TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PURWANCHAL CAMPUS

A REPORT
ON
STUDY AND FABRICATION OF PROTOTYPE OF REGENERATIVE BRAKING SYSTEM

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CERTIFICATE

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ABSTRACT

This project report presents a study and fabrication of prototype of Regenerative Braking System (RBS). During braking huge amount of energy is lost to atmosphere in the form of heat. It will be good if we could recover some of this energy somehow which is otherwise getting wasted out. This project report shows that, instead of surplus energy of the wheel being wasted as unwanted heat during braking, the motor act as a generator and recover some of it in the form of electricity. A mechanical system is chosen to eliminate losses related to energy conversion while capturing the rotational braking energy. The prototype of Regenerative Braking System consists of a wheel (mass=1.2kg, radius of gyration 0.2m) for the mechanical energy and a chain-sprocket drive for the transmission component and a DC motor (12V, 0.2Amp) for energy generation during braking. The results and calculations showed that prototype can function properly, that means it can recover some of the energy in the form of electricity during braking. It was observed that about 4% of energy can be recovered by the prototype of RBS when brake is applied to the flywheel rotating at the speed of 185rpm. The testing and result of our prototype shows that the overall effectiveness of the RBS improves with increasing rotational speed of the wheel and with increasing stopping/braking time. From the results, it was inferred that using the RBS concept can have a significant impact in recycling wasteful braking energy and produce electricity.

Keywords: Regenerative Braking System; Braking Energy; DC Motor as a Generator; Wheel

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LIST OF SYMBOLS

r	Wheel radius
P	Power
I	Current
V	Voltage
I_w	Moment of inertia of the wheel
ω	Angular velocity of the wheel
α	Angular acceleration of the wheel
T	Torque
N	Angular Speed (rpm)

LIST OF ABBREVIATION

CAD	Computer Aided Design
CVT	Continuously Variable Transmission
DC	Direct Current
ESS	Energy Storage System
EPA	Environmental Protection Agency
EV	Electric Vehicle
ECU	Electronic Control Unit
f-RBS	flywheel based Regenerative Braking System
HPA	Hydraulic Power Assist
HEV	Hybrid Electric Vehicle
HRB	Hydrostatic Regenerative Braking
ICE	Internal Combustion Engine
IGBT	Insulated Gate Bipolar Transistor
IOE	Institute of Engineering
KE	Kinetic Energy
LUV	Light Utility Vehicle
MSC-ADAMS	Microsoft Software Corporation Automated Dynamic Analysis of Mechanical Systems
NEDC	New European Driving Cycle
PWM	Pulse Width Modulation
RBS	Regenerative Braking System
SAE	Society of Automotive Engineers
US	United States
VSE	Vehicle State Estimator

CHAPTER I: INTRODUCTION

1.1 Project Introduction

The subject of Final Year Project, Study and Fabrication of prototype of Regenerative Braking System is a research and related scientific fields of study at the Faculty of Mechanical Engineering that is provided by final year students to fulfill the requirement. Under this subject, we were supervised by a lecturer and doing research regarded to the topic that has chosen.

The purposes of this project is to train and improve a students' ability to use knowledge and experience in related field of engineering. We were able to carry out research through scientific methods such as scientific research, collect and analyze data and produce a design or product. We were able to handle work with supervision and then independently in this final year project.

1.2 Background

Study and Fabrication of Prototype of Regenerative Braking System (RBS) is our project title. As we know, RBS is not the new technologies that exist at present. RBS was first used in the locomotive industry. Due to the lack of sophisticated technological knowledge on suitable battery power storage, therefore RBS attracted less interest and further study of this system is also suspended. Nowadays, pollution problems and the limited fuel resources for vehicles have made the RBS back to become an important system for future vehicles. RBS can reduce air pollution and fuel consumption[1].After understanding the importance of this RBS, we decided to study and design the prototype of Regenerative Braking System. In general, RBS is a system that can recuperate mechanical energy to electrical energy during braking action. This system allows the vehicle kinetic energy to be converted into electrical energy and be stored in the power storage system. This saved energy will be used again to move the vehicle.

Our final objectives are to convert the kinetic energy of rotating wheels into electrical energy during braking and to recover that braking energy to charge the battery. So, a DC motor will be assembled in the wheels. DC motor is used as brakes which convert the mechanical energy into electrical energy.

1.3 Problem Statement

At the 21th century, the automotive industry has post a great challenge in order to reduce the vehicle fuel consumption and emission, these is due to the shortage of fuel resources and worsen air pollution problem. According to figures released by the US Environmental Protection Agency (EPA), conventional ICE vehicles currently contribute 40-50% of ozone, 80-90% of carbon monoxide, and 50-60% of air toxins found in urban areas[1].

A study shows that, one third (21 to 24%) energy is consumed during brake. The invention of Regenerative Braking System is viewed as a solution to these problems, as it recovered wasted energy and restored to become another form of useful energy. Although we realize the beneficial and positive effect bring by Regenerative Braking System, but it still has its issue or problem to be solved; one of the major problems is regarded as the suitable battery to be used in this type of vehicle. Today, most Hybrid car batteries are one of these two types:

1. Nickel metal hydride

2. Lithium ion

Both are regarded as more environmentally friendly than lead-based batteries, but both battery are very expensive and still can cause environmental damage due to the toxic content[1].

The above mentioned problem statement is considered in feasibility study of implementation of RBS. No such research is done in the past to take care of these problems. Through the feasibility study, it was found that it is beneficial to implement regenerative braking system.

1.4 Objectives

General Objectives:

1. To apply the brake using DC motor.

2. To recover some part of energy lost during braking.

Specific Objectives:

1. To find out the amount of energy recovered.
2. To supply the amount of energy recovered with help of DC motor to the battery.

1.5 Methodology

a) Literature review

A thorough literature review was conducted with the help of different books, thesis reports, internet surfing, teachers and articles. The literature review of Regenerative Braking System and required components were identified.

b) Identification of problem

In the context of our country, it has been a great challenge in order to reduce the fuel consumption and emission. The problem of running down of battery is of great significance.

c) Fabrication and Assembly

After the completion of perusing the articles and drawings, the fabrication of a prototype of RBS with chain-sprocket mechanism for power transmission was fabricated in a workshop with the help of locally available materials. The fabrication was done in fabrication shop at Department of Mechanical Engineering, Purwanchal Campus.

d) Result discussion

Based on the available data and specifications, the energy needed for braking was calculated. The data was used in the selection of individual components and fabrication of the prototype of RBS. The recovered energy was calculated.

1.6 Limitations

- Driving motor is not able to rotate the wheel above the speed of 185 rpm.
- Friction brakes are still necessary for the emergency braking.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

In recent years, with the environmental consciousness enhanced, the development of Electric Vehicle is gradually taken seriously. However the travelling range of EVs cannot compete with the ability of the existing IC engine vehicles, which is the most important factor for hindering the development of EV[2]. Therefore, the RBS proposed in this project could convert the KE into electric energy and produces a reverse torque to reduce the speed of the motor without adding any component to the vehicle. RBS has been in extensive use on railways for many decades. The Baku-Tbilisi-Batumi railway (Transcaucasus Railway or Georgian railway) started utilizing regenerative braking in the early 1930s.

Early examples of this system were the front-wheel drive conversions of horse-drawn cabs by Louis Antoine Krieger in Paris in the 1890s. The Krieger electric landaulet had a drive motor in each front wheel with a second set of parallel windings (bifilar coil) for regenerative braking[3]. In England, the Raworth system of "regenerative control" was introduced by tramway operators in the early 1900s, since it offered them economic and operational benefits as explained by A. Raworth of Leeds in some detail[4][5][6]. These included tramway systems at Devonport (1903), Rawtenstall, Birmingham, Crystal Palace-Croydon (1906), and many others. Slowing the speed of the cars or keeping it in control on descending gradients, the motors worked as generators and braked the vehicles. The tram cars also had wheel brakes and track slipper brakes which could stop the tram should the electric braking systems fail. In several cases the tram car motors were shunt wound instead of series wound, and the systems on the Crystal Palace line utilized series-parallel controllers[7]. Following a serious accident at Rawtenstall, an embargo was placed on this form of traction in 1911; the regenerative braking system was reintroduced 20 years later[6].

The literature search was mainly focused on topics related to Electric and Hybrid cars. Various researches have been done in the area of Regenerative Braking System to make the system flexible so as to make it less complex. The research papers available for viewing and reference on internet search engines and through related websites for the knowledge and information sharing on public domain is cited below.

Fully Regenerative braking and Improved Acceleration for Electrical Vehicles: Generally, car brake systems use hydraulic brake technology, which converts the excess of kinetic energy into heat, effectively resulting in an energy loss. Regenerative braking technology focuses on converting this kinetic energy of the decelerating vehicle back into electrical energy that can then be reused for example during acceleration. Current hybrid vehicles are equipped with such regenerative braking technology, which makes them particularly interesting for situations with frequent deceleration, like city traffic. However, the technology used in these vehicles has its limitations and therefore does not stand on its own, but is always assisted with conventional hydraulic brakes. This paper looks at removing this limitation and allowing a vehicle to fully rely on regenerative braking technology to deal with any braking situation ranging from simple slow down to emergency stops. To enable this, multiple generators with different gear ratios are used. The additional benefit of this construction is that, by introducing the appropriate control circuit, the generators can be used as electrical engines. Since these motors are connected with different gear ratios there is a more consistent acceleration at any speed. The paper shows that the overall efficiency of the system is very close to the efficiency of the generators used while achieving braking performance similar to conventional braking mechanisms[8].

Study on Regenerative Braking of Electric Vehicle: In this paper, a control scheme for a constant regenerative current is given based on the analysis of several regenerative braking schemes. The three main control strategies discussed are maximum regenerative efficiency control, maximum regenerative power control and the constant regenerative current control. Analysis is performed for two modes, the continuous current mode and the discrete current model. Using the above analysis, a formula for regenerative efficiency of a control scheme is derived. The analysis of the braking system is done to find out two aspects, the electric loop efficiency and the regenerative energy efficiency. Using the results of the analysis, the paper concludes that the constant regenerative current control scheme is better than the maximum regenerative power control scheme and the maximum regenerative efficiency control scheme. Also, the paper concludes that the used method gives a higher regenerative braking efficiency and better control performance[9].

