Kinetic Energy Recovery System

Group 36 | Expo Presentation | April 25, 2021

California State University L.A.

College of Engineering, Computer Science and Technology

Advisor: Everardo Hernandez

Team: Claudio Sanchez, Edward Roemer, Enoch Asare, Sin Tsan Chan, Talal Binjubail

AGENDA

I. Introduction…………………………........Edward and Enoch

II. Project Management………………………….......Claudio

III. Technical Analysis……............….Claudio, Enoch and Talal

IV. Dynamic Braking System……………………..……....Team

V. Automatic Shifting.............Edward, Enoch and Sin Tsan

VI. Thermal Electric Generators………...………Claudio

VII. Bicycle Design……………………….……………Claudio

VIII. Summary…………………………….………………Edward

INTRODUCTION:

EDWARD AND ENOCH

BACKGROUND

SCOPE & PROBLEM

DELIVERABLES

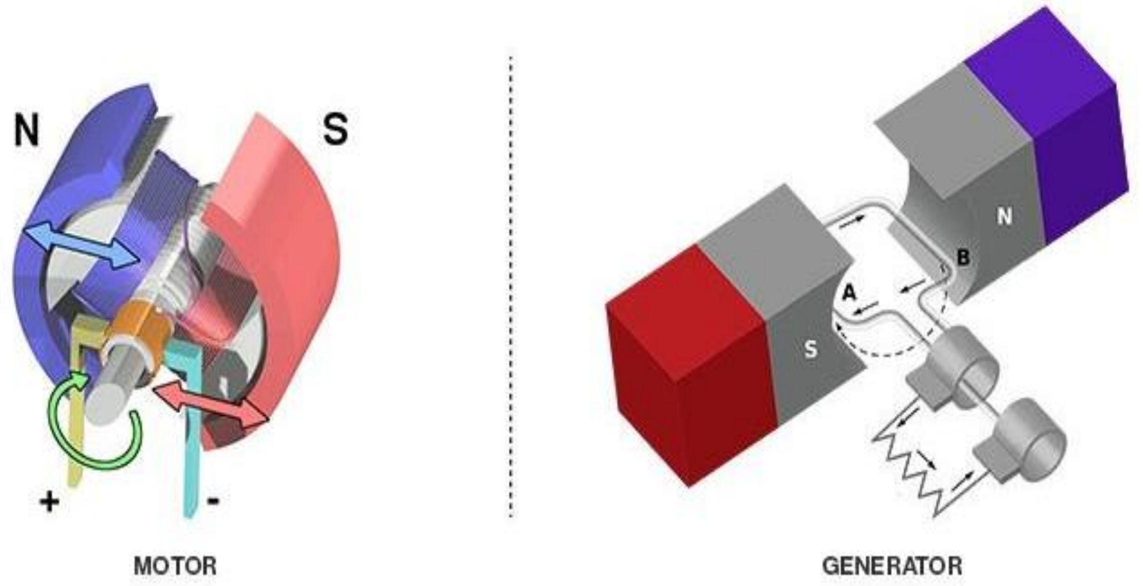
BACKGROUND

What is Kinetic Energy Recover?

- Brakes create a loss of kinetic energy in a system
  - Friction
- Deceleration other than friction
  - Energy can be saved and stored

Dynamic Braking:

- As electrons flow through a coil it creates a magnetic field
- Applying the same magnetic field to the coil creates an electric current



[1]

SCOPE & PROBLEM

Scope

- The objective of this project is to design a kinetic energy recovery system for a bicycle which recover's energy through braking.

Problem

- Generating energy at a rate faster than the battery can charge

DELIVERABLES

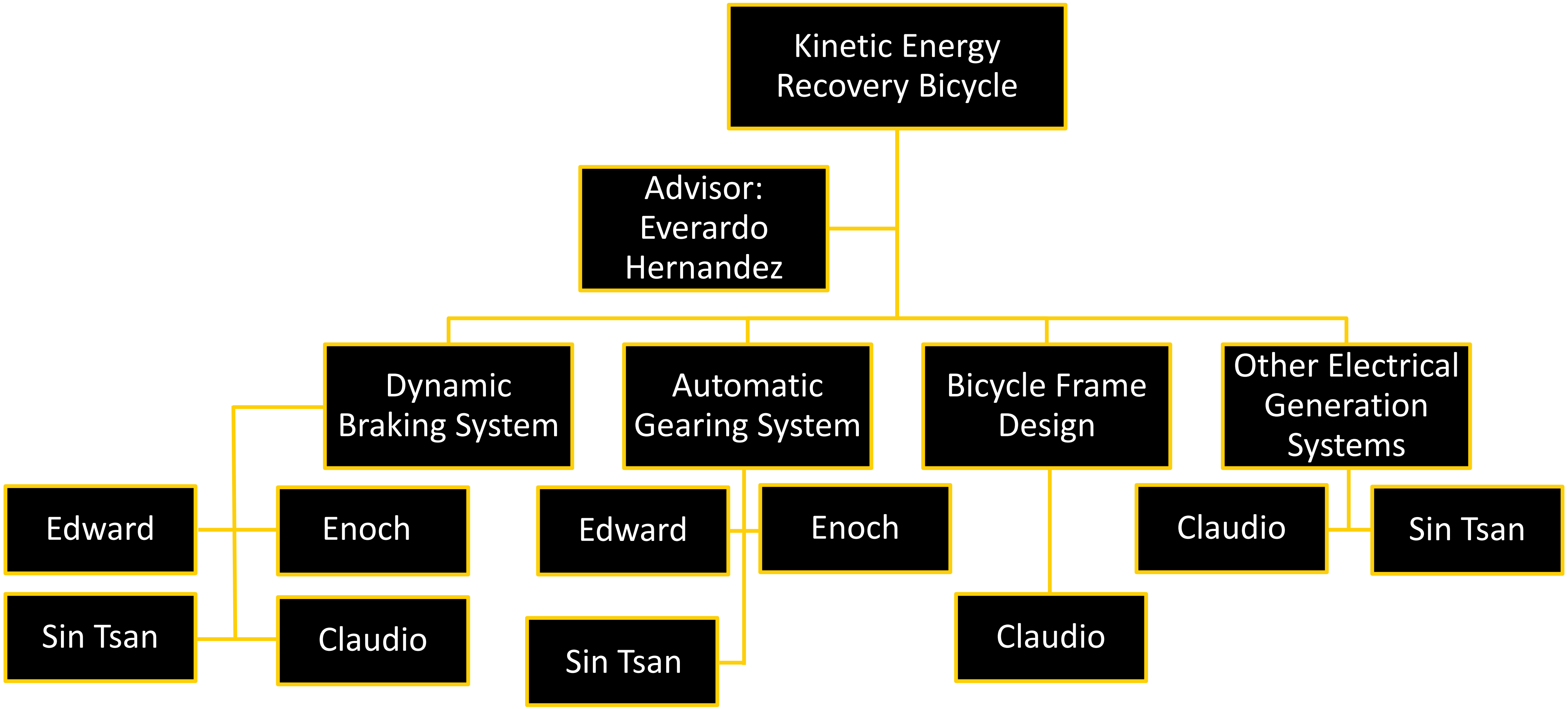
Item Number	Deliverable Description
1	Dynamic Braking System
2	Automatic Gearing System
3	Bicycle Frame Design
4	Thermoelectric Generator

PROJECT MANAGEMENT:

CLAUDIO

PROJECT ORGANIZATION

PROJECT ORGANIZATION

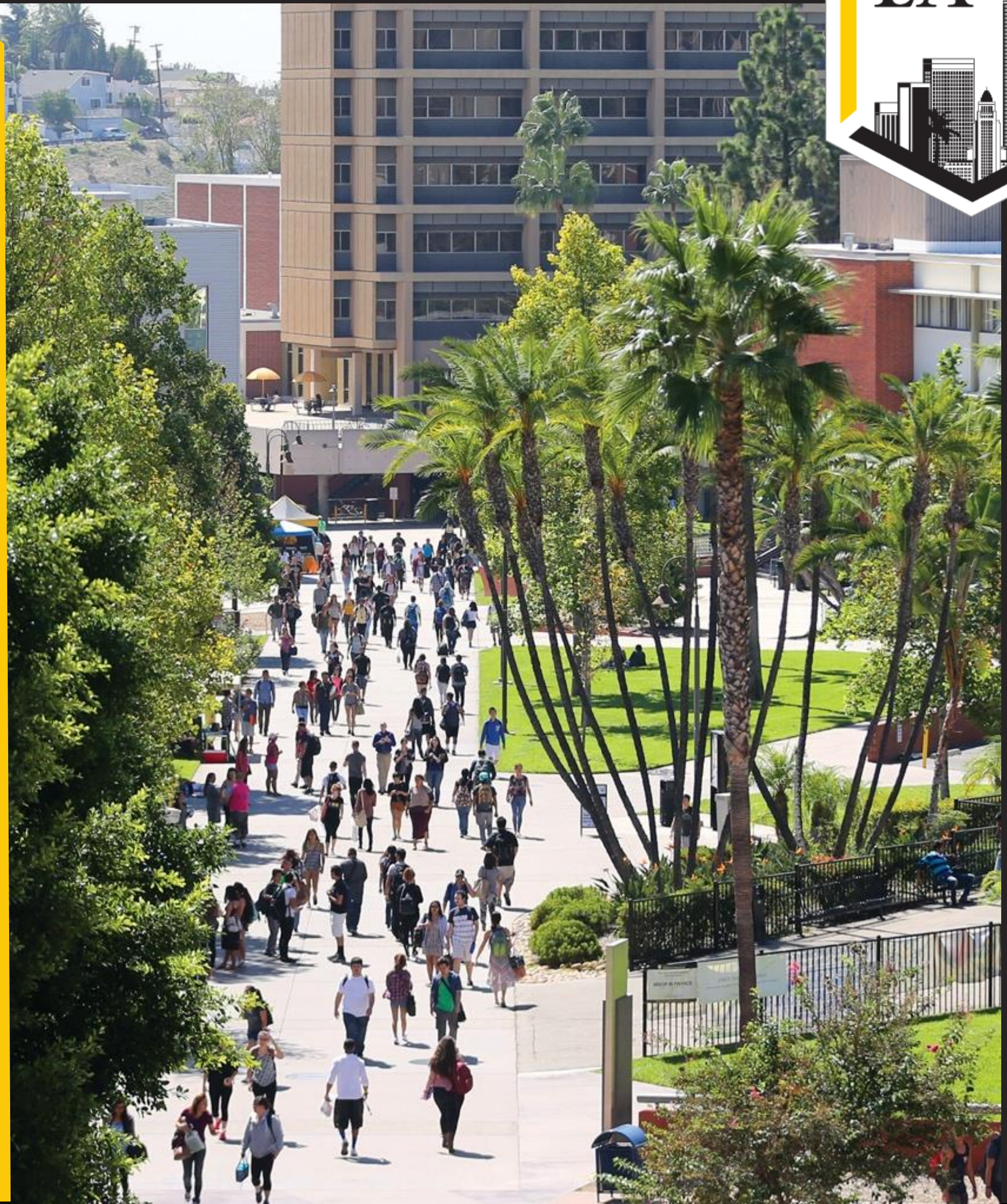


TECHNICAL ANALYSIS:

CLAUDIO, ENOCH AND TALAL

REQUIREMENTS

FORCES REQUIRED TO MOVE



REQUIREMENTS

Level Number	Title	Requirement	Source	Method of verification
1	Regeneration	>5% Energy Recovery	Average Market Regeneration	Algorithm
2	Maximum Power	750 Watts	California Standard Regulations	Distributer
3	Maximum Speed	20mph	California Standard Regulations	Algorithm
4	Controller	Throttle-Assisted	California Standard Regulations	Planning

Average Power Output And Torque Required

- Assume:
    - 177 *lb*. weight of bicycle accelerates from rest to 12.5 mph in 8 seconds.
- Average power output to accelerate the bicycle

$$\text{Initial speed} = 0\,\frac{m}{s} \quad \text{and} \quad \text{Final speed} = 12.5\,mph = 5.588\,\frac{m}{s}$$

- Total weight $= 77.11\,kg$
- Newton's second law: $F_a = ma = m\frac{v-u}{t}$

$$F_a = 77.11\ Kg\,\frac{5.588\ \frac{m}{s} - 0\ \frac{m}{s}}{8\ s} = 77.11\ Kg * \frac{5.588\ \frac{m}{s}}{8\ s} = 77.11\ Kg * 0.69475\,\frac{m}{s^2} = 53.57\ N$$

Friction And Air Resistance Forces

$$F_x = ma_x$$
$$F_A - F_{AR} - F_f = ma_x$$
$$Applied - Air\ Resistance - Friction = (mass\ of\ bike + rider) * (acceleration\ required\ to\ move)$$
$$a_x = 2.6 \frac{m}{s^2}$$

$$F_A = F_{AR} + F_f + ma_x$$

Friction

$$F_f = \mu F_N$$

$\mu = friction\ coeffient\ (0.002 - 0.004)$

Air Resistance

$$F_{AR} = \frac{C_d \rho v^2 A}{2} = \left(\frac{kg}{m^3}\right)\left(\frac{m}{s}\right)^2 (m^2) = k \frac{m}{s^2} = N$$

