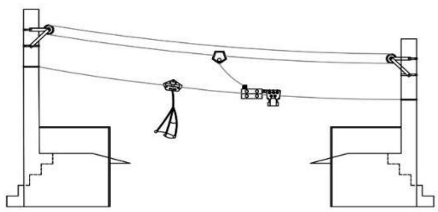

Figure 5: ReGen Set-up

For the actual testing, First, the brake block and ReGen are positioned to the breaking point of the cable. The rider then gears up and rides the zipline. The trolley of the rider eventually hits the wooden brake block, which then hits ReGen that would generate electricity. Timer is started when the trolley carrying the rider hits ReGen. A tachometer is pointed to the rider to measure final speed in rpm. If speed is not measured, the process should be repeated from the very beginning. When the rider comes to a complete halt, timer is stopped. A switch discharges the regulated voltage, then buck-boost voltage and current are measured using a DMM, respectively. Upon recording the needed data at Table III, the test subject repeats the whole process until all his trials are done. After 10 trials, the authors move on to the next test subject.

For this study, the authors considered 3 test subjects of weights 53kg, 64kg, and 70kg. The measurable values are recorded for both ON- and OFF – switch cases. The tests showed random results and for orderly viewing the authors sorted the data in increasing speeds.

III. Results and Discussion

Based on the results presented at Table 2, the prototype is deemed to be in good working condition since it gave the results anticipated by the authors. From here, it can be said that the buck-boost converter regulates voltage to 13.61V if the generated voltage is approximately 2V. This 13.61V is set by the authors on the converter since the lead-acid battery needs 13.5-13.8V in ambient 25 °C to charge.

Table 2
Zipline Operating Parameters

Speed (rpm)	Generated Voltage (V)	Boosted Voltage (V)	Buck-Boost Current (mA)	Open Circuit Voltage (V)
107.00	1.74	0.81	40.70	1.62
119.00	1.77	0.95	47.60	1.71
131.00	2.01	1.13	54.40	13.61
145.00	2.24	1.24	62.50	13.61
149.00	2.43	1.41	71.70	13.61
165.00	2.78	1.53	76.80	13.61
172.00	2.83	1.64	83.60	13.61
180.00	3.15	1.77	89.20	13.61
190.20	3.20	1.93	95.90	13.61
204.00	3.46	2.11	106.10	13.61

In Table 3, it can be noted that speed upon braking for a test subject, though sorted, is of increasing value with very little increments. Despite the small difference between speed values, it resulted to notable buck-boost voltage and current values. Increasing speed showed an increase on the said voltage and current values. The boosting property of the controller can also be seen from the data, since generated voltage is boosted for values greater than 1.78V. It is also observed that if the rider has a braking speed of approximately 128rpm, ReGen generates voltage ample enough to charge the battery. From our tests, it can be said that anyone of any weight can ride the zipline and generate electricity using ReGen, but those weighing more than 50kg would charge the batteries faster.

Table 4 shows buck-boost current flowing through the battery during battery-charging phase. Time during charging is recorded to see the changes in buck-boost current during battery charging. Current can be seen dissipating from its maximum value to 0 A during charging. It implies that a single ride generates a certain amount of current, responsible for battery charging, and that multiple rides would eventually fully charge the said storage medium.

Table 3
Light Weight Data

Light Weight 53 Kg					
Trial	Braking Speed (rpm)	V_{gen} (V)	Switch On/Off	$V_{BuckBoost}$ (V)	$I_{BuckBoost}$ (mA)
1	127.4	1.77	On	1.75	39.45
		1.77	Off	0.00	0.00
2	127.6	1.81	On	13.61	48.10
		1.78	Off	0.00	0.00
3	128.1	1.94	On	13.61	51.10
		1.78	Off	0.00	0.00
4	128.8	1.98	On	13.61	54.30
		1.78	Off	0.00	0.00
5	130.1	2.01	On	13.61	54.40
		1.78	Off	0.00	0.00
6	130.4	2.03	On	13.61	56.40
		1.78	Off	0.00	0.00
7	131.0	2.09	On	13.61	57.80
		1.78	Off	0.00	0.00
8	132.5	2.14	On	13.61	59.50
		1.78	Off	0.00	0.00
9	134.8	2.21	On	13.61	50.50
		1.78	Off	0.00	0.00
10	135.2	2.24	On	13.61	62.50
		1.78	Off	0.00	0.00

Table 4
Regen Discharging Time Vs Load Current for Heavy Weight Division

Trial 1 Heavy weight	
Time (sec)	Current (mA)
0.00	120.80
0.12	120.60
0.24	115.70
0.49	105.80
0.74	102.60
1.11	99.70
1.23	80.80
1.47	58.60
1.97	1.64
2.19	0.02
Average Current	83.71

As stated earlier, a rider of speed approximately 128rpm prompts faster battery charging. For this study, even the lightest rider can charge the batteries faster than any other rider that would weigh less than his since he exceeded the 128rpm limit. This 53kg-rider can charge the battery in 1.47 seconds with an average current of 19.56mA. Whereas the 70- kg rider has 2.19 seconds charging time with 83.71mA average current. The total battery charging time is 2.08 seconds. The results is shown in Table 5.