Regenerative Braking for Electric Vehicle based on Fuzzy Logic Control Strategy: In this paper to recycle more energy during regenerative braking, a regenerative braking force calculation controller is designed based on fuzzy logic. Here, Sugeno's fuzzy logic controller is used which has 3 inputs and the output is the braking force. The three inputs are vehicle speed; driver's braking requirements and the battery's state of charge. Fuzzy membership functions are defined for the above inputs and outputs and the output is found out in the range of 0 to 1. Each input has a membership value of high, medium and low based on which the fuzzy rules are developed. The simulations which are carried out show a substantial improvement in energy efficiency of an electric vehicle[10].

Benchmarking of Regenerative Braking for a Fully Electric Car:
Short range of electric vehicles is one of the stumbling blocks in the way of electric cars to gaining wide user acceptance and becoming a major market player. The possibility to recover vehicle energy otherwise lost as heat during braking is an inherent advantage of a hybrid electric or a fully electric vehicle. Regeneration has the potential to answer this problem by aiding in range extension with recuperation of vehicle energy during braking. The control and dynamics of braking undergoes a major change as compared to a conventional vehicle with friction braking, due to the addition of motor-generator. In this research two regenerative braking concepts namely serial and parallel have been studied and implemented on an electric vehicle. Also a point of interest is to find if any additional states are required from the Vehicle state estimator (VSE) which would aid in regeneration. From the results obtained we try to draw a conclusion on the difference in energy recuperation level in the two strategies with consistent pedal feel in mind. The proposed brake torque distribution strategy has been tested through the simulation on the New European Driving Cycle (NEDC) drive cycle and straight line braking scenario. Care has been taken to observe and adjust brake torque such that wheel lock up is prevented and hence regeneration is un-interrupted. The research couldn't come with any additional parameters to be added to VSE. However, it would be worthwhile to employ VSE to achieve a more accurate estimation of the braking force, which may aid in prolonging regeneration time and hence more energy recuperation. The results provide a good case to invest more time and money into developing serial regenerative braking as it clearly out-performs parallel regenerative braking strategy. The simulation tests conducted in this research are for a longitudinal braking scenario. Further investigation is required to study effects with lateral motion and cornering manoeuvres[11].

A Flywheel Regenerative Braking System: This thesis presents a flywheel based mechanical regenerative braking system (RBS) concept for a Formula SAE type race car application, to improve the performance and/or efficiency of the race car. A mechanical system is chosen to eliminate losses related to energy conversion while capturing the rotational braking energy. The Flywheel-Regenerative Braking System (f-RBS) concept consists of a metal flywheel design of truncated cone geometry for the energy storage system (ESS) component and a V-belt CVT with a fixed gear for the transmission component of the RBS system. Race car lap data and race car specifications are used for designing/sizing the components. Mathematical models are developed for design, integration and operation of the f-RBS system. It was observed that a maximum of 27 % of energy requirements of the race car can be supplied by the f-RBS. Also, a Virtual test rig model is created using MSC ADAMS, an advanced dynamics/virtual prototyping software, in order to test the whole f-RBS system for performance, as a preliminary alternative to experimental testing. Initial testing is performed to validate the regenerative braking principle employed, to establish the actual operating limits of the virtual test rig and for an initial analysis of performance improvement by utilization of the f-RBS system. From the results, it was inferred that using the f-RBS concept can have a significant impact in recycling wasteful the braking energy and provide additional energy to the racecar[12].

Loi Wei Cheong (2012) explained in the report having topic “Regenerative Braking System: Energy Measurement” about the working of RBS, main components, energy efficiency, benefits and future scope.

Morkel(2010) explained the requirement for infrastructure development, challenges and opportunities for design and deployment of emerging infrastructure related to regenerative braking and potential benefits. He have also explained the crucial points to maximize the benefits for reducing fuel consumption and control between the vehicle and the electric power grid to provide for clean electricity with safety.

Holmes et al (2010) explained in their report the working of electric vehicle and compared it with the conventional IC engine and hybrid electric vehicle. The report provided the details of pros and cons of EV and HEV along with the future views of technology.

UmutcanDogan and GulgunKayakutlu (2016) of Istanbul Technical University, Turkey explained about the storage of Regenerative Braking Energy in electric vehicles.

Santos et al (2006) studied the power converter and its control for an Electric Vehicles and solutions encountered during development were discussed in this paper. The focus was directed towards strategies and construction problems for the power converter(controllers), the protection and control of the power train.

2.2 Introduction to Conventional Braking System

Braking in a moving vehicle means the application of the brakes to slow or stop its movement, usually by depressing a pedal. The braking distance is the distance between the time the brakes are applied and the time the vehicle comes to a complete stop. In braking conventional vehicle, the vehicle is stopped by making the contact of moving body with frictional rubber pad i.e. brake liner which absorbs K.E, and this is wasted in the form of heat in surroundings. Each time we brake, the momentum of vehicle is absorbed and to re-accelerate the vehicle, we have to redevelop that momentum by using more power from engine. Thus, it will ultimately result in huge waste of energy. The total amount of energy lost in this process depends on how often, how hard and for how long the brakes are applied[13].

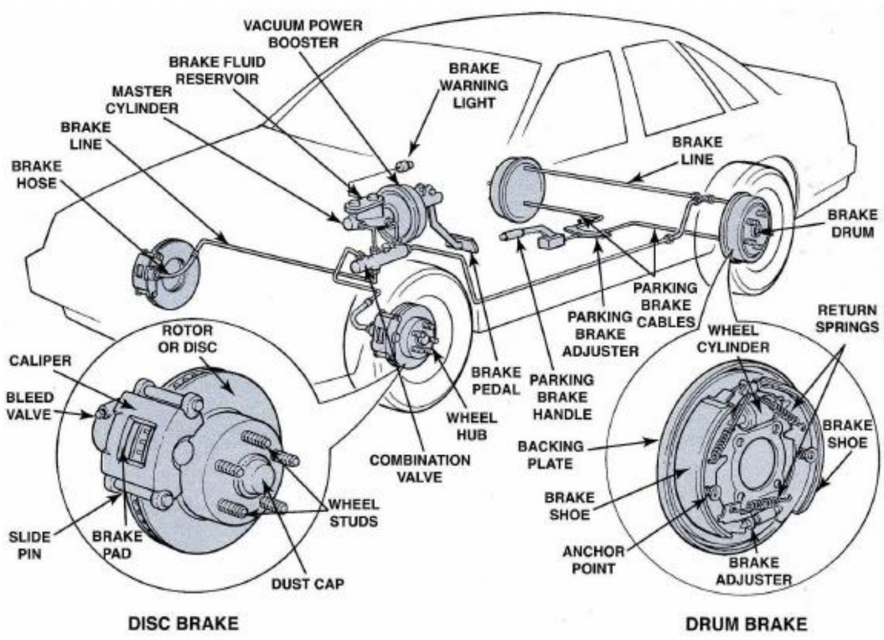

Figure 2.1: Conventional Braking (Source: Slideshare.net)

2.3 Regenerative Braking System

Regenerative braking is one of the emerging technologies which can be very beneficial. The use of regenerative braking in a vehicle not only results in the recovery of the energy but it also increases the efficiency of vehicle(in case of hybrid vehicles) and saves energy, which is stored in the auxiliary battery.

This technology of regenerative braking controls the speed of the vehicle by converting a portion of the vehicle's kinetic energy into another useful form of energy. The energy so produced could then be stored as electrical energy in the automobile battery, or as mechanical energy in flywheels, which can be used again by the vehicle.

The fig.2.2.shown below shows the simple representation of regenerative braking system.

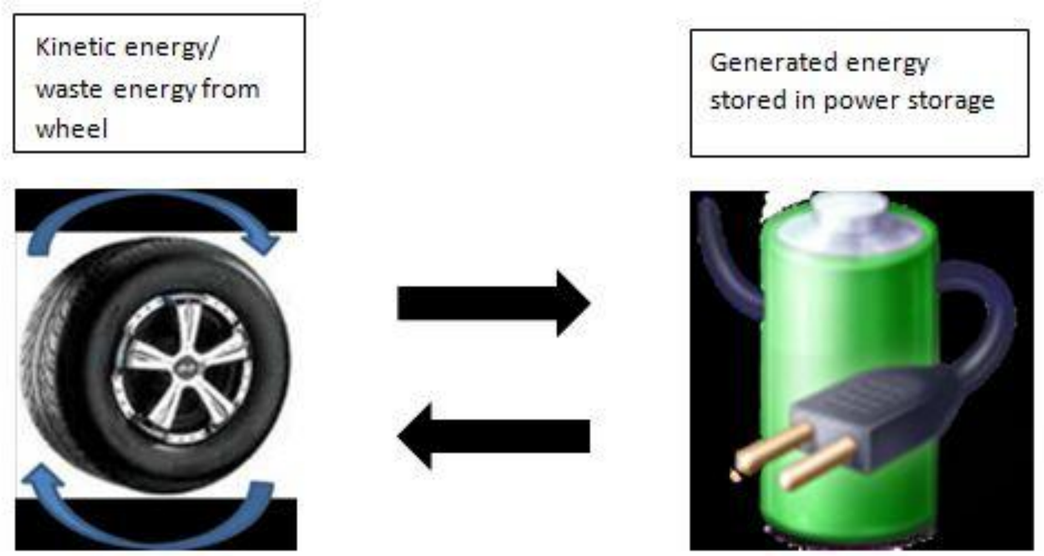

Figure 2.2: Simple representation of regenerative braking system (Source: slideshare.net)

Regenerative braking refers to a process in which a portion of the kinetic energy of the vehicle is stored by a short term storage system. Energy normally dissipated in the brakes is directed by a power transmission system to the auxiliary battery during deceleration [14]. The energy that is stored by the vehicle is converted back into kinetic energy and used whenever the vehicle is to be accelerated. The magnitude of the portion available for energy storage varies according to the type of storage, drive train efficiency, and drive cycle and inertia weight [14]. The effect of regenerative brakes is less at lower speeds as compared to that at higher speeds of vehicle. So the friction brakes are needed in a situation of regenerative brake failure, to stop the vehicle completely.

2.3.1 Components of RBS

There are four elements required which are necessary for the working of regenerative braking system, these are:

Energy Storage Unit (ESU):

The ESU performs two primary functions:

- To recover & store braking energy.
- To absorb excess engine energy during light load operation.