$C_d = drag\ coefficient\ (1.1\ for\ upright\ comuter)$

$v = velocity\ (\frac{m}{s})$

$\rho = density (\frac{kg}{m^3})$

$A = frontal\ area\ (m^2)$

Rolling resistance And Air Resistance Forces

Rolling resistance of the bicycle

$$F_R = \mu_f W = \mu_f mg$$

$$F_R = 0.008 \times 77.11\, kg \times 9.81 \frac{m}{s^2} = 6.05N$$

Resistance offered by air

$$F_A = \frac{1}{2} C_d \rho A v^2$$

$$F_A = \frac{1}{2} \times 1.1 \times 1.2 \frac{kg}{m^3} \times 0.51 m^2 \times \left(5.588 \frac{m}{s}\right)^2 = 10.51N$$

The total forces required to accelerate the bicycle is

$$F_{tot} = F_a + F_R + F_A$$

$$F_{tot} = 53.57\, N + 6.05\, N + 10.51N = 70.13N$$

Average Power Output And Torque

$$\text{Power } (p) = F * v$$

$$P = 70.13N * 5.588\frac{m}{s} = 391.88\,W$$

Torque needed at the center of the wheel to reach required speed from rest

$$\tau = F \times d$$

$$\tau = 37.95N + 6.05N + 10.51N * (14\ in * 0.0254\frac{m}{in})$$

$$\tau = 70.13\ N \times \frac{29}{2}\ inch \times 0.0254\,m = 25.83\ Nm$$

DYNAMIC BRAKING SYSTEM: TEAM

BACKGROUND

PROBLEM STATEMENT

INTRODUCTION TO CAPACITOR

COMPONENT SELECTION

CALCULATIONS

RESULTS

ELECTRICAL SCHEMATIC

DYNAMIC BRAKING SYSTEM

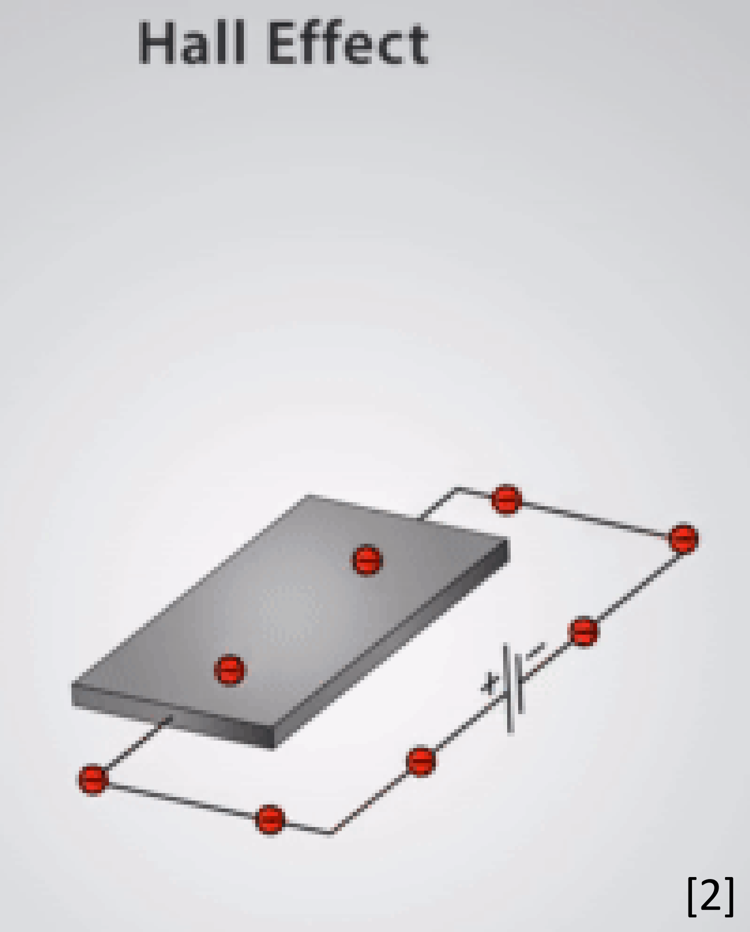
Motor is used as driver and generator

Hall Sensor

- Measures RPM by change in magnetic field
- Senses the direction of current in a wire

Vedder Electronic Speed Controller (VESC)

- Electronic speed controller regulates the speed of motor
- Programmable
    - Max/min speed
    - Maximum charge current



[2]

ENERGY: DYNAMIC BRAKING SYSTEM

Energy Produced From Stopping

$$E = \eta \frac{1}{2} m v^2$$

- Assume:
  - Mass = m = 100kg
  - Velocity = V ≈ 9 m/s (20 mph)
  - Efficiency = η = 90%

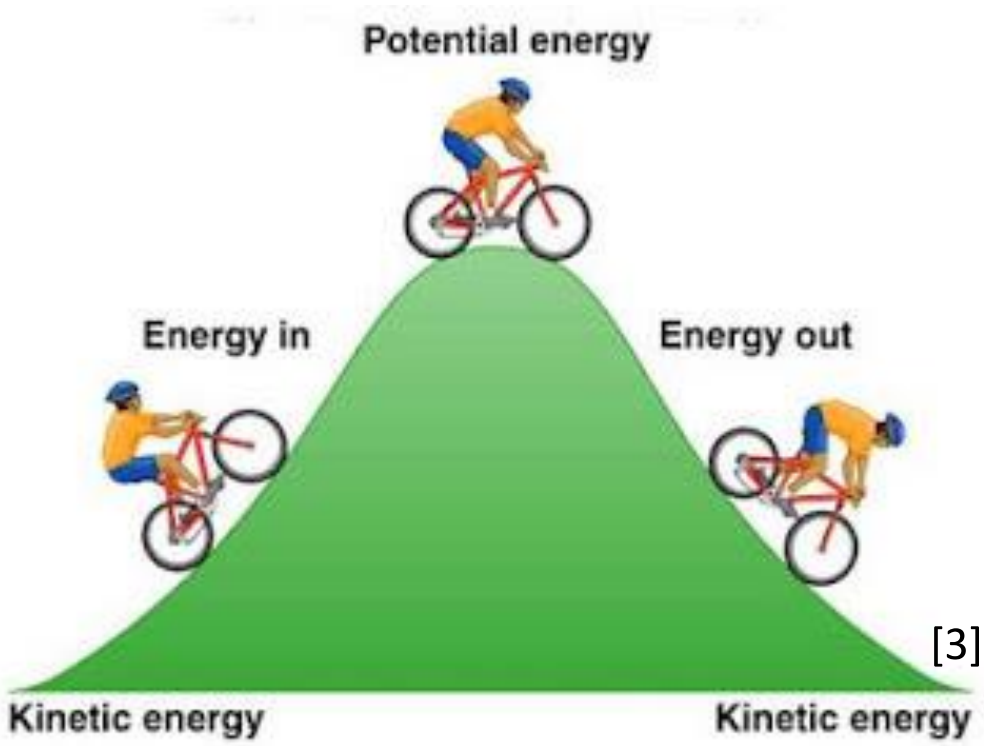
$$E \approx 3.6\ KJ$$

Time Needed to Stop

- Theoretical Li-ion Battery:
  - 48V
  - Charge 5a

$$5a \cdot 48V = 240 \frac{J}{s}$$

$$\frac{3.6\ KJ}{240 \frac{J}{s}} = 15s$$

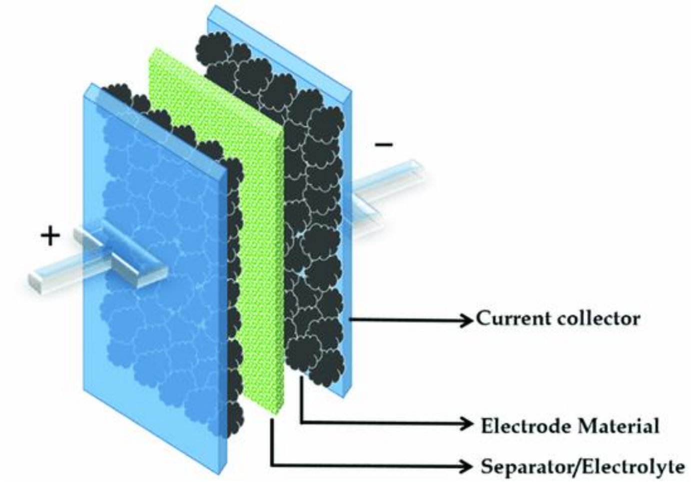


[3]

CAPACITOR: DYNAMIC BRAKING SYSTEM

Super Capacitor

- Quickly charges and discharges
- Holds a high amount of energy



[5]

Energy Stored in a Capacitor:

$$E = \frac{1}{2} C (Volts)^2$$ [4]

Energy Produced by Stopping:

$$E = \eta \frac{1}{2} m v^2$$

Equality of Energies:

$$C = \frac{m v^2 \eta}{(Volts)^2}$$

COMPONENT SELECTION: DYNAMIC BRAKING SYSTEM

Maximum Voltage

- Higher battery charge rate
- Higher torque from motor
- Lower Capacitance Minimum

Motor Selection:

- 48 V
- 750 W
- Hall Sensor
- VESC controlled

[6]

BATTERY SELECTION: DYNAMIC BREAKING SYSTEM

- Powers 750 W motor
- 48 V system
- Capacity
  - $750\ W\ * \frac{1}{2} hour = 375\ Wh$
  - $\frac{375\ Wh}{48V} = 7.81\ Ah$

- Includes Battery Management System (BMS)
  - To control current from capacitors

Specifications:
- 48 V
- 10Ah
- Lithium-ion Battery
- BMS
- Waterproof

[7]

CAPACITOR SELECTION: DYNAMIC BREAKING SYSTEM

- 48 V system
- Minimum 3 Farads
- Capacitors in Parallel
    - Voltage is equivalent
    - $C_{eq} = \sum C_n$
- Capacitors in Series
    - $V_{eq} = \sum V_n$
    - $\frac{1}{C_{eq}} = \sum \frac{1}{C_n}$

[8]

Specifications:
- 2.7 V
- 100F
- Carbon Aerogel

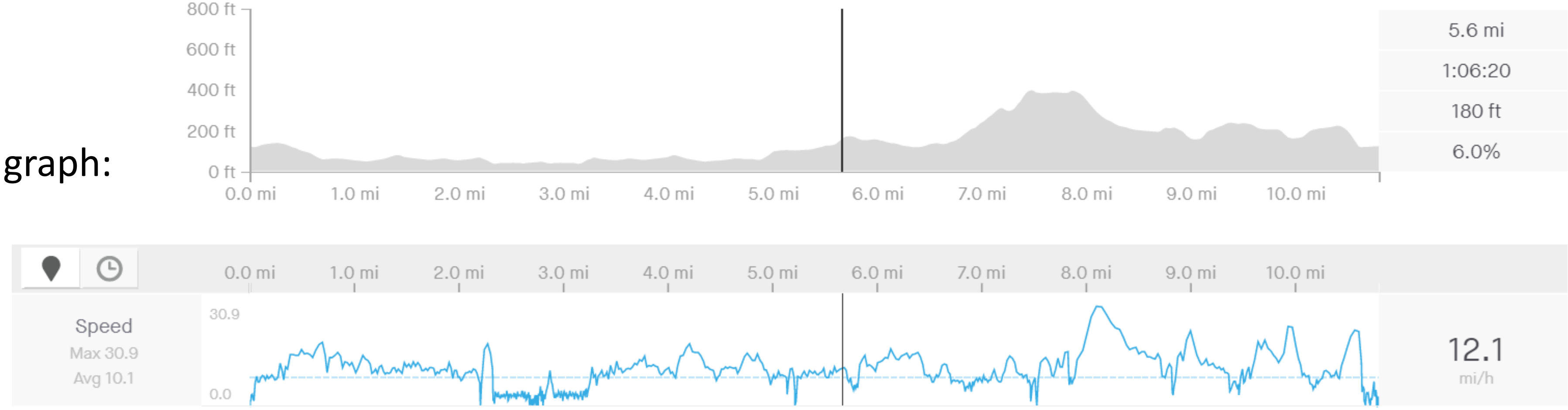
MATLAB CODE

- To find the best capacitors for the task MATLAB code was written to help out
- Based on:
  - Equations previously discussed
  - Known values
  - Distributer options
- Outputs:
  - Proper battery size
  - Number of capacitors needed
  - Wiring Array
  - Total Capacitance of the bank