Table 5
Average Speed and Current of The Rider, And the Operating Time of Regen

Weight classification	Average Speed (rpm)	Average Current (mA)	Battery Charging Time (sec)
Light=53 kg	130.6	19.56	1.47
Medium=64 kg	164.1	69.46	2.57
Heavy=70 kg	183.8	83.71	2.19
Total		52.08	2.08

Figure 6 shows the graphical representation of the gathered buck-boost current values from different speeds and its corresponding charging time. The graph goes down, representing the dissipation of current upon charging the battery. It also shows that on all tests, approximately 120mA is the highest buck-boost current value produced by ReGen.

Though the relationship between the two mentioned values are not linear, it can be stated that current dissipates over time as it flows to the battery.

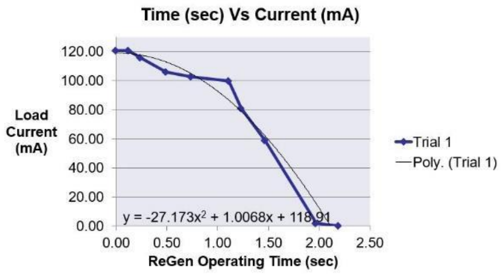

Figure 6: Buck-Boost Current(mA) Vs Battery Charging Time(Sec) forHeavy Weight Rider

Figure 7 shows the graphical representation of voltage generated at different speeds on all weight divisions. The black line shows the linear trend line equation and the R-squared value. It shows that the results obtained are almost linear and that generated voltage and speed have an almost linear relationship. This shows that generated voltage increases as speed is increased. It means at increasing rider weights, the geared dc motor is driven at higher speeds, thereby generating greater voltage values, making the battery charge faster.

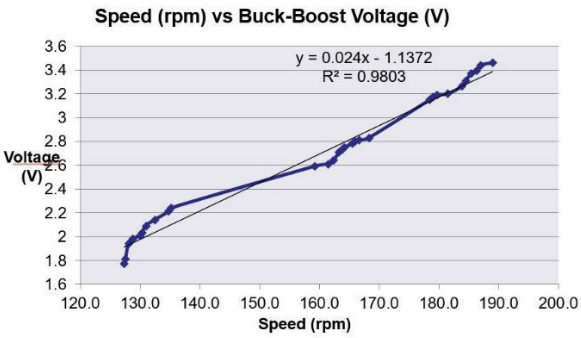

Figure 7 Speed(rpm) Vs Generated Voltage(V) for Light Weight, Medium Weight, and Heavy Weight Riders.

From here, computations are made to determine how much time it would take to fully charge the 4Ah lead acid battery based from the above results. The lengthy solution, which can be seen on the thesis paper of this study, showed that 53- to 70-kg people should ride the zipline, for 11 to 12 days to fully charge the 12V 4Ah lead acid battery. This can then power up its light loads such as ornate LED lights, or even intermittent loads like Christmas lights

IV. CONCLUSION

The group recovered energy from the braking system of a Zipline ride using buck-boost converter. The prototype for this study, ReGen, generates electricity ample enough to charge the battery. Measurable quantities with regards to energy generated are recorded while some are calculated to verify the effectivity of the prototype.

The authors, upon choosing a location for implementation of prototype, obtained the necessary operating parameters of the said site. Adventure Zone provided the horizontal and vertical distances of the site, as well as the strength and diameter of cables used in the Zipline. The authors used these quantities to compute for maximum velocity and acceleration, which are used on latter parts of the study. These operating parameters are also used as reference for the design of the prototype.

A prototype is constructed, based on the designs made by the authors. The trolley part of ReGen consisted of metal plates, bearings, and rollers made from a machine shop. Three geared DC motors are directly coupled to the rollers of the trolley, which would be responsible for the generation of electricity. The regulator part consisted of capacitors, buck-boost converter, and a switch are interconnected and placed inside a case. A 12V 4Ah lead-acid battery completed the entirety of ReGen, and this duly constructed prototype underwent testing for recording of data needed for the final objective.

Upon using ReGen on actual tests, generated voltages and currents are measured using a DMM. It is proven to generate voltages up to 3V while braking, which is then boosted by the buck-boost converter to 13.61V. The prototype can also charge the battery with currents of up to approximately 120mA. By using the operating parameters of the zipline, as well as the recorded data from testing, it can be said that the most ideal number of days needed to fully charge the 4Ah 12V lead-acid battery is 624 days.

As reflected on the graphs and tables of this study, generated voltage is linearly dependent to speed and thereby weight, making generated voltage higher with increased speed or heavier rider weights. Despite the minimal resulting buck- boost currents, it can still be said that the prototype is working well enough to produce a certain amount of mAh for battery charging [11]. In time, further modifications can greatly improve results. But for now, it can be said that the objectives are met and the study is a success.

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