The selection criteria for effective energy storage include:

- High specific energy storage density
- High energy transfer rate
- Small space requirement

The energy recaptured by regenerative braking might be stored in one of three devices:

- An electrochemical battery
- A flywheel
- Compressed air

Batteries:

With this system as we know, the electric motor of a car becomes a generator when the brake pedal is applied. The kinetic energy of the car is used to generate electricity that is then used to recharge the batteries. With this system, traditional friction brakes must also be used to ensure that the car slows down as much as necessary. Thus, not all of the kinetic energy of the car can be harnessed for the batteries because some of it is "lost" to waste heat. Some energy is also lost to resistance as the energy travels from the wheel and axle, through the drive train and electric motor, and into the battery.

When the brake pedal is depressed, the battery receives a higher charge, which slows the vehicle down faster. The further the brake pedal is depressed, the more the conventional friction brakes are employed.

The motor/generator produces AC, which is converted into DC, which is then used to charge the Battery Module. So, the regenerative systems must have an electric controller that regulates how much charge the battery receives and how much the friction brakes are used.

Fly wheels:

In this system, the translational energy of the vehicle is transferred into rotational energy in the flywheel, which stores the energy until it is needed to accelerate the vehicle.

The benefit of using flywheel technology is that more of the forward inertial energy of the car can be captured than in batteries, because the flywheel can be engaged even during relatively short intervals of braking and acceleration. In the case of batteries, they are not able to accept charge at these rapid intervals, and thus more energy is lost to friction.

Another advantage of flywheel technology is that the additional power supplied by the flywheel during acceleration substantially supplements the power output of the small engine that hybrid vehicles are equipped with:

a) Continuously Variable Transmission (CVT):

The energy storage unit requires a transmission that can handle torque and speed demands in a steeples manner and smoothly control energy flow to and from the vehicle wheels.

b) Controller:

An “ON-OFF” engine control system is used. That means that the engine is “ON” until the energy storage unit has been reached the desired charge capacity and then is decoupled and stopped until the energy storage unit charge fall below its minimum requirement.

c) Regenerative Brake Controllers:

Brake controllers are electronic devices that can control brakes remotely, deciding when braking begins ends, and how quickly the brakes need to be applied. During the braking operation, the brake controller directs the electricity produced by the motor into the batteries or capacitors. It makes sure that an optimal amount of power is received by the batteries, but also ensures that the inflow of electricity isn't more than the batteries can handle.

The most important function of the brake controller, however, may be deciding whether the motor is currently capable of handling the force necessary for stopping the car. If it isn't, the brake controller turns the job over to the friction brakes. In vehicles that use these types of brakes, as much as any other piece of electronics on board a hybrid or electric car, the brake controller makes the entire regenerative braking process possible [13].

2.3.2 Working of Regenerative Braking Using Electric Motor

The working of the regenerative braking system depends upon the working principle of an electric motor, which is the important component of the system. Generally the electric motor, is actuated when electric current is passed through it. But, when some external force is used to actuate the motor (that is during the braking process) then it behaves as a generator and generates electricity. That is, whenever a motor is run in one direction the electric energy gets converted into mechanical energy, which is used to accelerate the vehicle and whenever the motor is run in opposite direction it functions as a generator, which converts mechanical energy into electrical energy. This makes it possible to employ the rotational force of the driving axle to turn the electric motors, thus regenerating electric energy for storage in the battery and simultaneously slowing the car with the regenerative resistance of the electric motors[15]. This electricity is then used for recharging the battery and also for some other purposes.

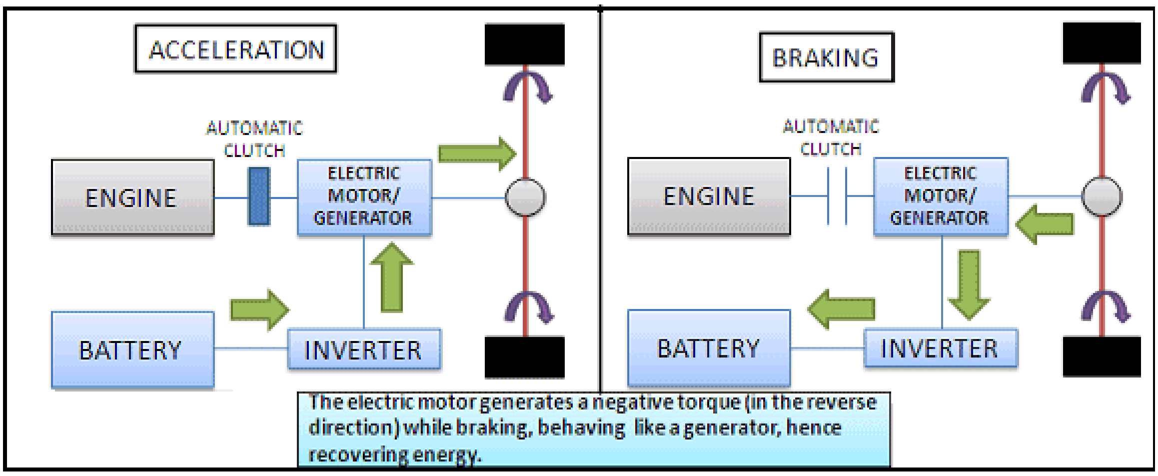

Figure 2.3: Energy conversion process in RBS (Source: quora.com)

2.3.3 Types of RBS

Based on the mode of storage of energy some of the system developed can be listed they are:-

a) Electric Regenerative braking

In an electric system which is driven only by means of electric motor the systemconsists of an electric motor which acts both as generator and motor. Initially when the system is cruising the power is supplied by the motor and when the there is a necessity for braking depending upon driver's applied force on the brake pedal the electronic unit controls the charge flowing through the motor and due to the resistance offered motor rotates back to act as a generator and the energy is energy is stored in a battery or bank of twin layer capacitors for later use.

During acceleration, the Motor/generator unit acts as electric motor drawing electrical energy from the batteries to provide extra driving force to move the car as (Shown in fig 2.4). With this help from the motor, the car's internal combustion engine that is smaller and with lower peak power can achieve high efficiency. During braking electric supply from the battery is cut off by the electronic system. As the car is still moving forward, the Motor/ Generator unit is acts as electric generator converting kinetic energy into electrical and store in the batteries (shown in fig 2. 5) for later use.

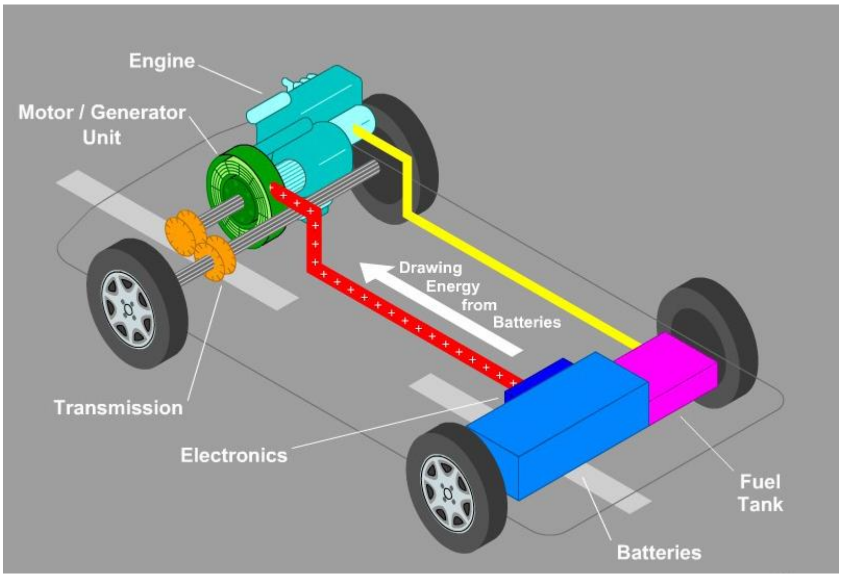

Figure 2.4: Showing energy consumption from battery (Source: grabcad.com)

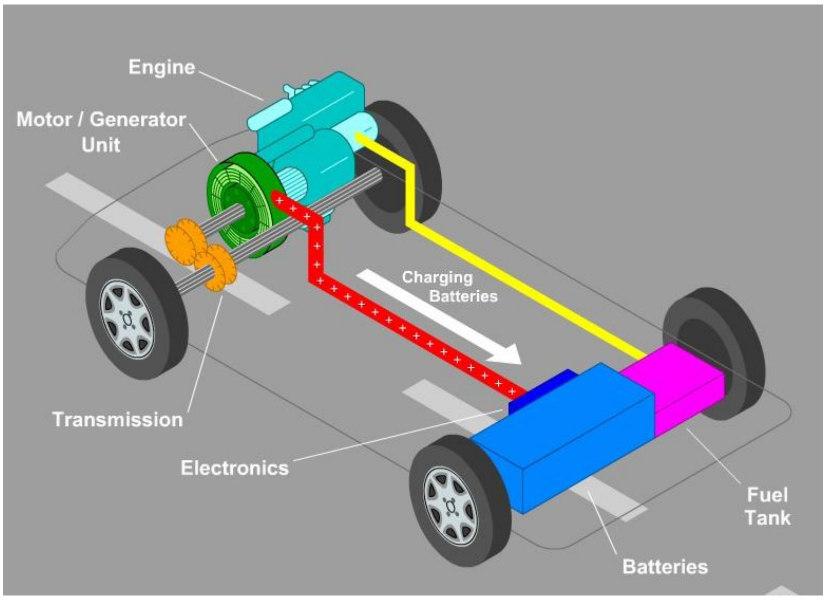

Figure 2.5: Showing charging of battery when brake applied (Source: grabcad.com)

b) Hydraulic Regenerative Brakes

Hydrostatic Regenerative Braking (HRB) system uses electrical/electronicComponents as well as hydraulics to improve vehicle fuel economy. An alternative regenerative braking system is being developed by the Ford Motor Company and the Eaton Corporation. It's called **Hydraulic Power Assist** or **HPA**. With HPA, when the driver steps on the brake, the vehicle's kinetic energy is used to power a reversible pump, which sends hydraulic fluid from a low pressure accumulator (a kind of storage tank) inside the vehicle into a high pressure accumulator. The pressure is created by nitrogen gas in the accumulator, which is compressed as the fluid is pumped into the space the gas formerly occupied. This slows the vehicle and helps bring it to a stop. The fluid remains under pressure in the accumulator until the driver pushes the accelerator again, at which point the pump is reversed and the pressurized fluid is used to accelerate the vehicle, effectively translating the kinetic energy that the car had before braking into the mechanical energy that helps get the vehicle back up to speed. It's predicted that a system like this could store 80 percent of the momentum lost by a vehicle during deceleration and use it to get the vehicle moving again.