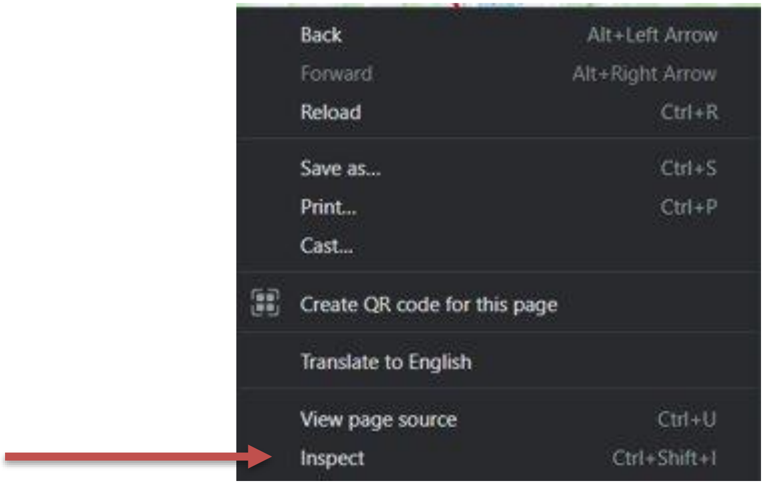
```
your weight(lb): 200
battery info
battery voltage: 48
rated current in: 5
power of the motor(W): 750
time needed to stop at rated current = 15.105306 seconds
battery capacity needed for 1/2 hr: 7.81
capacitancy needed = 3.146939 Farad
Capacitor info
capacitor's voltage: 2.7
capacitor's capacitance(F): 100
amount of capacitors needed = 18
parallel = 1
series = 18
capacitor bank: 48.60 volts, 5.56 Farad>>
```

DATA AQUISITION

- Real Bicycle Data
  - STRAVA app
- Displayed as a dynamic graph:
  - Distance
  - Time
  - Elevation
  - Percent Grade
  - Velocity
- Using “Inspect Element”
  - Data is found
  - Moved to Excel spread sheet
  - MATLAB can access that spreadsheet



[9]



ENERGY ALGORITHM

- Energy generated:
  - Only when the velocity is decreasing from one point to another
  - Takes into consideration the change in elevation

$$\underbrace{Energy_{Generated}}_{} = \underbrace{-\frac{1}{2}m\Delta v^2}_{\text{Kinetic Energy}} \underbrace{- mg\Delta h}_{\text{Potential Energy}}$$

  - Decrease in velocity or altitude means positive energy gain toward the KERS
  - Does not count the times when the bike slows going uphill

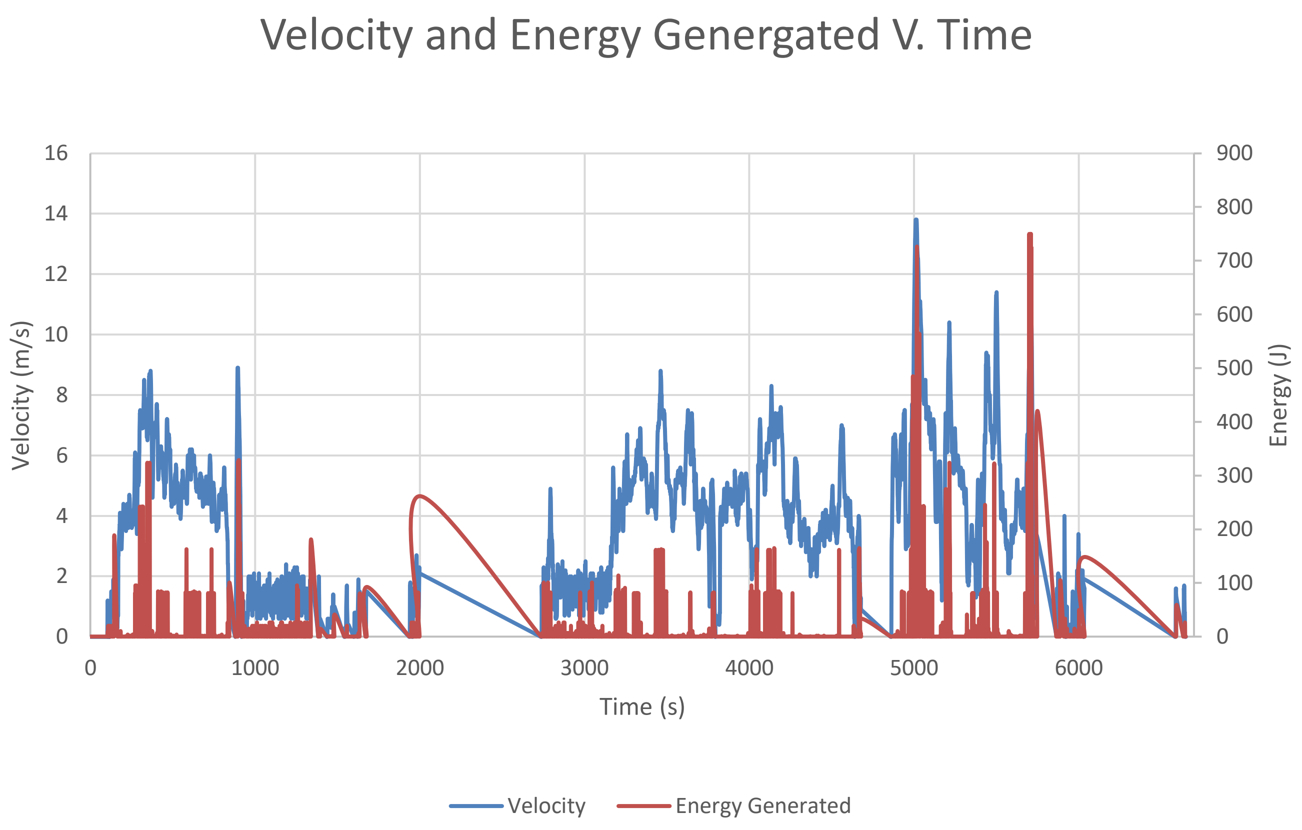
ENERGY ALGORITHM

- Energy Used
  - Only when the velocity is increasing from one point to another
  - Only when speeds are lower than 10 MPH
    - Assist from stop or speed below 10 MPH
  - Assumes rider is pedaling
    - Average person puts out 75 W on average [10]
  - Assist going up hill
    - Any percent grade greater than 9%
      - "Moderate Slope" [11]
  - $Energy_{Used} = \underbrace{\frac{1}{2}m\Delta v^2}_{\text{Kinetic Energy}} + \underbrace{mg\Delta h}_{\text{Potential Energy}} - \underbrace{75\Delta t}_{\text{Energy Produced by Rider}}$
- Energy cannot exceed the energy of the motor for either case
  - 750 W

ENERGY GENERATED

- Quick negative changes in velocity coincide with peaks in energy generated

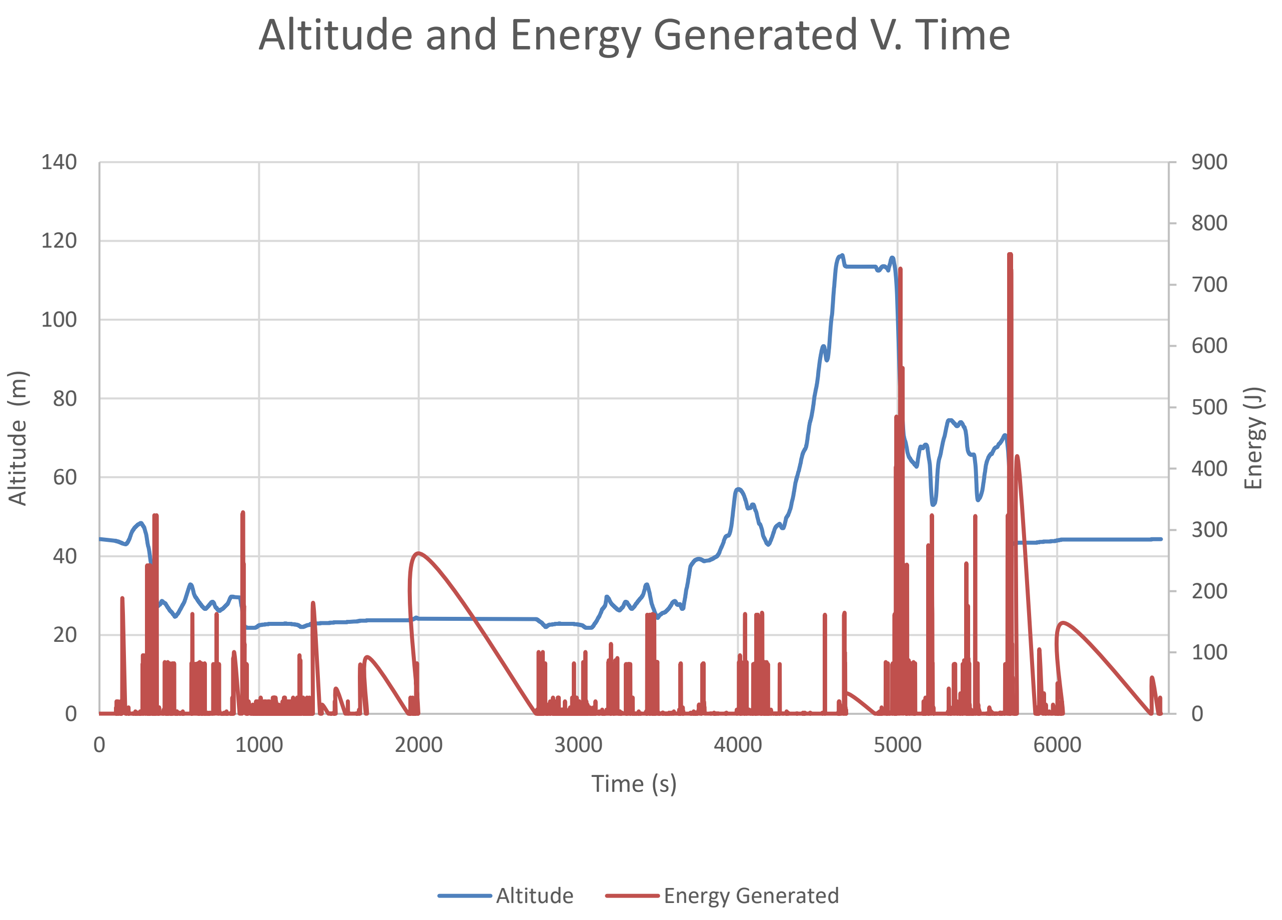
- Gradual slopes in velocity change show similar patterns



ENERGY GENERATED

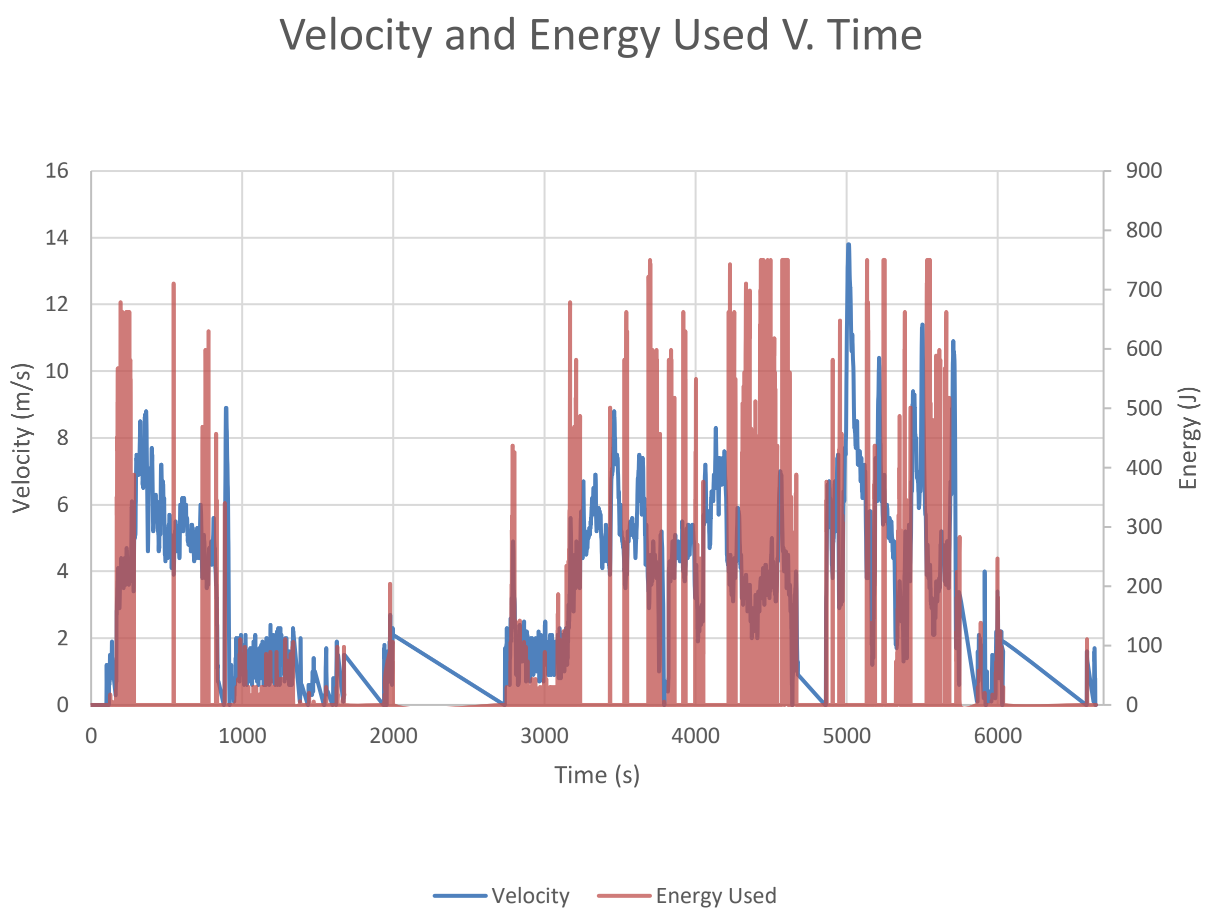
- Fast drops in altitude coincide with peaks in energy generated