The Hydrostatic Regenerative Braking (HRB) system is intended for commercial vehicles and mobile equipment. The company says that initial measurements show that the HRB system reduces the fuel consumption in these vehicles by up to 25%.

In the HRB system, braking energy is converted to hydraulic pressure and stored in a high-pressure hydraulic accumulator. When the vehicle accelerates, the stored hydraulic energy is applied to the transmission reducing the energy that the combustion engine has to provide. An electronic controller and a hydraulic valve manifold control the process.

At present, these hydraulic regenerative brakes are noisy and prone to leaks; however, once all of the details are ironed out, such systems will probably be most useful in large trucks[16].

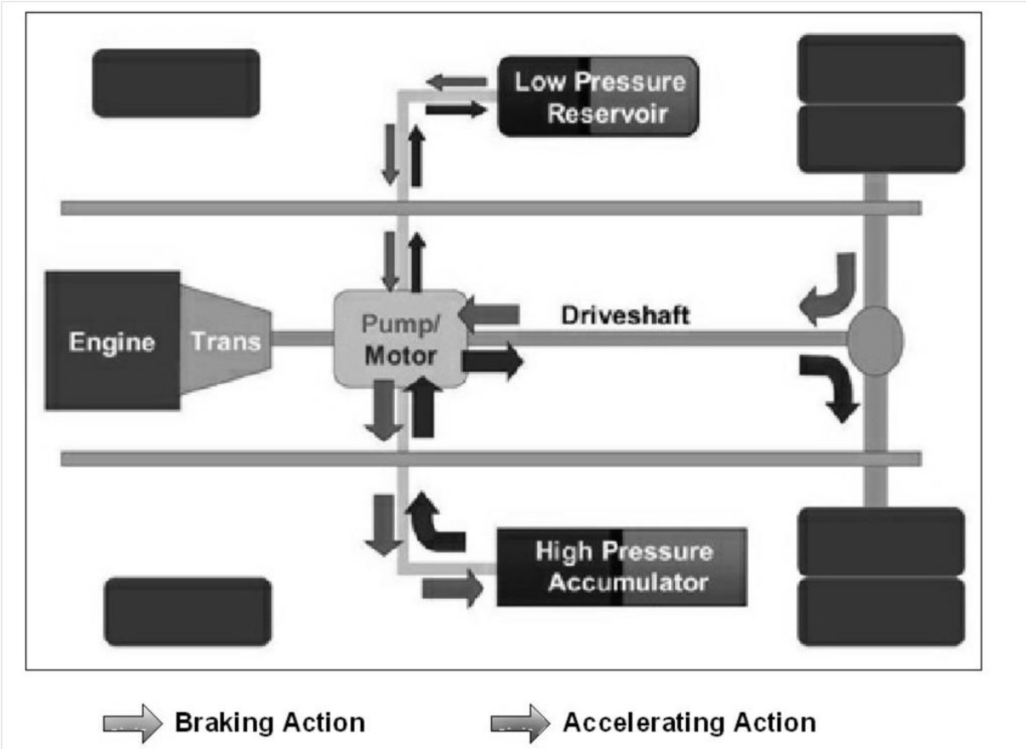

Figure 2.6: Hydraulic Regenerative Brake (HRB) (Source: autospies,com)

2.3.4 Benefits of RBS

1. Improved Fuel Economy- Dependent on duty cycles, power train design, control strategy, and the efficiency of individual components.

2. Increases the lifespan of friction braking system.

3. Reduction in Engine wears-An electric vehicle also allows for regenerative braking which increases efficiency and reduces wear on the vehicle brakes.

4. Approximately 20-25% saving in fuel consumption.

5. Reduction in brake wear- reducing cost of replacement brake linings cost of labor to install them, and vehicle down time.

6. Emissions reduction- engine emissions reduced by engine decoupling, reducing total engine revolutions and total time of engine operation.

7. Operating range is comparable with conventional vehicles- a problem not yet overcome by electric vehicles.

8. The regenerative energy can also be used for the application of accessories.

2.3.5 Downsides of RBS

1. Only work for wheels connected to motors.

2. Aided complexity of brake control system.

3. Friction brakes are still necessary for safety.

2.3.6 Application of RBS

1. For recovering Kinetic energy of vehicle lost during braking process.

2. One theoretical application of regenerative braking would be in a manufacturing plant that moves material from one workstation to another on a conveyer system that stops at each point.

3. Regenerative braking is used in some elevator and crane hoist motors.

4. Regenerative braking system is used in some cars and railways.

CHAPTER III: CONSTRUCTION, WORKING PRINCIPLE, CAD MODEL AND COMPONENT SPECIFICATIONS

3.1 Construction of the Prototype of RBS

Figure 3.1: Fabricated prototype of RBS

The prototype consists of two electric motors, one is fixed in the metal plate attached with the frame and the other is fixed with the lever which is fixed in the frame with pin-joint. The wheel attached in the frame can be adjusted to avoid the slip of chain over the sprocket. The driver sprocket is attached with the shaft of the motor and the driven sprocket is fixed in the wheel. Power is transmitted from the motor to the wheel with the help of the chain drive. Electronic Control Unit is kept in the frame and is provided with the voltage regulator, potentiometer, capacitor, inductor, transistor and brake switch. The whole unit of Regenerative Braking System is mounted on the frame. A DC motor is used as brake which is provided with the lever. DC motor at the brake converts the rotational mechanical energy to electrical energy. This energy we can show in the multimeter which can display the ampere and voltage generated.

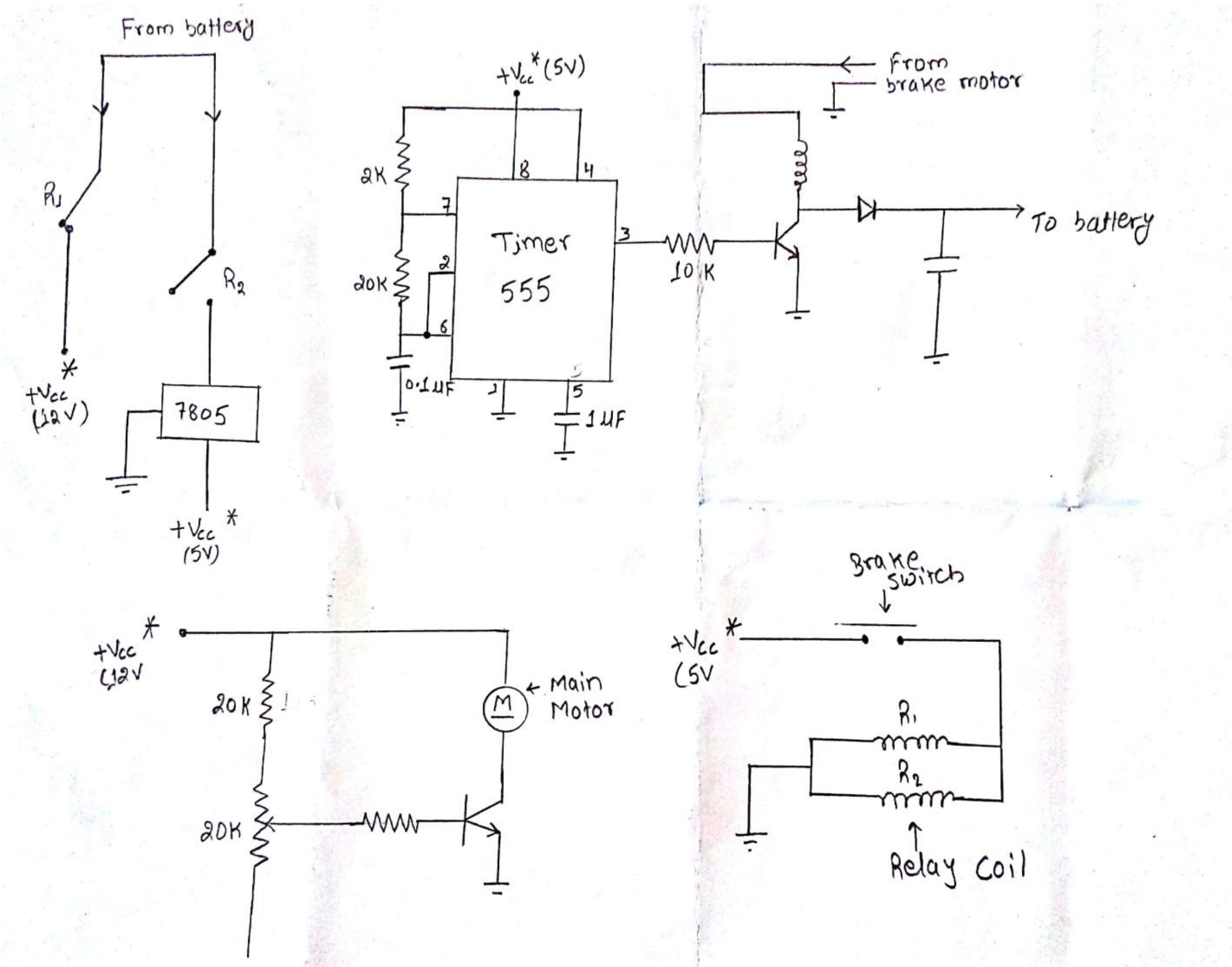

Figure 3.2: Circuit Diagram of ECU

3.2 Working of the prototype

Motor when connected to a battery, rotates the driver sprocket which is fixed in the shaft of the motor. The driver sprocket moves the chain and the chain moves the driven sprocket connected to the wheel. Then the wheel starts rotating. The friction losses during the braking are considered. Potentiometer which regulates the voltage is used for varying the speed. Brake lever is provided with the dc motor which is fixed to the frame. During the braking action, motor acts as a generator producing electrical energy which can be indicated in the LED light. Each time we brake, the output voltage from the dc motor is stored in the capacitors. After the output voltage exceeds 12V, the electrical energy is then stored in the battery.

Energy Flow

The kinetic energy of the wheel during braking is used to rotate the motor in reverse direction. Thus the motor now acts as a generator, feeding the battery with power. The flow of energy takes place in the following order:

Kinetic energy of the wheel is transformed into electric energy produced by dc motor, which is stored in the capacitor and utilized to re-charge the battery. The recovered electrical energy can also be used for applications such as wifi, lightning, radio,etc.

3.3 Selection of material and Costing for the prototype of RBS

For fabrication of system prototype, the below listed material were used based on the system requirement, availability, and economic feasibility.

Table 3.1: Cost Estimation of Prototype of RBS

S.N.	Items	Specification	Quantity	Cost
1.	Hollow square bar	20x20mm		-
2.	Battery	12V, 7.2Amp	1	2000
3.	DC Motor	12V,0.2Amp	2	2000
4.	Wheel	640mm dia	1	800
5.	PCB		1	120
6.	Transistor	TIP 112	2	150
7.	Relay	5V	2	160
8.	Capacitor	25V, 1000µF	2	20
9.	Resistor	10K	4	10
10.	Voltage Regulator	7805	1	25
11.	Potentiometer	10K	3	75
12.	Diode		1	5
13.	Capacitor	100pF, 10µF	3	75
14.	IC	555	1	35
15.	Inductor		1	75
16.	LED	12V	1	100
17.	Brake Switch		1	180
18.	Chain		1	300
19.	Sprocket	40mm dia	2	200
20.	Miscellaneous			2000
	Total			8150

3.4 CAD Model

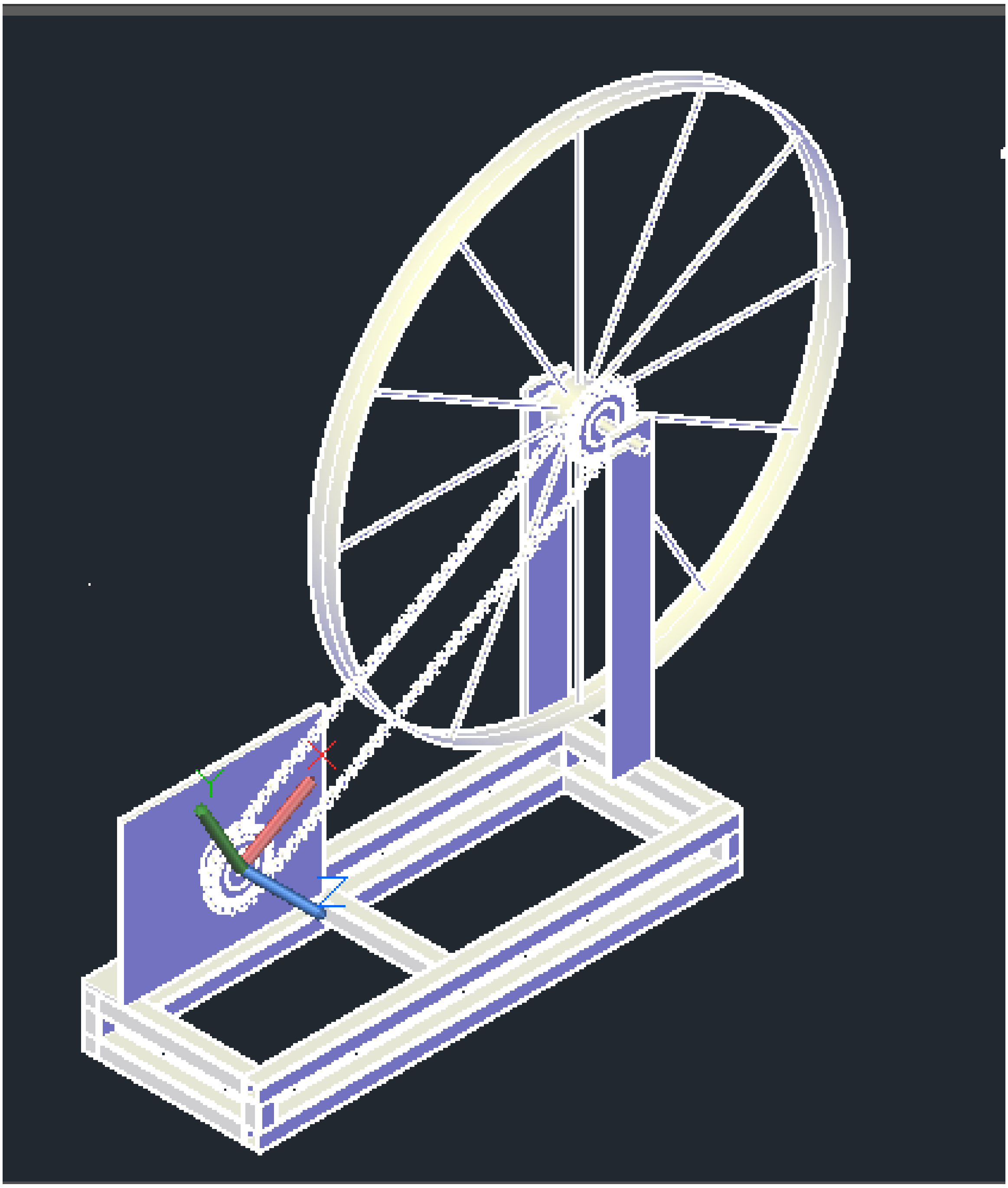

Figure 3.3: Isometric View of RBS Prototype

CHAPTER IV: FABRICATION AND ASSEMBLY

4.1 Fabrication

While carrying out the process of fabrication and assembly of the prototype of RBS, different types of machining operations such as drilling, hack sawing, filing, grinding, welding, etc. were encountered. Most of the operations were performed in the fabrication section and machining section of Purwanchal Campus, I.O.E, while some of them were performed outside, and some of the parts were easily purchased in the market.

The frame was made from hollow metal bar, solid bar, plane sheet in fabrication shop. The chain-sprocket drive was fitted with the wheel in the fabrication shop. Motors, clips, nuts and bolts, springs, were purchased from the market. The components of Electronic Control Unit were purchased and circuit board kit was made with the help of the experts in the relevant field.

4.2 Assembly

After the fabrication of the mechanical components and the purchase of components from the market, the assembly work was started. The following steps were carried out during the assembly of the prototype of RBS.

a) Firstly, the frame for the prototype was made ready by using the metal bars with the modeled dimensions. The two rectangles were made from the metal bars and then they were welded parallelly one over the other with the solid beams.

b) The wheel was placed in between the two parallel solid beams which were welded in the frame and were provided with the adjustable nuts.

c) The driver sprocket was machined in the shaft of the driving motor. The center distance between the driver sprocket and the driven sprocket was obtained and the motor was placed in the metal sheet welded over the frame. Then, the chain was placed over the two sprockets.

d) A dc motor was attached with the lever with clips and the lever was fixed in the frame with the help of spring and pin joint.

e) Then, the electronic components were assembled to prepare a circuit board kit. It was then placed over the frame.

Battery, motors and the ECU were connected with the help of flexible wires.

CHAPTER V: ANALYSIS, TESTING AND RESULT

5.1 Analysis of regenerative braking energy

This section provides a method for calculating required braking power, available output electrical power and efficiencies.

Table 5.1: Wheel Characteristics

Wheel characteristics	
Parameters	Values
Mass of the wheel	1.2kg
Radius of gyration	0.2m

The following equations are used to calculate the amount of brake torque required to stop the wheel.

The moment of inertia of the wheel is given by:

Moment of Inertia (I_w)= mk^2 (5-1)

where, m = mass of the wheel

k = radius of gyration

The kinetic energy of the wheel is given by:

$$KE = 1/2 I_w \omega^2 \quad (5\text{-}2)$$

While braking,

$$\text{Angular deceleration } (\alpha) = (\omega_2 - \omega_1)/\Delta \quad (5\text{-}3)$$

where, Δ = stopping time

$\omega_2 = 0$ (final angular velocity)

The braking torque is given by:

$$\text{Braking Torque } (T_b) = I_w\alpha \tag{5-4}$$

The power required during braking is given by:

$$\text{Braking Power } (P_b) = \omega T_b \tag{5-5}$$

Theoritical Assumption:

At full rpm, Brake Power = 0

At o rpm, Brake power = ωT

The KE of the wheel is always lost during braking operation.

The output electrical power is calculated as:

$$\text{Output Power}(P_{out}) = IV \tag{5-6}$$

where, I = output current

V = output voltage

The efficiency with which the prototype regenerates the braking energy into electrical energy is given by:

$$\text{Efficiency } (\eta) = \text{Output Power/Braking Power} \tag{5-7}$$

5.2 Testing

Braking action was performed in different rotating speeds of the wheel. The corresponding output voltage and current given by the dc motor was measured with the help of multi meter.