- Using brakes to maintain/slow speed downhills



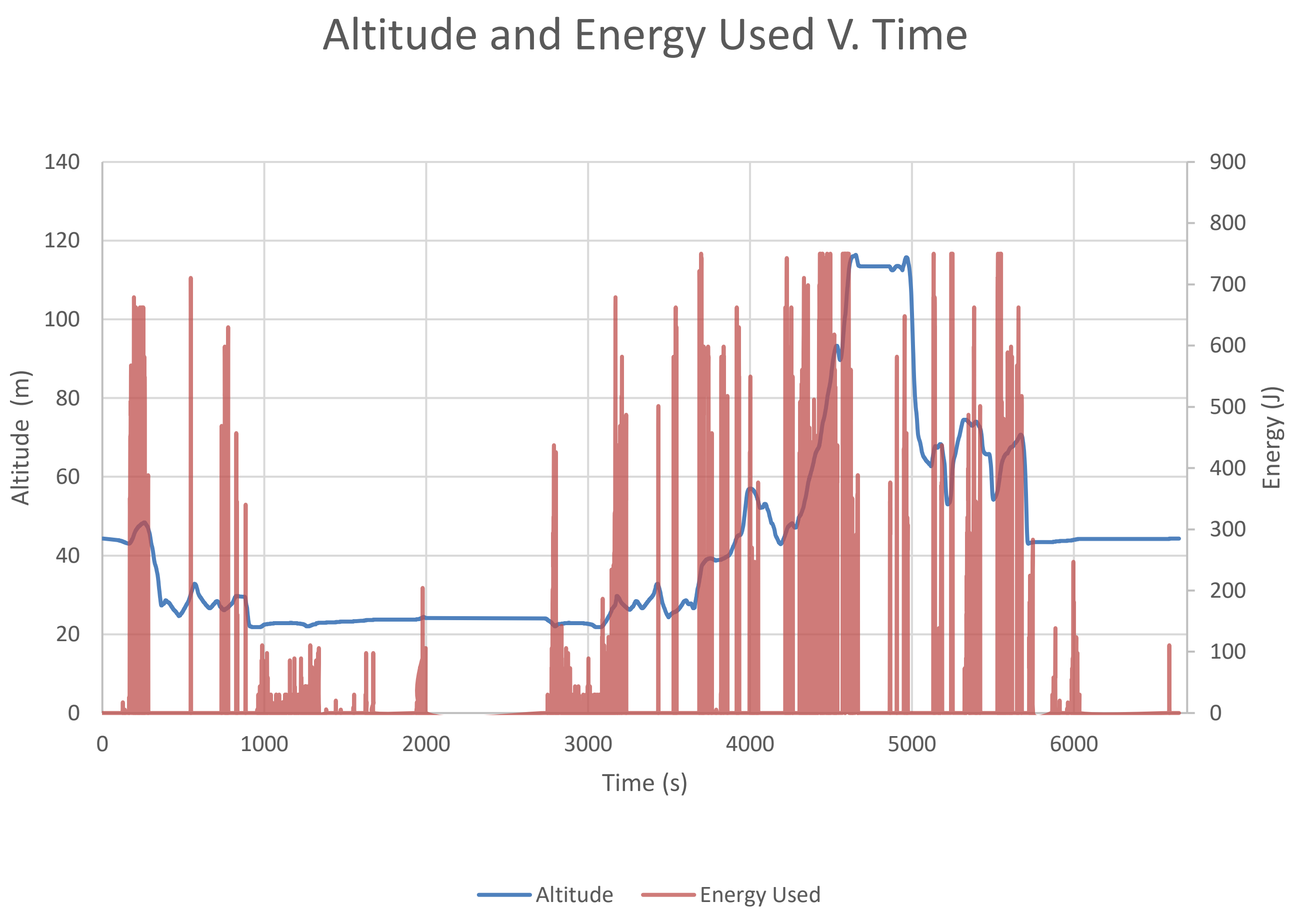
ENERGY USED

- Energy used coincides with positive changes in velocity
- Motor is used to assist from a stop or slow speed

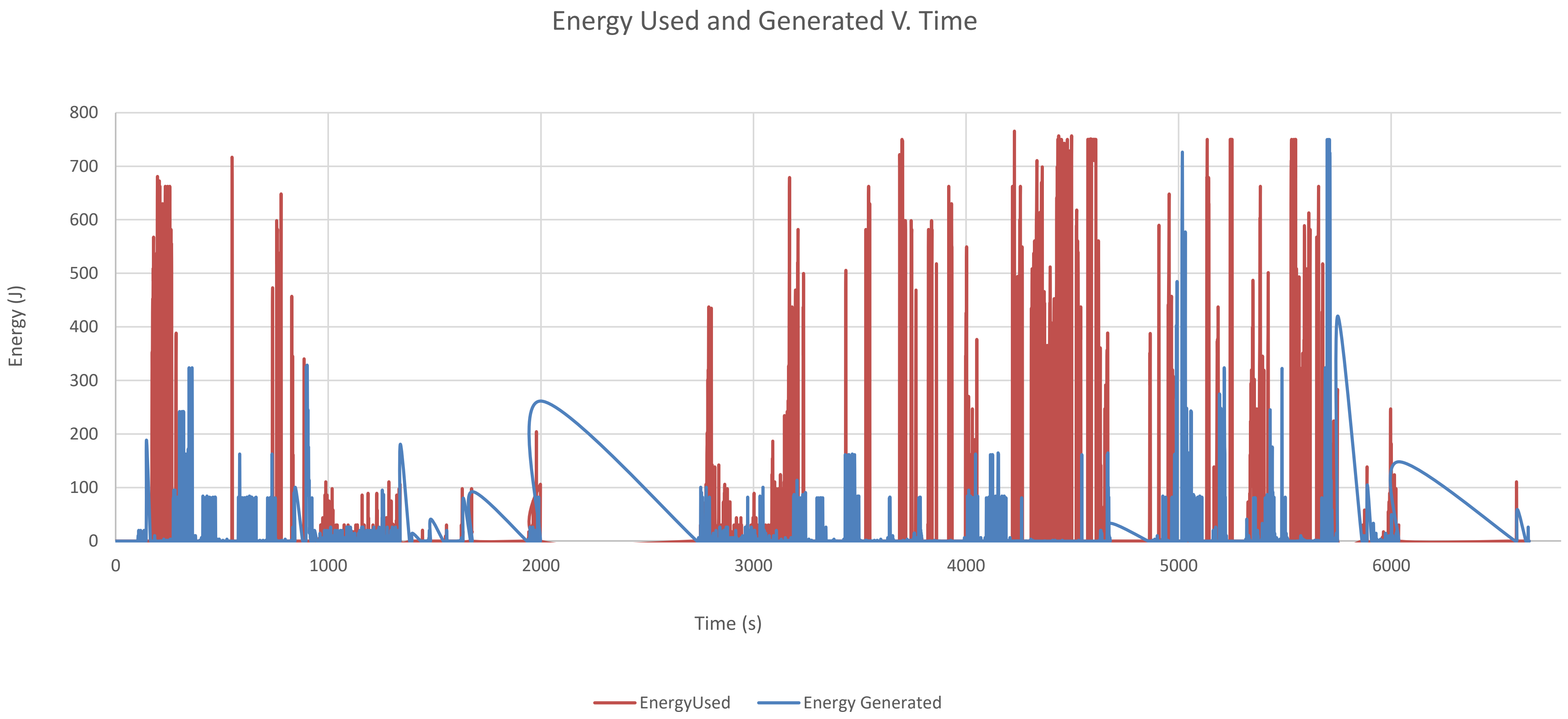


ENERGY USED

- Peaks in energy used coincide with moderately steep hills
- Motor is used to assist rider going uphill



COMPARISON

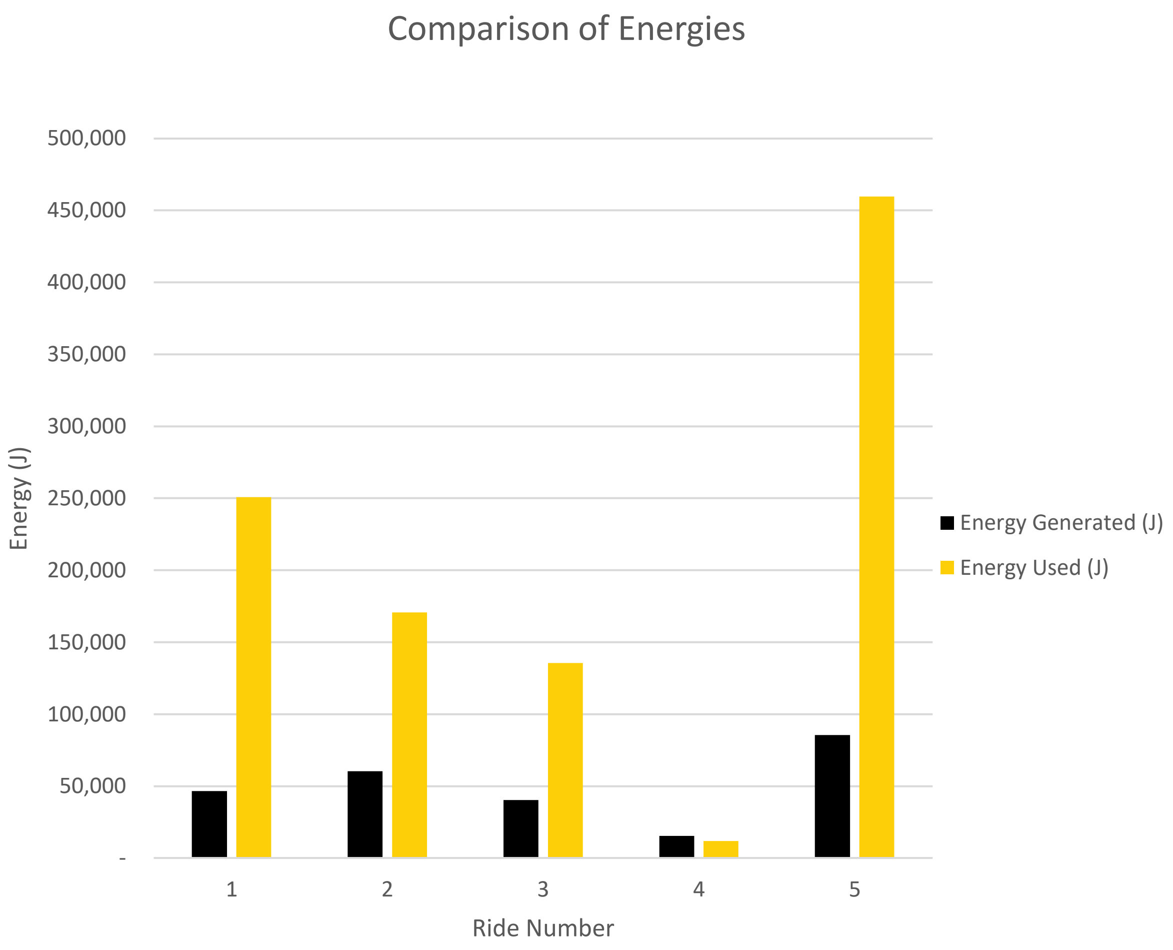


Energy Used and Generated V. Time
Energy (J)
800
700
600
500
400
300
200
100
0
0
1000
2000
3000
4000
5000
6000
Time (s)
EnergyUsed
Energy Generated