Table 5.2: Result of Testing of Prototype

S.N.	Speed (rpm)	Stopping Time(sec)	Current (mA)	Voltage (V)
1.	40	3	2.1	1.97
2.	72	4	3.5	2.74
3.	92	4.5	3.7	3.18
4.	185	5	12.6	10.85

5.3 Results

5.3.1 Calculations :

From equations (5-1) to (5-7):

Case 1: At N= 40 rpm,

$I= 1.2*(0.2)^2 = 0.048\ kgm^2$

$\omega= (2\pi*40)/60$
$= 4.19$ rad/s

KE of wheel= $(0.048*4.19^2)/2$
= 0.421 J

Stopping time (Δ) = 3 sec

Angular acceleration (α) = (0-4.19)/3
= -1.396 rad/sec^2 (wheel deceleration)

Required Braking Torque (T_b) = 0.048*1.396
= 0.067 N-m

Required Braking Power (P_b) = 4.19*0.067
= 0.28073 W

Output Power (P) = $1.97*2.1*10^{\wedge-3}$
= 0.004137 W

Efficiency (η) = 0.004137/0.28073
= 0.0147
= 1.47%

Case 2: At N= 72 rpm,

$\omega= (2\pi*72)/60$
$= 7.54$ rad/s

KE of wheel= $(0.048*7.54^2)/2$
=1.364J

Stopping time (Δ) = 4sec

Angular acceleration (α) = (0-7.54)/4
= -1.885 rad/sec^2 (wheel deceleration)

Required Braking Torque (T_b) = 0.048*1.885
= 0.09048 N-m

Required Braking Power (P_b) = 7.54*0.09048
= 0.6822 W

Output Power (P) = 2.74*3.5*10$^{\wedge-3}$
= 0.00959 W

Efficiency (η) = 0.00959/0.6822
= 0.01405
= 1.405%

Case 3: At N= 92rpm,

ω= (2π*92)/60
= 9.634rad/s

KE of wheel= (0.048*9.634^2)/2
= 4.455 J

Stopping time (Δ) = 4.5 sec

Angular acceleration (α) = (0-9.364)/4.5
= -1.8728 rad/sec^2 (wheel deceleration)

Required Braking Torque (T_b) = 0.048*1.8728
= 0.08989 N-m

Required Braking Power (P_b) = 9.364*0.08989
= 0.866 W

Output Power (P) = 3.18*3.7*10$^{\wedge-3}$
= 0.011766W

Efficiency (η) = 0.011766/0.866
= 0.0136
= 1.36%

Case 4: At N= 185rpm,

ω= (2π*185)/60
= 19.37rad/s

KE of wheel= $(0.048*19.37^2)/2$
= 9.004 J

Stopping time (Δ) = 5 sec

Angular acceleration (α) = (0-19.37)/5
= -3.874rad/sec^2 (wheel deceleration)

Required Braking Torque (T_b) = 0.048*3.874
= 0.155 N-m

Required Braking Power (P_b) = 19.37*0.155

= 3.002 W

Output Power (P_{out}) = 10.85*12.6*$10^{\wedge-3}$
= 0.1367W

Efficiency (η) = 0.13671/3.002
= 0.0455
= 4.55%

5.3.2 Performance Graph:

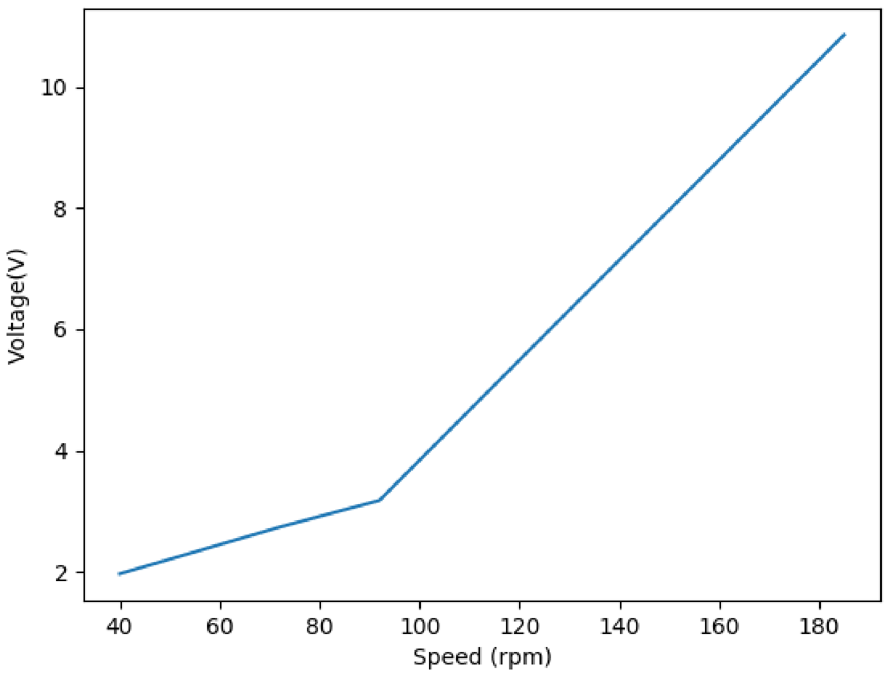

Figure 5.1: Speed vs Voltage

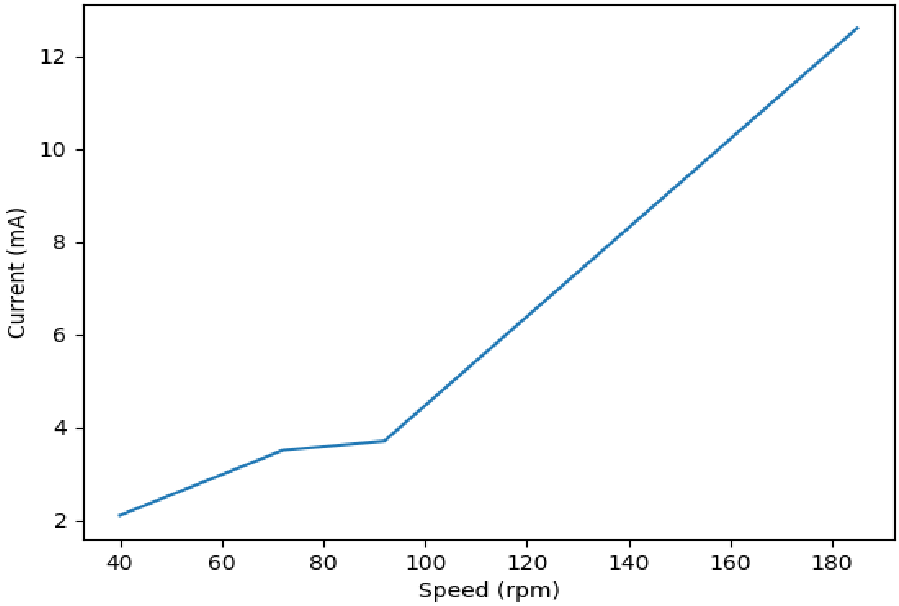

Figure 5.2: Speed vs Current

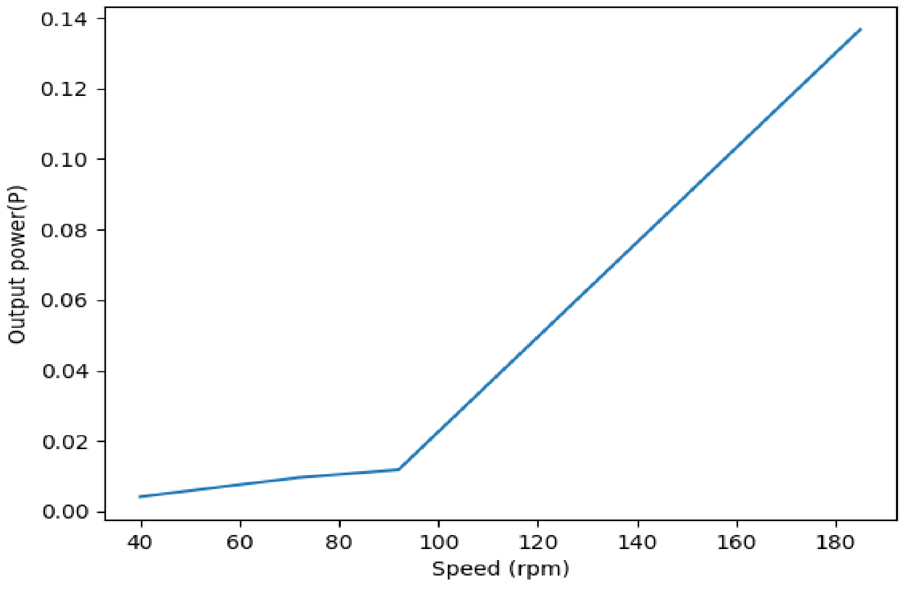

Figure 5.3: Speed vs Output Power

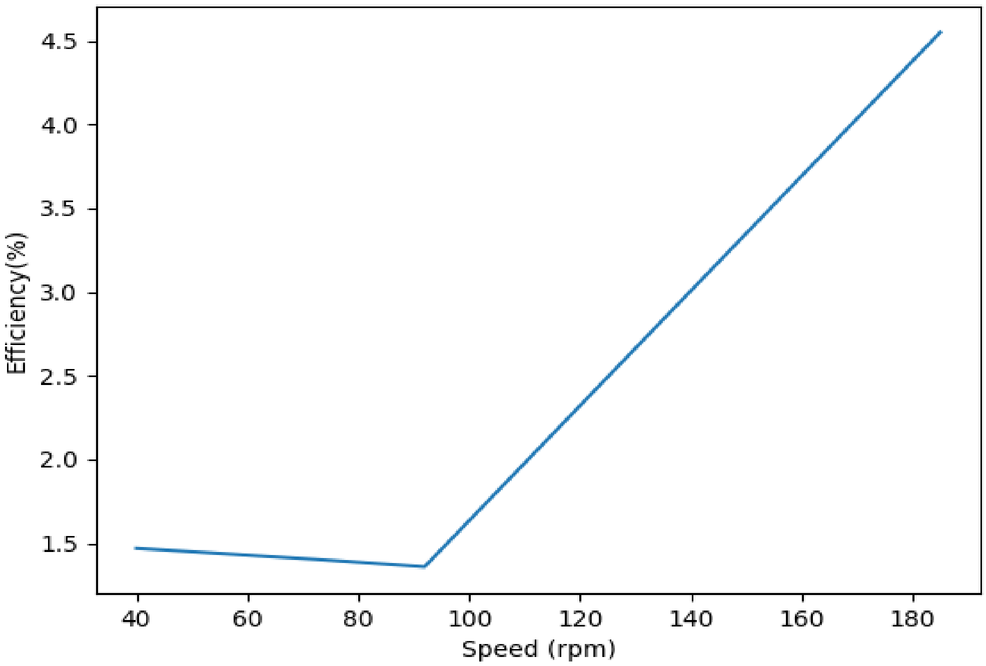

Figure 5.4: Speed vs Efficiency

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The project was successful to fulfill the desired objectives in recovering the braking energy. This project required continuous dedication and patience and was a great challenge in fabrication and development of it. The prototype for powering LED and storing the electrical energy using regenerative braking has been presented in this work. Throughout the course of normal operation and braking, electricity is stored in the capacitor and then the battery is charged. The overall effectiveness of the RBS improves with increasing rotational speed of the wheel and with increasing stopping/braking time. For the rotational speed of the wheel at 185 rpm, the LED light will operate continuously with stopping time of 5 second. At this speed, the prototype of RBS is able to recover about 4% of the wheel's KE. The efficiency of the prototype can be improved by enhancing the rotational speed of the wheel.