COMPARISON

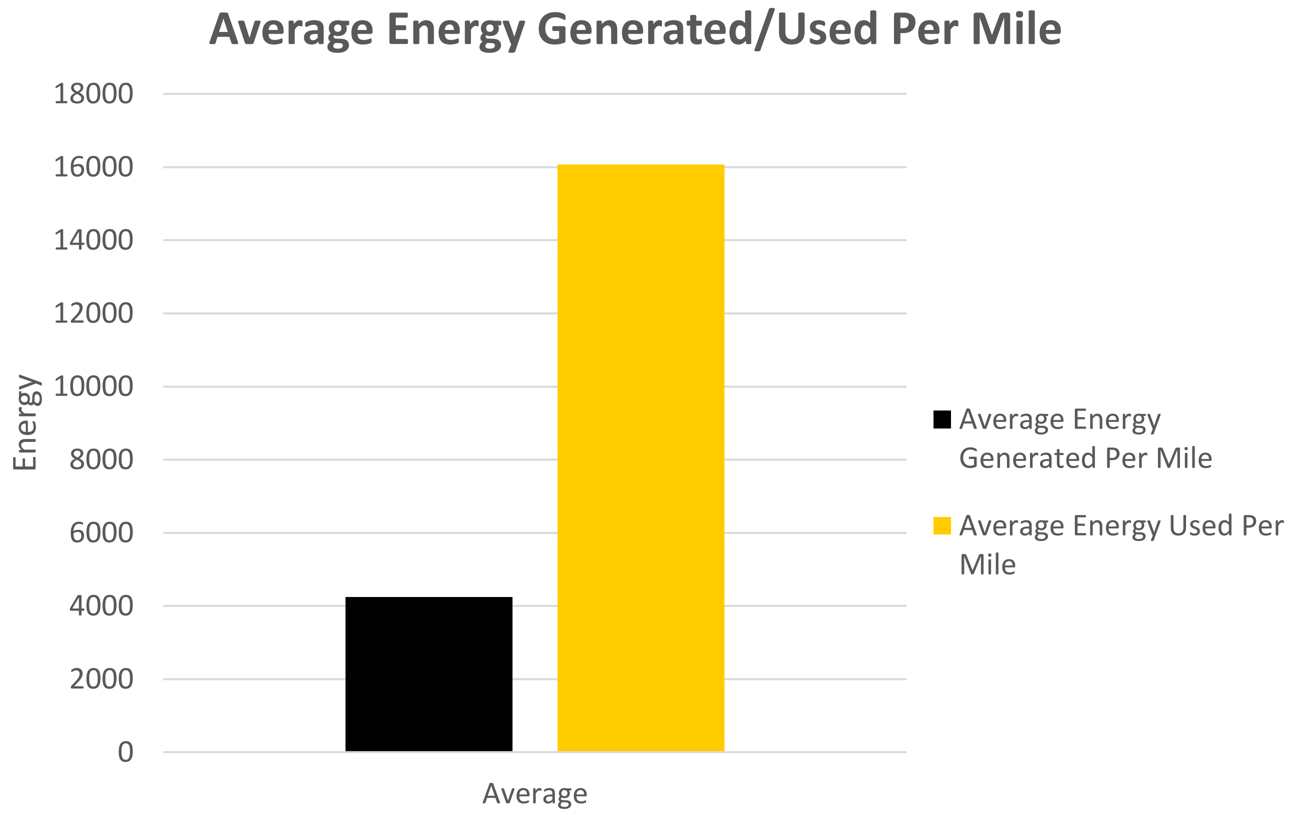
Ride	Energy Generated (J)	Energy used(J)	Efficiency of Ride
1	46,530.51	250,862.84	18.55%
2	60,325.51	170,791.88	35.32%
3	40,392.93	135,630.21	29.78%
4	15,450.99	11,815.58	130.77%
5	85,405.26	459,581.98	18.58%

Ride	Total Energy In Battery (J)	Energy Generated Percent of Total Battery	Energy Used Percent of Total Battery
1	1,728,000	2.69%	14.52%
2		3.49%	9.88%
3		2.34%	7.85%
4		0.89%	0.68%
5		4.94%	26.60%

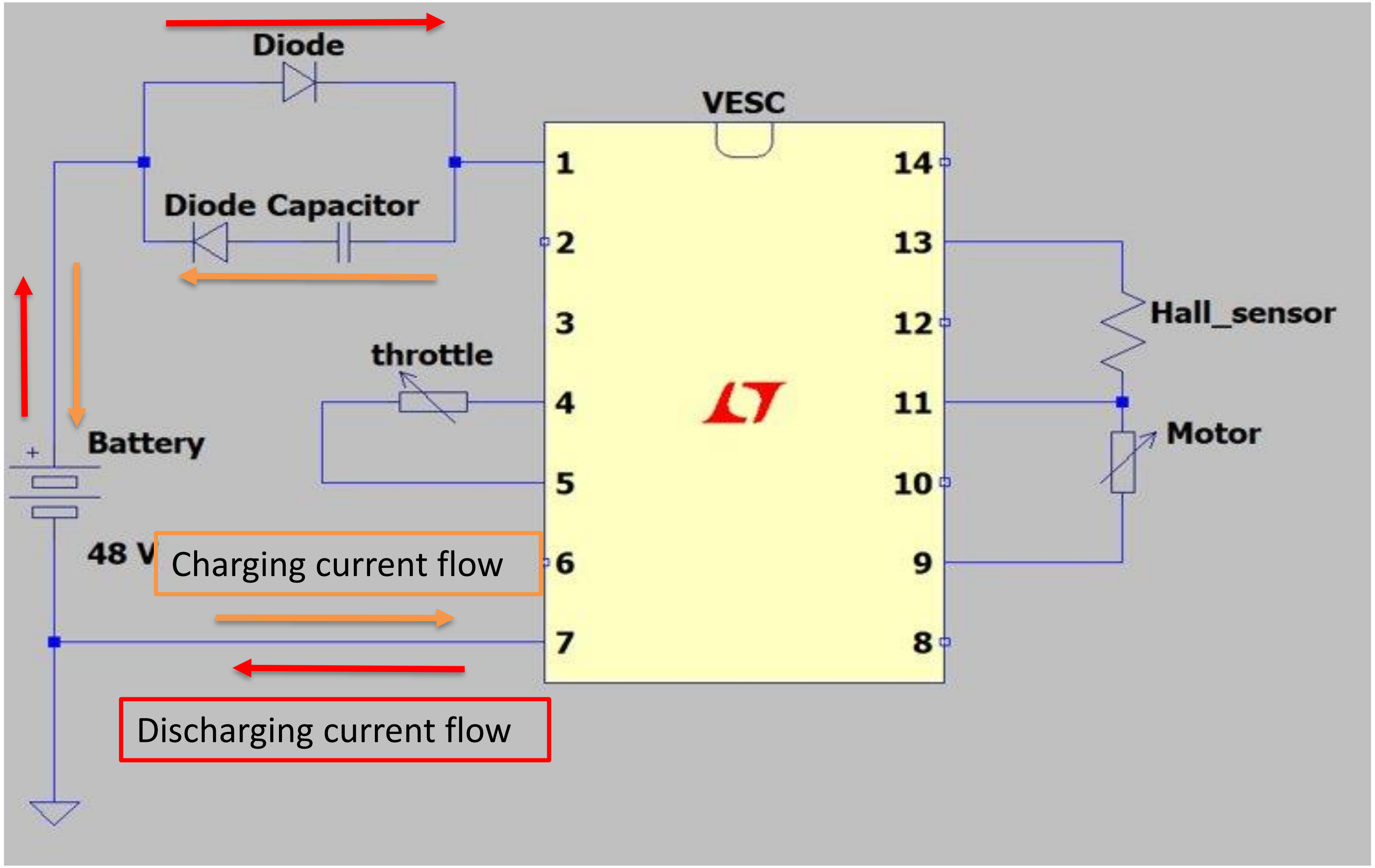


COMPARISON

Ride	Energy Generated Per Mile (J/mi)	Energy Used Per Mile (J/mi)
1	4,308.50	23,228.67
2	5,752.87	16,287.36
3	3,142.19	10,550.76
4	2,818.82	2,155.59
5	5,224.70	28,115.09
Average	4,249.41	16,067.49
Average Efficiency	26%	



ELECTRICAL SCHEMATIC: DYNAMIC BRAKING SYSTEM



AUTOMATIC GEARING SYSTEM:

EDWARD, ENOCH AND SIN TSAN

AUTOMATIC GEARING SYSTEM INTRODUCTION

ELECTRICAL SCHEMATIC

CADENCE SENSOR

SHIFTING SYSTEM

SHIFTING SPEEDS

AUTOMATIC GEARING SYSTEM

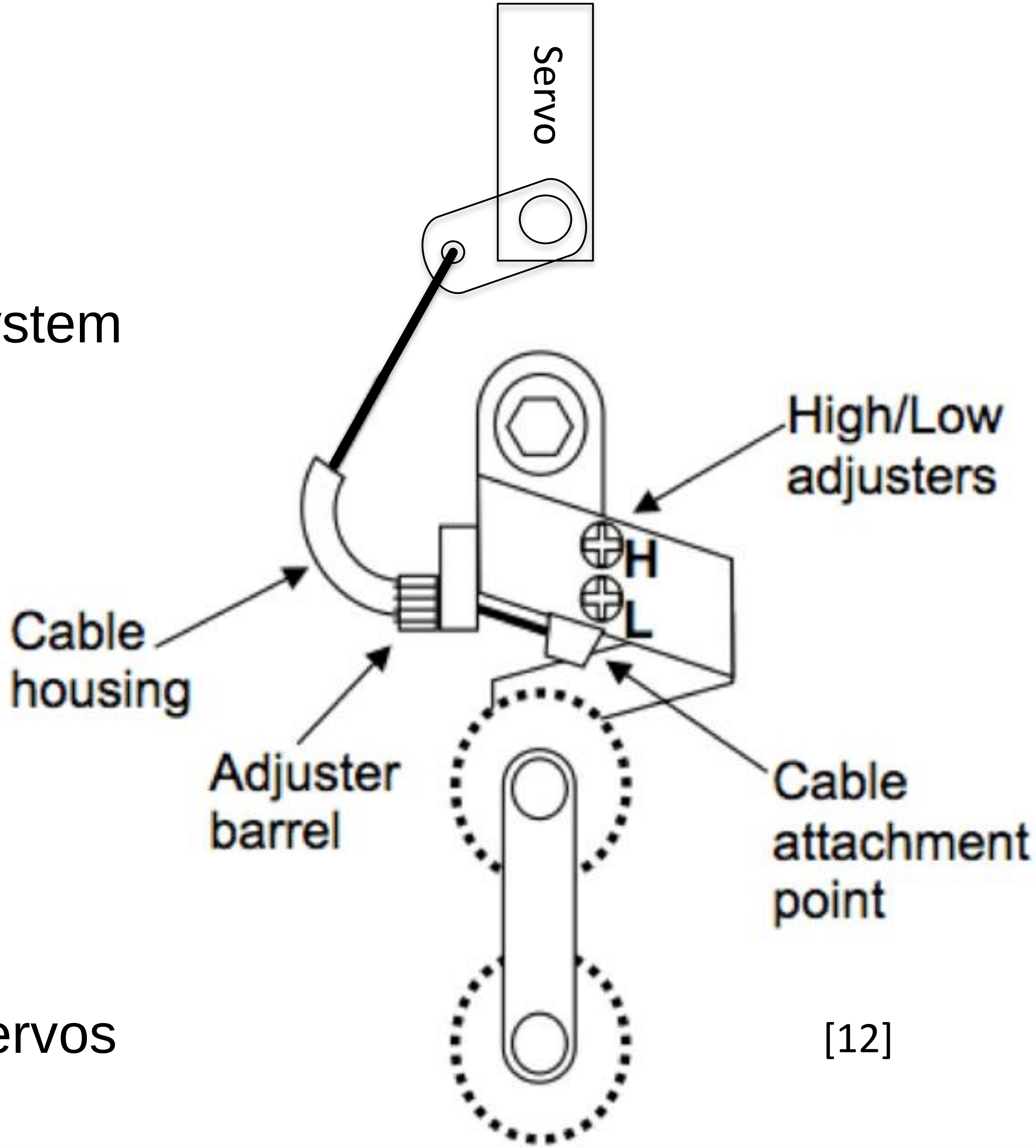
- Arduino based system
    - Independent battery
- Varies gear sizes dependent on speed of system
    - Derailleur cable controlled by servo

Cadence Sensor

- Measures speed of rotating wheel

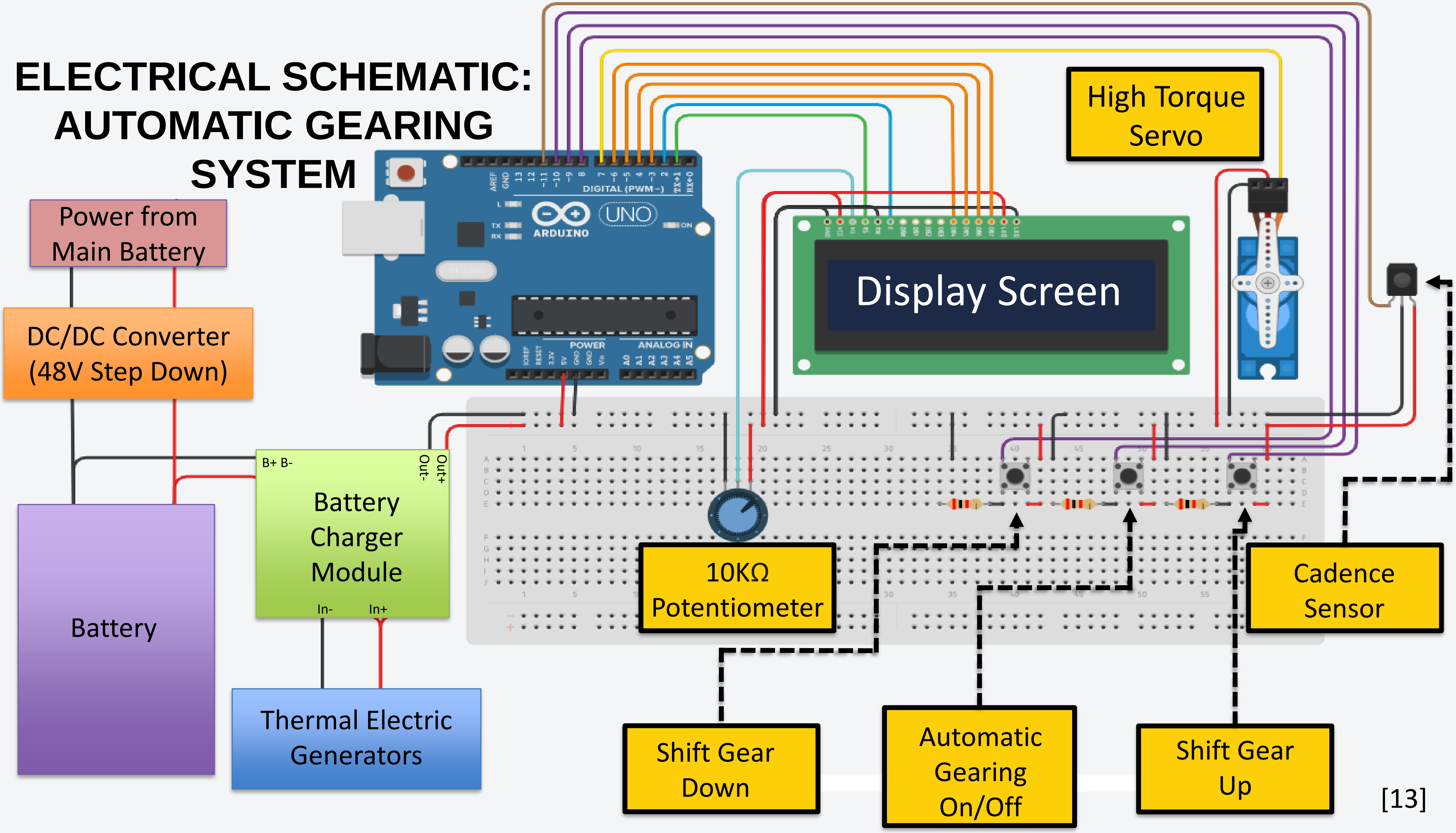
High Torque Servo

- Motor able to actuate in degrees
- Metal gears are more resistant to slippage
- Higher torque output than average hobby servos



[12]

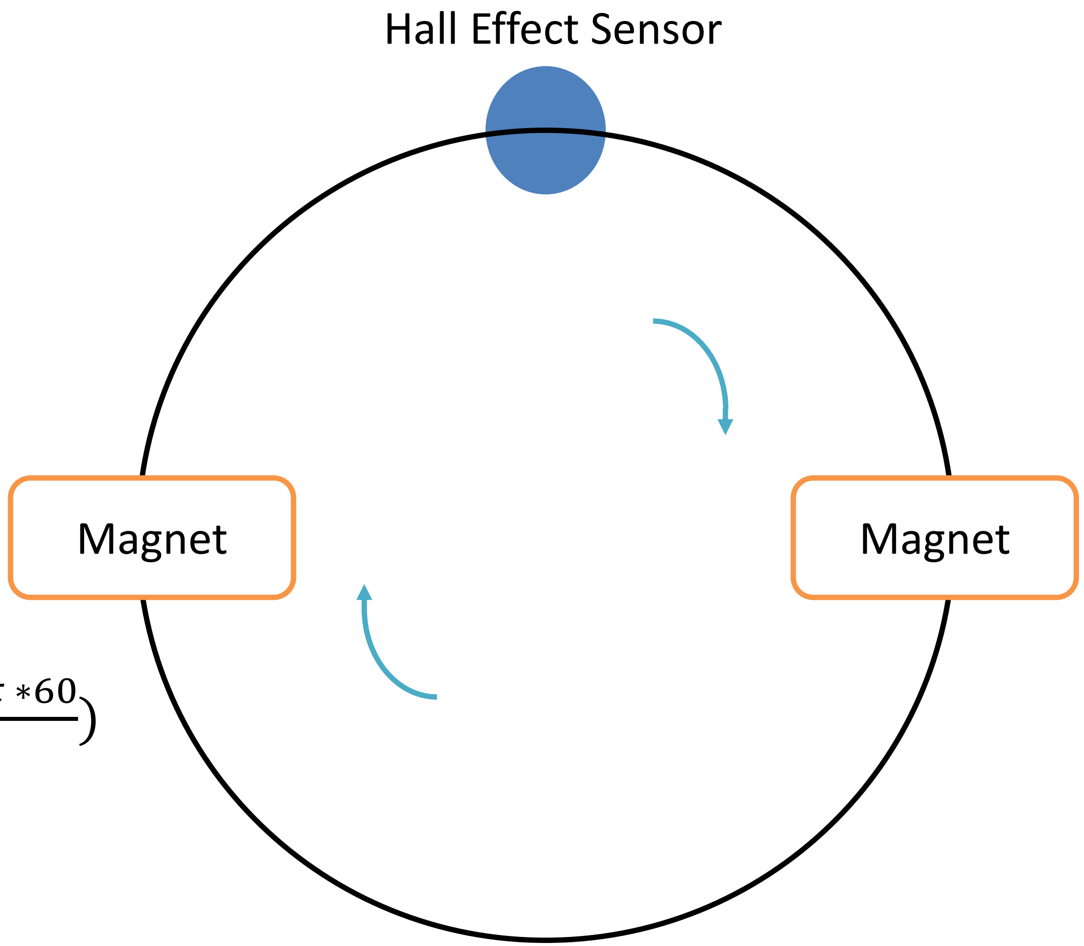
ELECTRICAL SCHEMATIC: AUTOMATIC GEARING SYSTEM



[13]

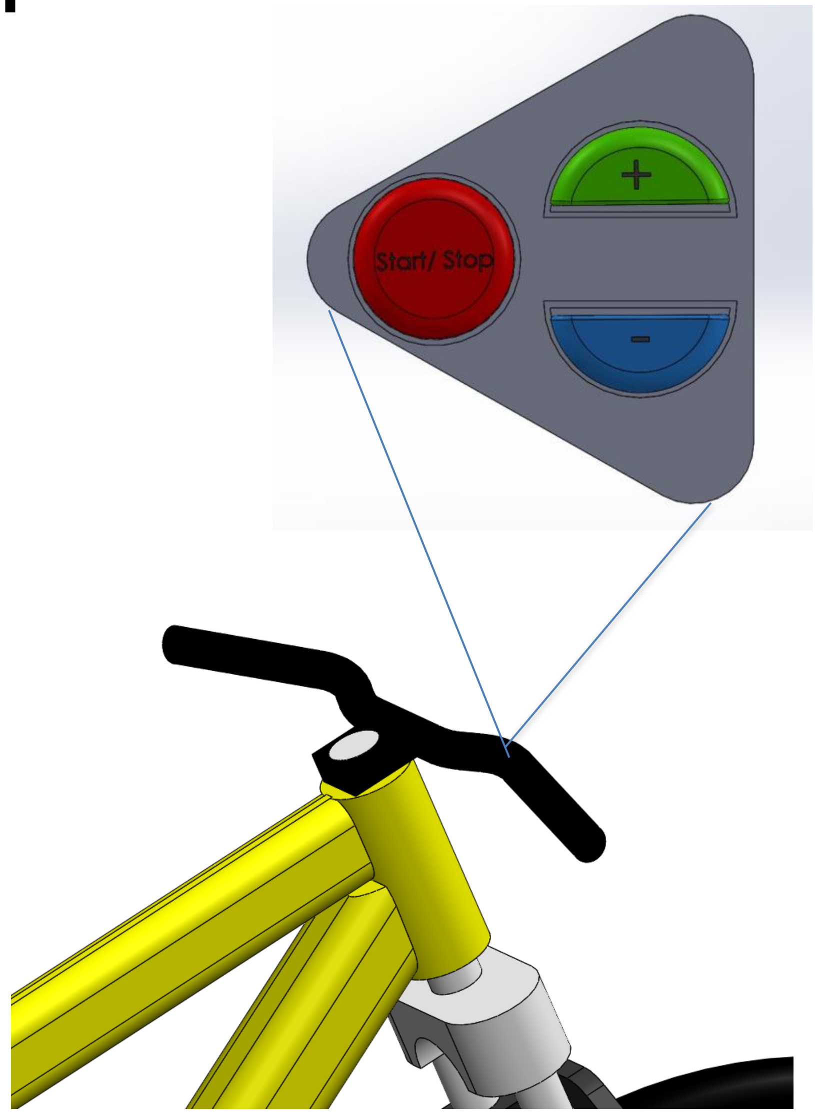
AUTOMATIC GEARING SYSTEM: CADENCE SENSOR

- Uses Hall Sensor
    - Non Latching
        - Measures changes in magnetic state
        - Magnets on rear wheel
    - High Sensitivity
        - Able to measure high speeds
- Measures in half revolutions
    - Returns revolutions per minute (RPM)
    - $Speed\ (MPH) = \frac{Rotations}{min}\left(\frac{Wheel\ Diameter * \pi * 60}{63360}\right)$



AUTOMATIC GEARING SYSTEM

- Each gear is designated a degree on the servo
- Two modes
  - Manual Shift
    - Takes input from buttons to change gears
  - Automatic Shift
    - Shifts each gear when it is in the range of a specified speed
    - Pauses the system to shift
    - Includes Manual Shift



AUTOMATIC GEARING SYSTEM

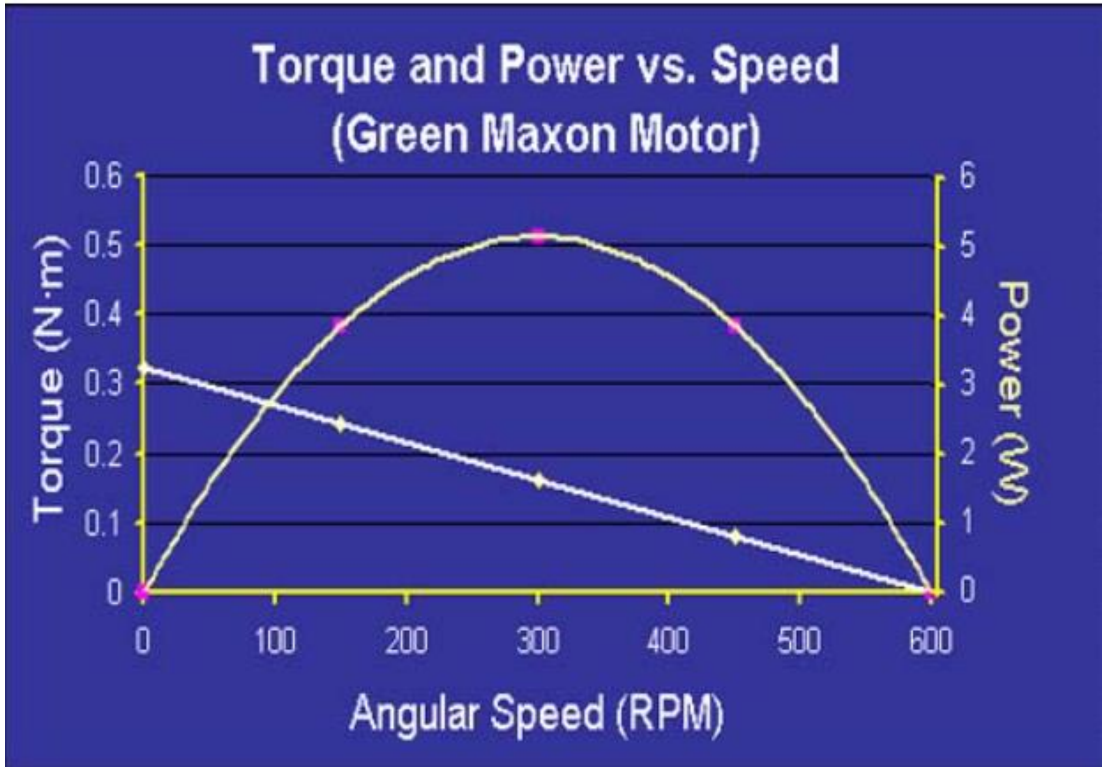
$$GR = \frac{\#\ of\ Teeth_{\ gears}}{\#\ of\ Teeth_{\ motor}}$$

$$\tau_{stall_{gear}} = \frac{\tau_{stall_{motor}}}{GR}$$ [14]

$$\omega_{no\ load_{gear}} = \omega_{no\ load_{motor}} * GR$$ [14]

$$\tau = \tau_{stall_{gear}} - \frac{\omega * \tau_{stall_{gear}}}{\omega_{no\ load_{gear}}}$$ [14]

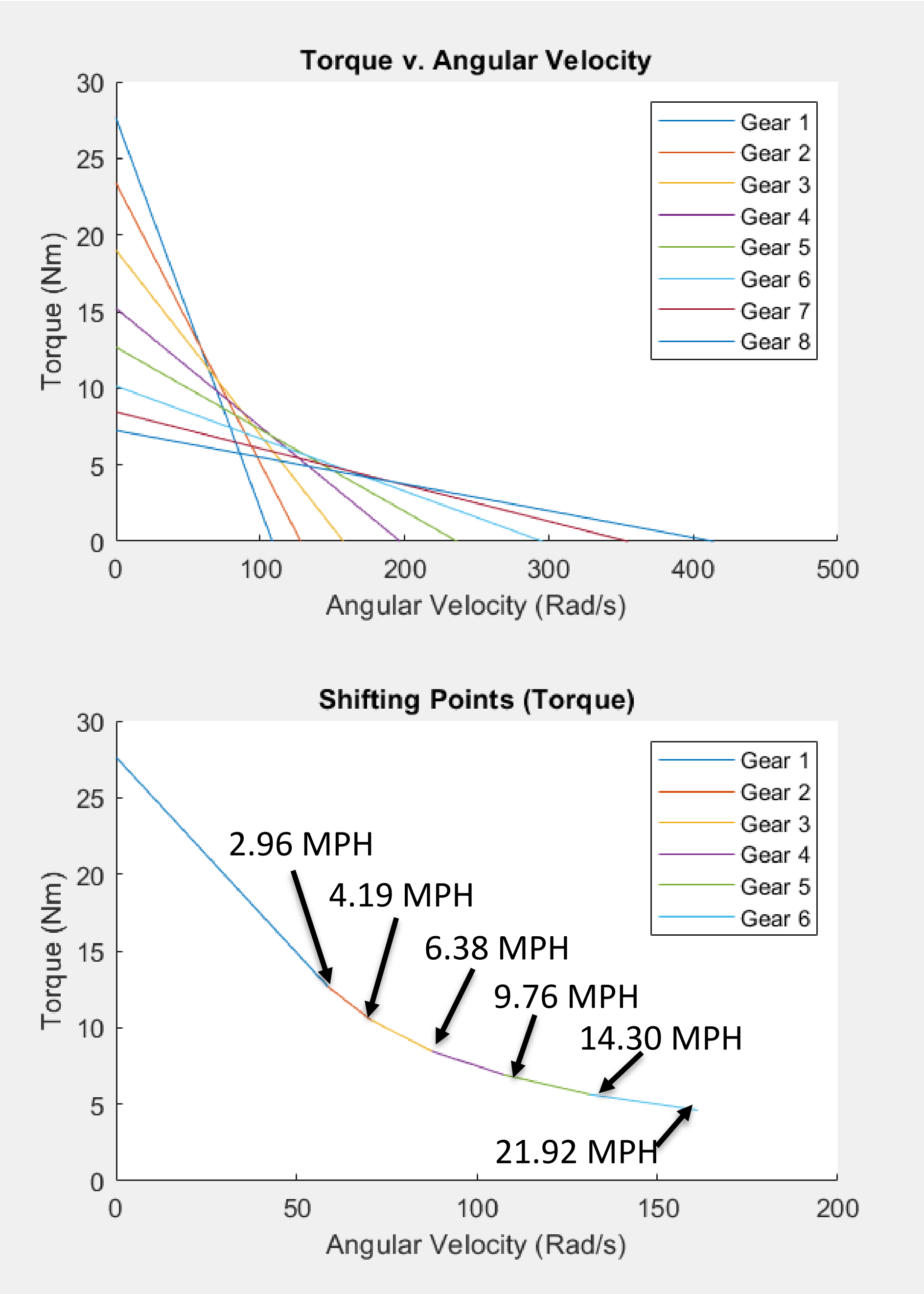
$$P = (\tau_{stall_{gear}} * \omega) - \frac{\omega^2 * \tau_{stall_{gear}}}{\omega_{gear}}$$ [14]



[14]

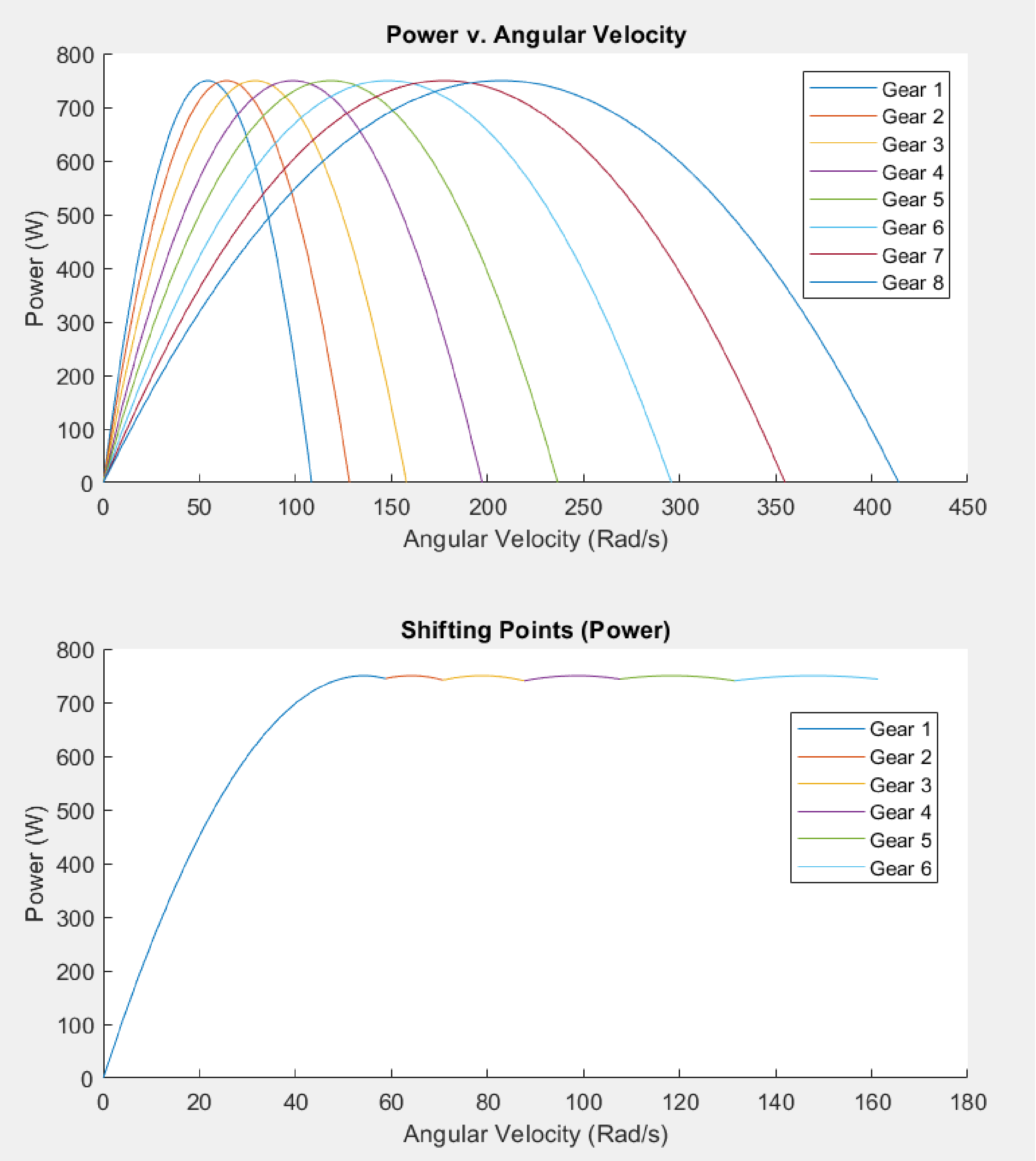
AUTOMATIC GEARING SYSTEM

- Shifting point = intersecting point
  - Reduce shift shock
- Limit to 6th gear
  - California Standard Regulation (<20mph)
  - $\omega_{motor} = 1358\, rpm = 21.92 MPH$



AUTOMATIC GEARING SYSTEM

- Speeding up from 0 to 20MPH
  - Power max all time
  - High efficiency



THERMAL ELECTRIC GENERATOR:
CLAUDIO

INTRODUCTION TO THERMAL ELECTRIC GENERATORS

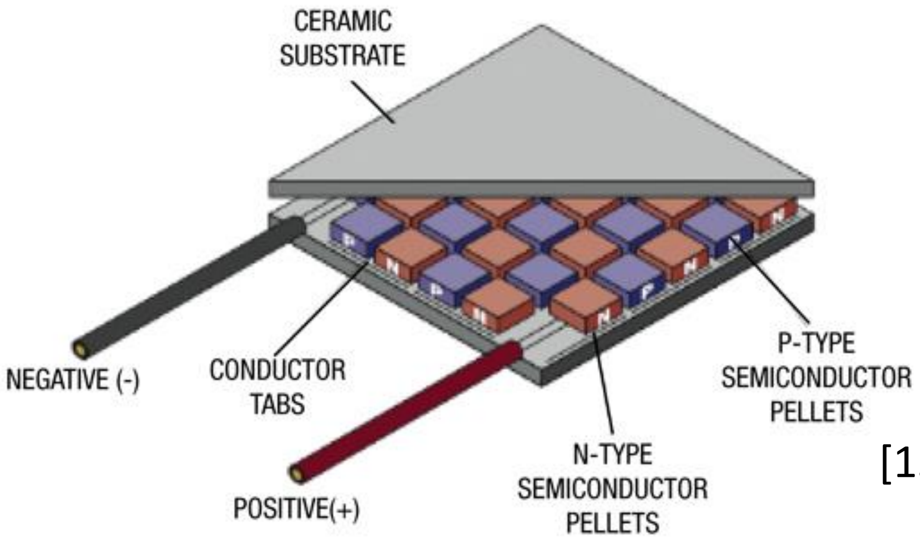
COMPONENT SELECTION

ASSEMBLY

HOW IT WORKS

Thermoelectric generators work by using a temperature difference between plates to convert into electrical energy.

Place along casing in along with heat sink in order to create a larger temperature difference.



[15]

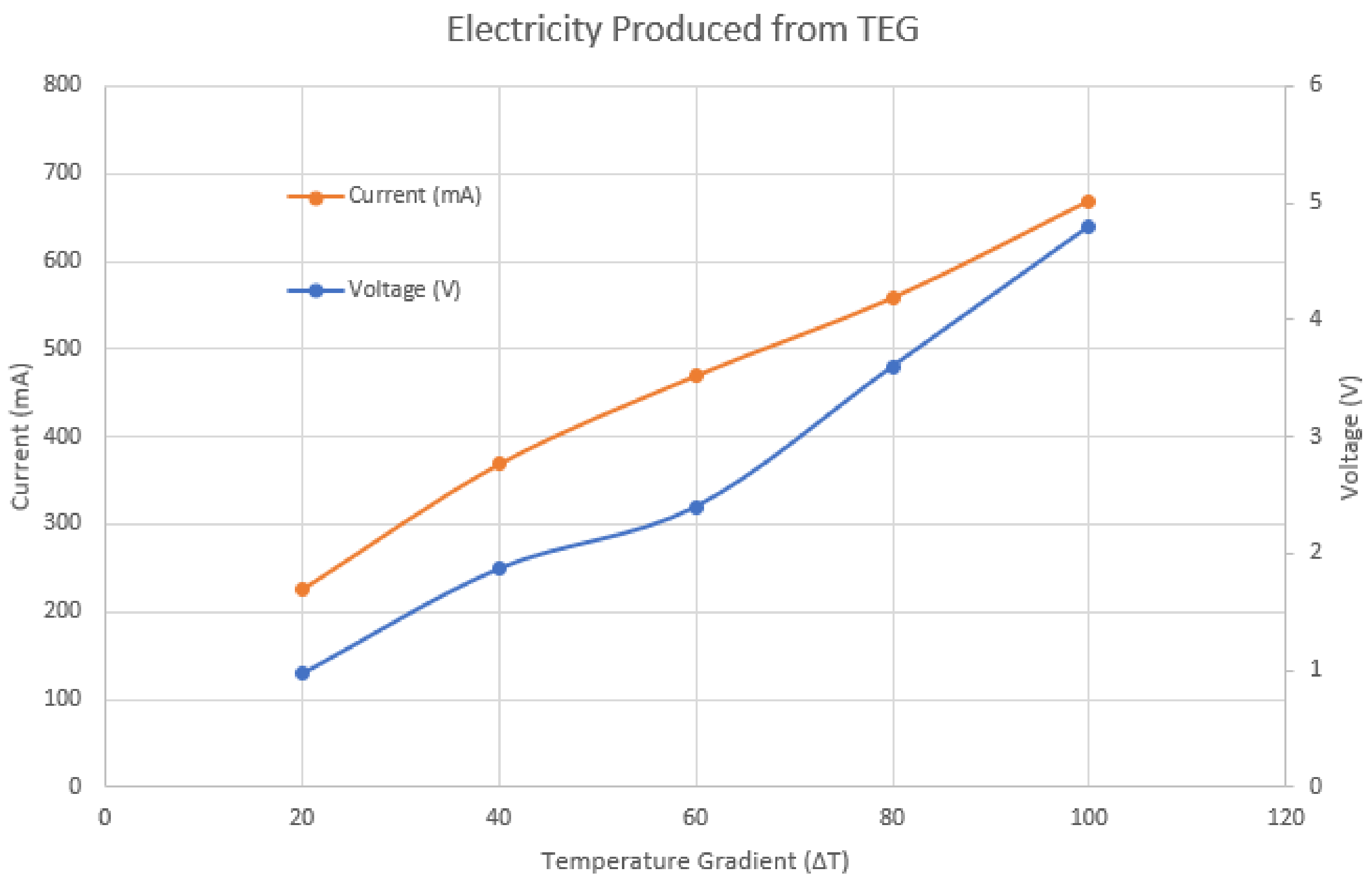
THERMOELECTRIC

- I = -αSdT [16]

α= local conductivity

S = Seebeck coefficient

Dt=temperature gradient



HEAT SINK

$$\dot{Q} = hA_s(T_s - T_\infty)$$

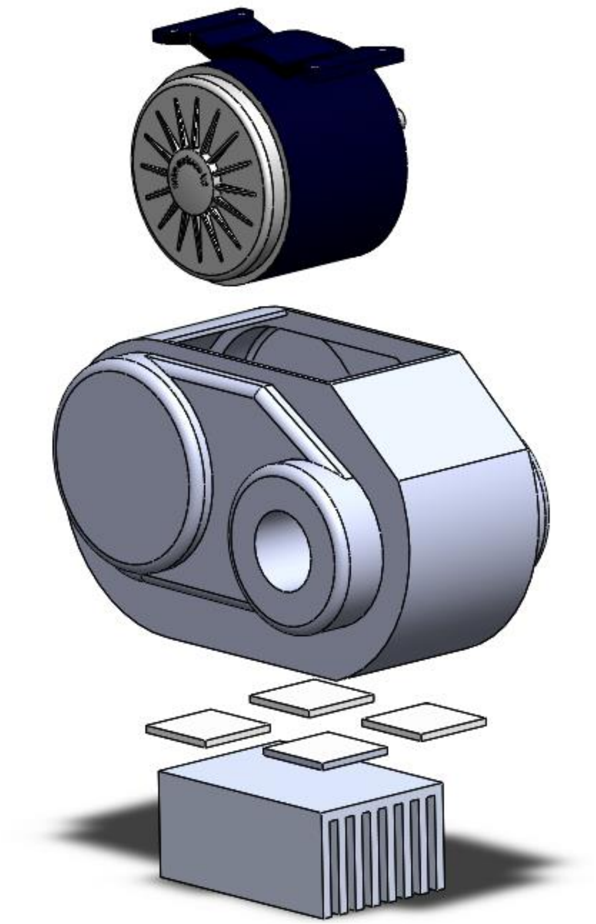
$$\dot{Q} = 62\, {}^{W}/_{m^2 * k}\, (0.0505\, m^2)(80℃ - 27℃)$$

$$\dot{Q} = 165W$$

$$A_s = \frac{\dot{Q}}{h(T_s - T_\infty)}$$

$$A_s = \frac{165W}{62\, {}^{W}/_{m^2 * k}\, (75℃ - 27℃)}$$

$$A_s = 0.055m^2$$



BICYCLE DESIGN:
CLAUDIO

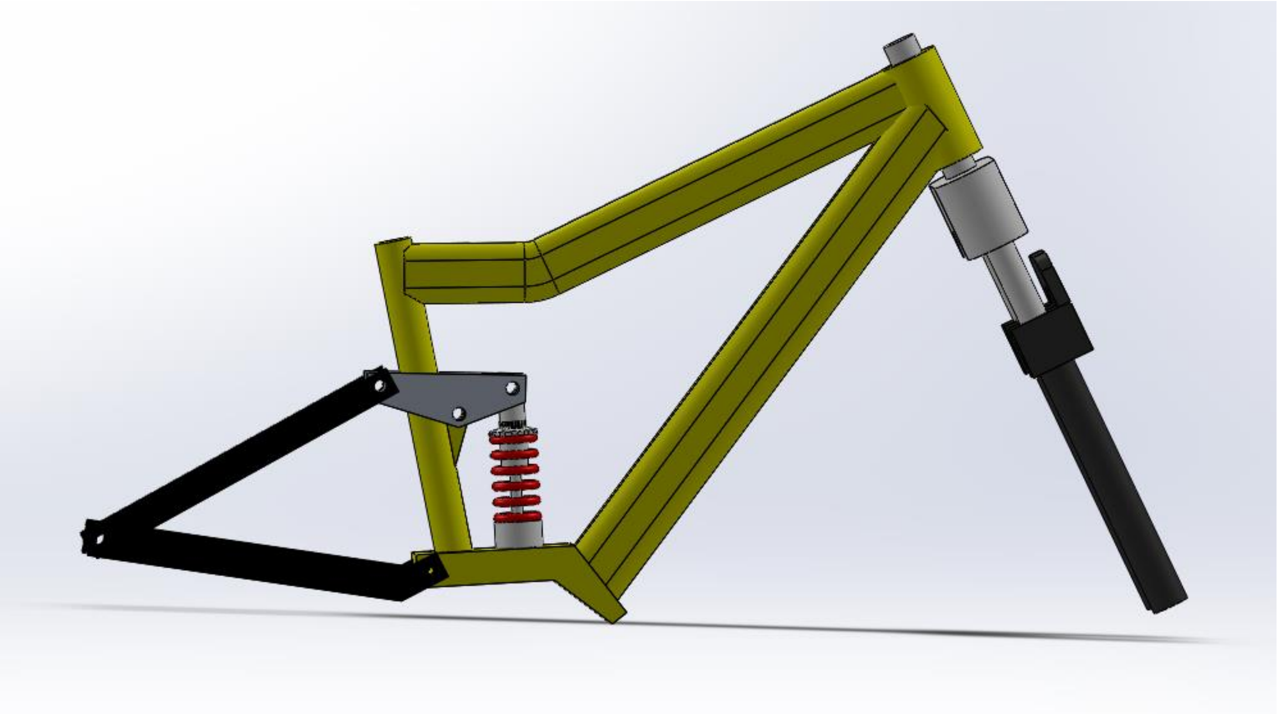
SUSPENSION SYSTEM

DESIGN

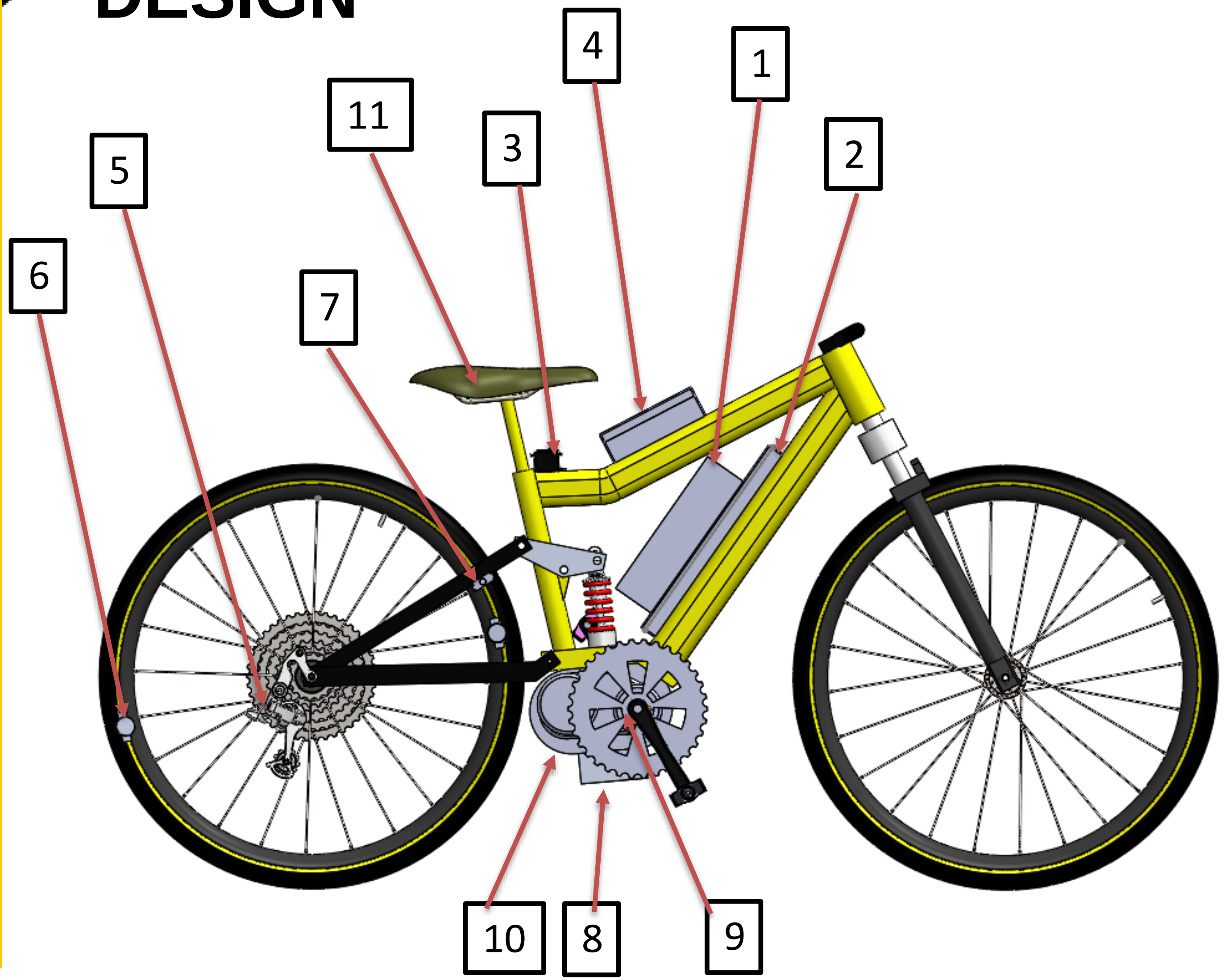
SUSPENSION SYSTEM

Full Suspension

- Better handling
- Ride smoother
- Handle variety of terrain



DESIGN



1. Battery
2. Capacitor Bank
3. High Torque Servo
4. Arduino Case
5. Derailleur
6. Magnets
7. Cadence Sensor
8. Heat Sink
9. Freewheel
10. Motor
11. Adjustable Seat

SUMMARY: EDWARD

CONCLUSION

CONCLUSION

- Fixed the problem of the limited charging current
  - Using a supercapacitor bank
  - Battery Management System
  - 26% Energy Recovery on average
- Created an Automated Gearing System
  - Most comfortable ride possible with no extra work
  - More efficient system
  - Maximum speed of 20 MPH
- Bicycle Designed on SolidWorks

REFERENCES

[1] BYJUS, "Difference Between Motor and Generator," BYJUS, 2020. [Online].

Available: https://byjus.com/physics/difference-between-motor-and-generator/.

[Accessed December 2020].

[2] "What is Hall Effect and How Hall Effect Sensors Work", https://www.youtube.com/watch?v=wpAA3qeOYil

[3] Lasantha, "Derivation of Kinetic energy formula and worked examples," scienceuniverse, 2012.

[4] “Capacitors and capacitance (video),” *Khan Academy*. [Online]. Available: https://www.khanacademy.org/science/physics/circuits-topic/circuits-with-capacitors/v/capacitors-and-capacitance. [Accessed: 07-Dec-2020].

[5] S. R. Aneeya K Samantara, "Materials Development for Active/Passive Components of a Supercapacitor: Background, Present Status and Future Perspective," 2018.

[6] Kunray, "Kunray 48V 750W DC Brushless Mid Drive Motor, Electric Motorcycle Motor, BLDC Motor Kit with Speed Controller, E-Motorcycle, Dirt Bike Tricycle E-Bike Conversion Kit 2800RPM," AMAZON, 2021.

REFERENCES

[7] BtrPower, "BtrPower 36V 48V Ebike Battery,10AH Lithium ion Battery Pack with 3A Charger and BMS for Electric Bike,Scooter,Motorcycle,250W 350W 500W 750W Motor," AMAZON, 2021.

[8] Banggood, "3pcs 2.7v100f Super Capacitor 2.7V 100F Farad Capacitor," Banggood, 2021.

[9] STRAVA, "Morning Ride: Sunday, December 20, 2020," STRAVA, 2020.

[10] T. B. I. EUGENE A. AVALLONE, Marks' Standard Handbook for Mechanical Engineers, McGRAW-HILL, 1996.

[11] Barcelona Field Studies Centre, "Slope Steepness Index," geographyfieldwork.com, Barcelona, 2020.

[12] C. Nodder, "Shifting adjustment," Bike Boo Boos, 2012.

[13] A. Tinkercad, "Circuit Design," Tinkercad, 2020.

[14] M. Page, "Understanding D.C. Motor Characteristics," MIT: Center for Innovation in Product Development, 1999.

[15] D. Scansen, "Thermoelectric Energy Harvesting," Digi-Key Elelectronics, 26 10 2011. [Online]. Available: https://www.digikey.com/en/articles/thermoelectric-energy-harvesting. [Accessed December 2020].

REFERENCES

[16] A. B. J. M. B. M. F. T. M. I. Nesrine Jaziri, "A comprehensive review of Thermoelectric Generators: Technologies and common applications," Energy Reports, vol. 5, 2019.