6.2 Recommendations

The prototype is capable of recovering the kinetic energy of the wheel through regenerative braking. Also, this prototype helps us to understand RBS and it's working in a simple way. However, there are certain recommendations that can be made for this project.

- Encapsulation of braking motors, battery and ECU with Aluminium cover to prevent from water.
- Dust removal from the wheel for the protection of rubber bush of DC motor from wear and tear by use of brushes.
- Compare the practical braking power obtained at different speed of wheel during deceleration with theoretical power.
- Measuring output current and voltage at certain interval of speed of the wheel during deceleration.
- Calculation of braking power taking theoretical assumption into consideration.
- Plotting of characteristic curve between different braking power and corresponding speed of the wheel during deceleration of the wheel.

CHAPTER VII: FUTURE ENHANCEMENT

Regenerative braking system require further research to develop a better system that captures more energy and stops faster. As the time passes, designers and engineers will perfect regenerative braking system, so these system will become more and more common. All vehicles in motion can benefit from these systems by recapturing energy that would have been lost during braking process.

Future technologies in regenerative brakes will include new types of motors which will be more efficient as generators, new drive train designs which will be built with regenerative braking in mind, and electric systems which will be less prone to energy losses.

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APPENDIX

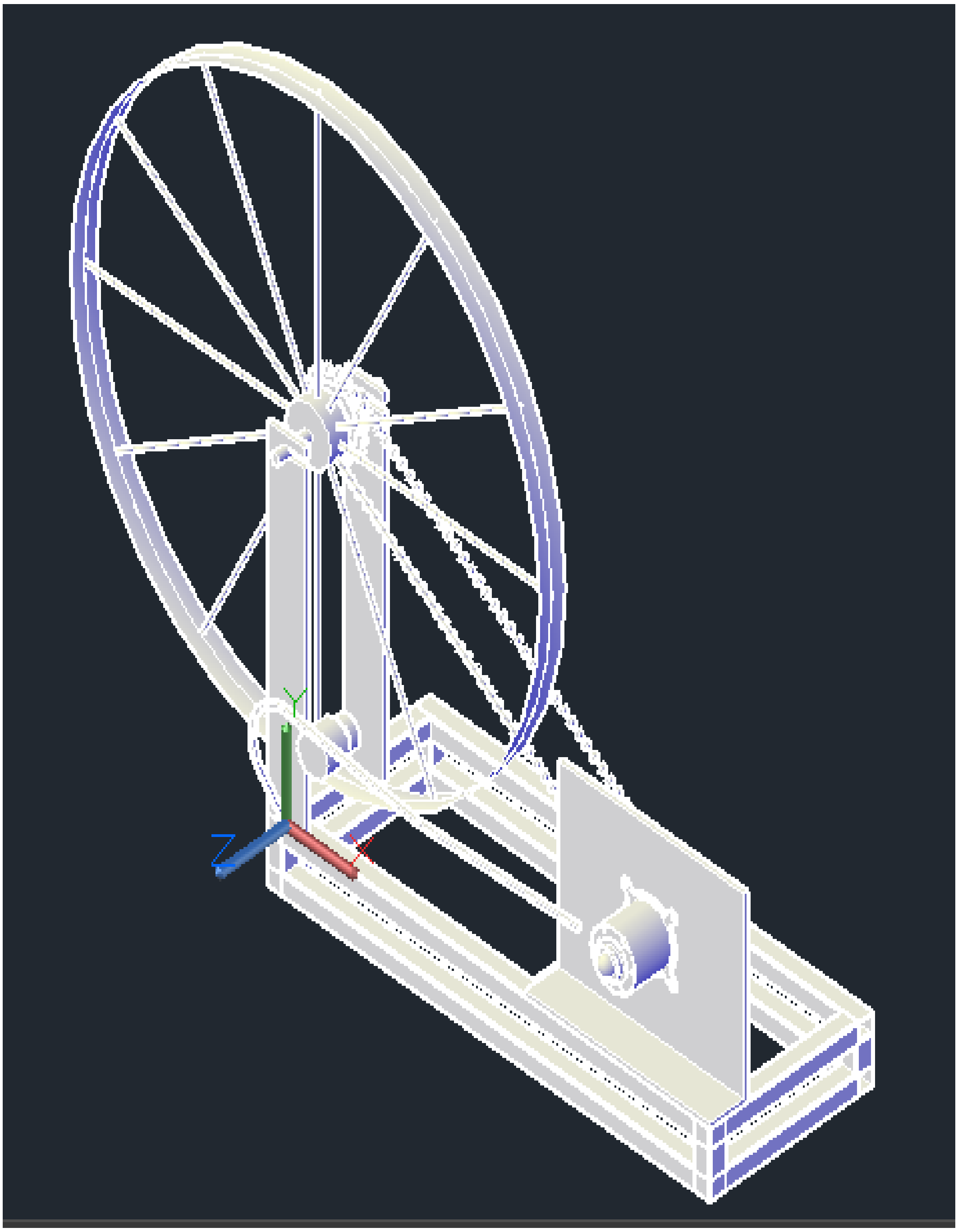

Figure A1: Isometric View of RBS Prototype

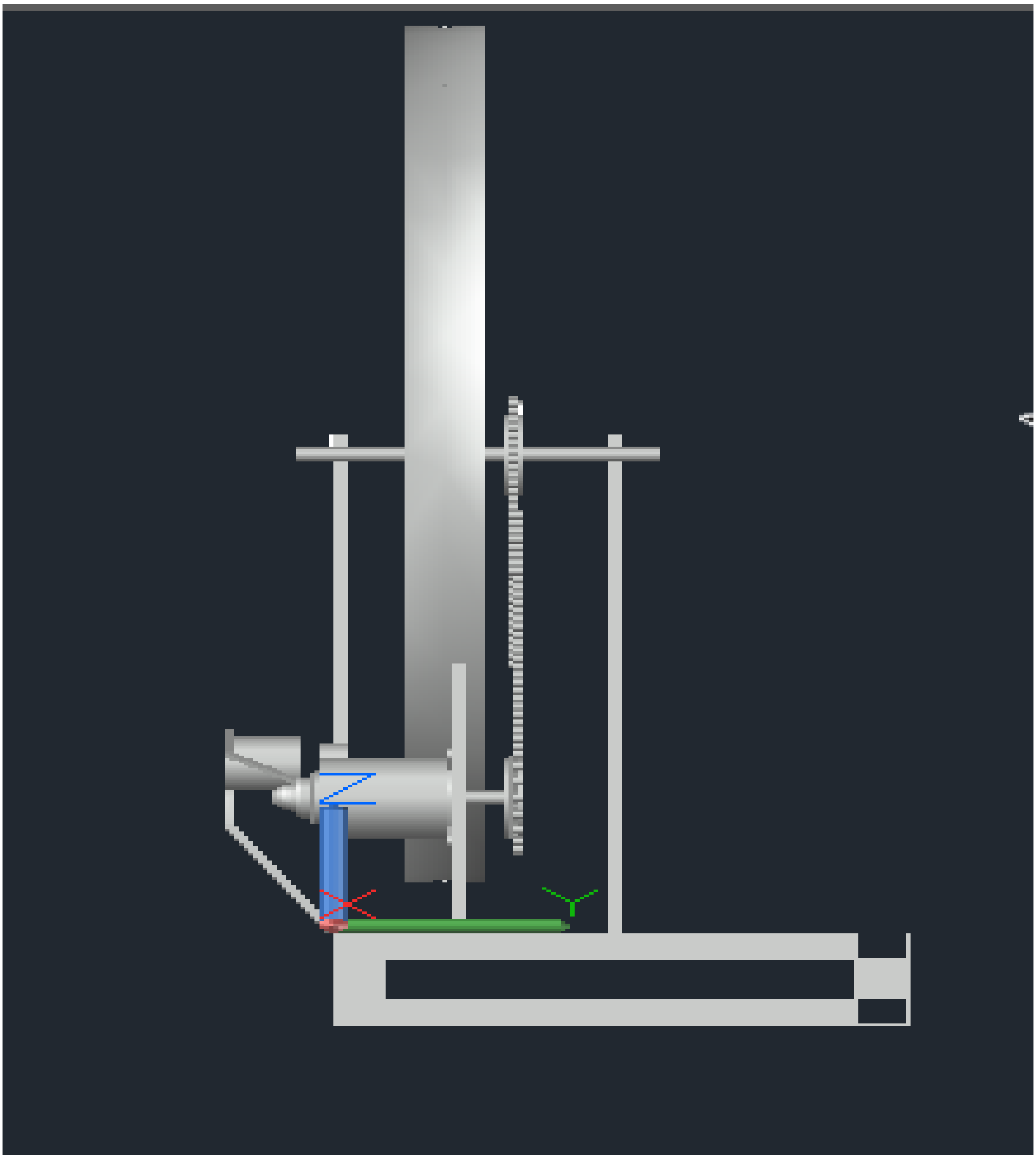

Figure A2: Front view of RBS Prototype

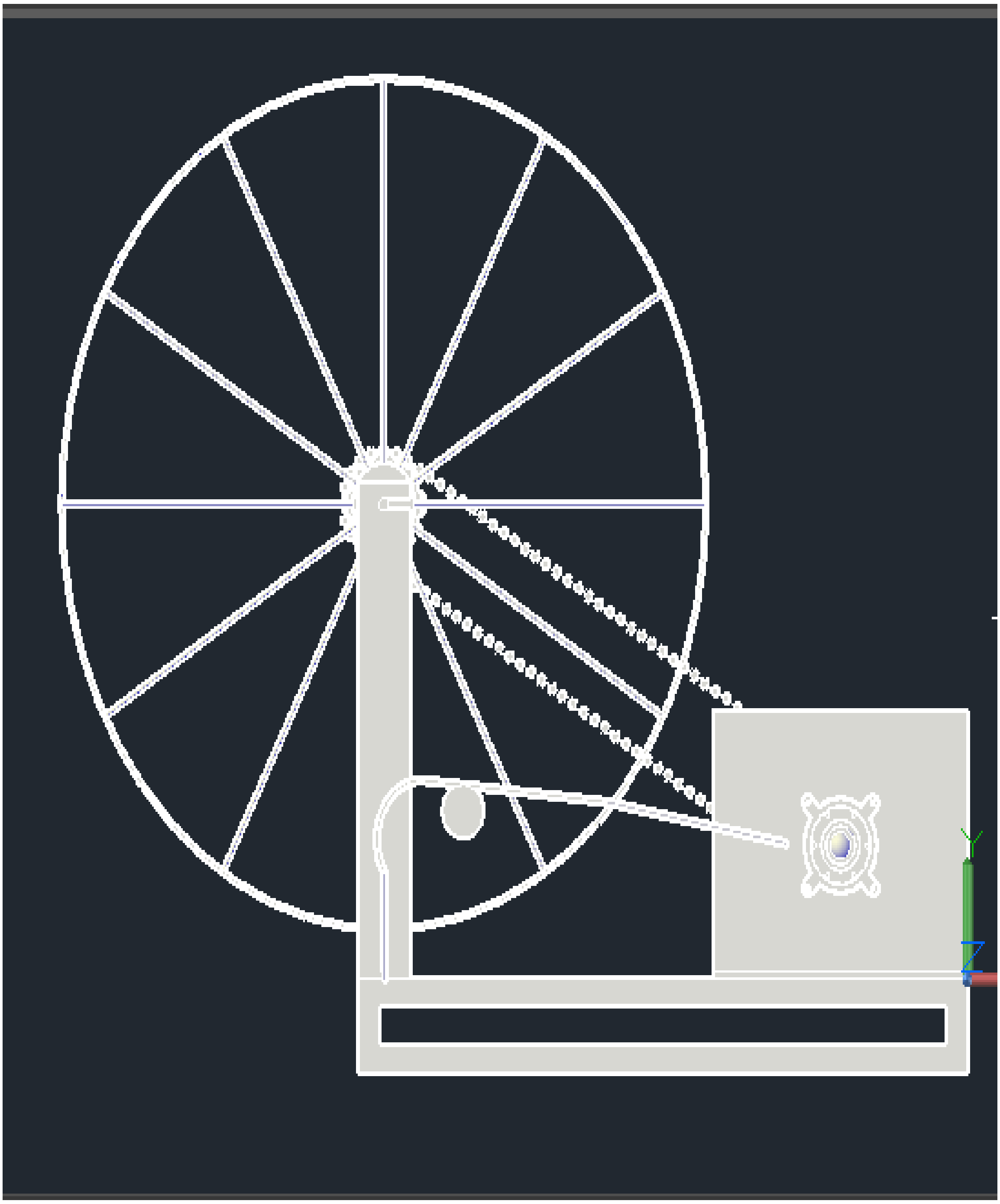

Figure A3: Left side view of RBS Prototype

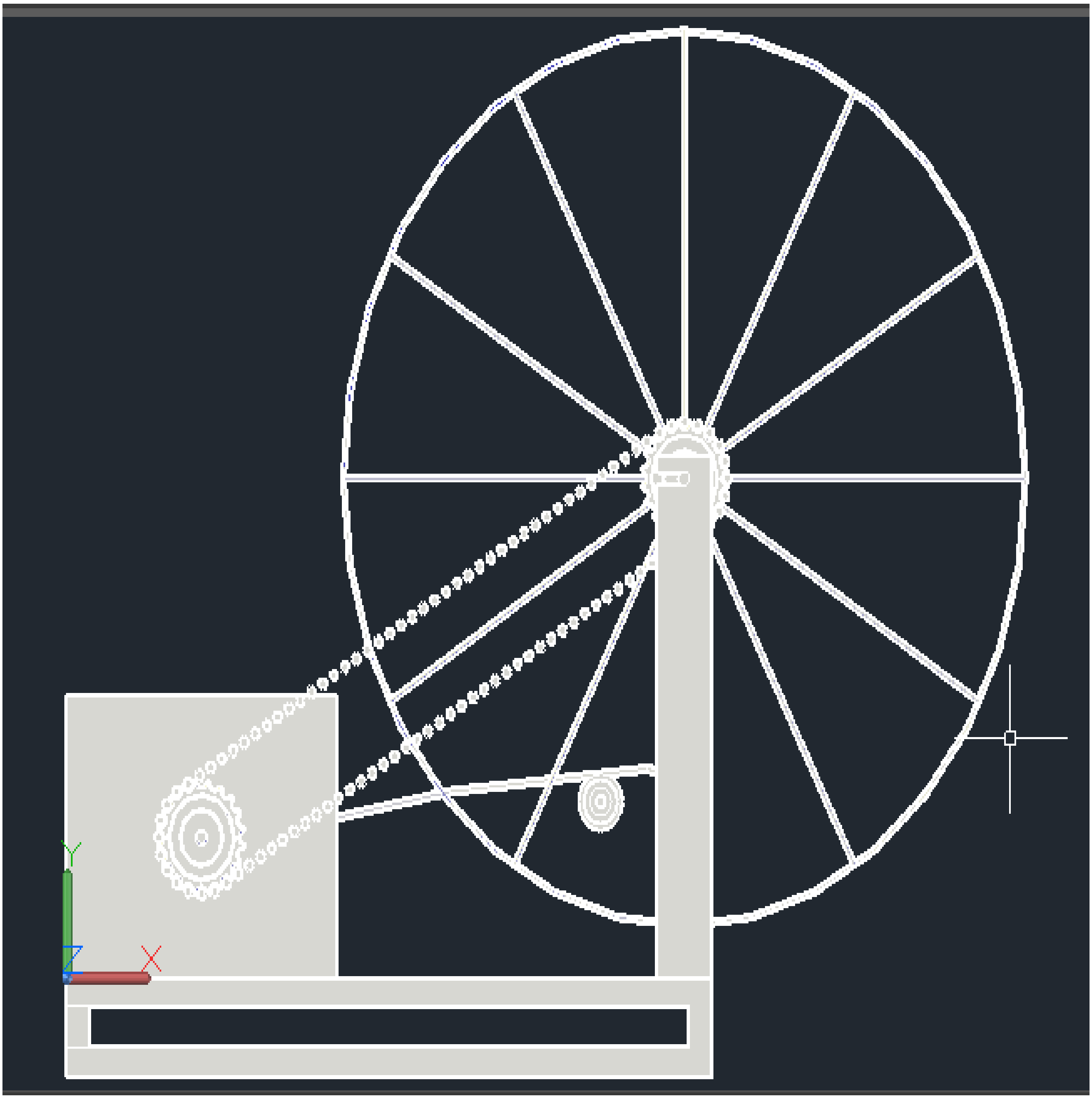

Figure A4: Right side view of RBS Prototype

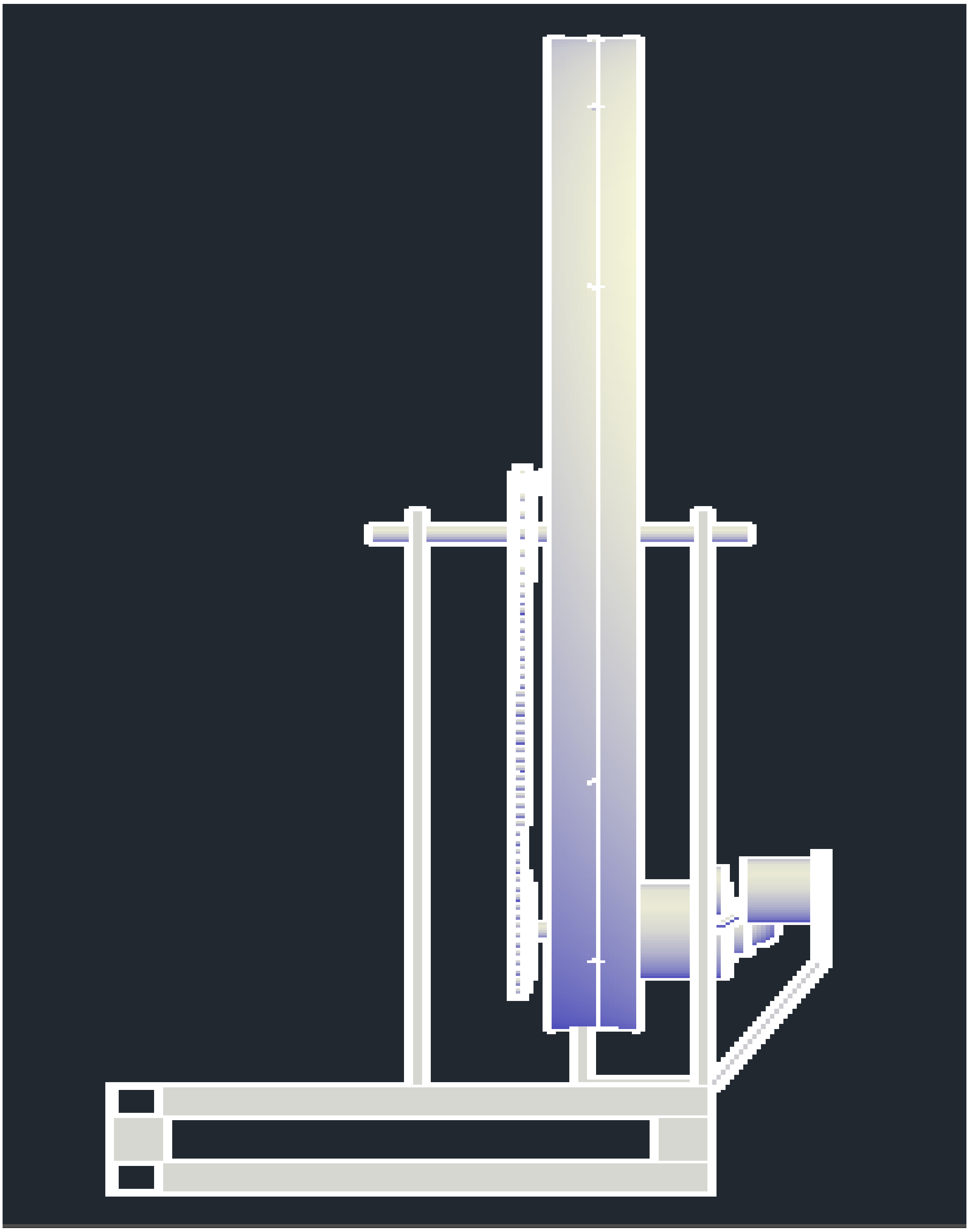

Figure A5: Back View of RBS Prototype

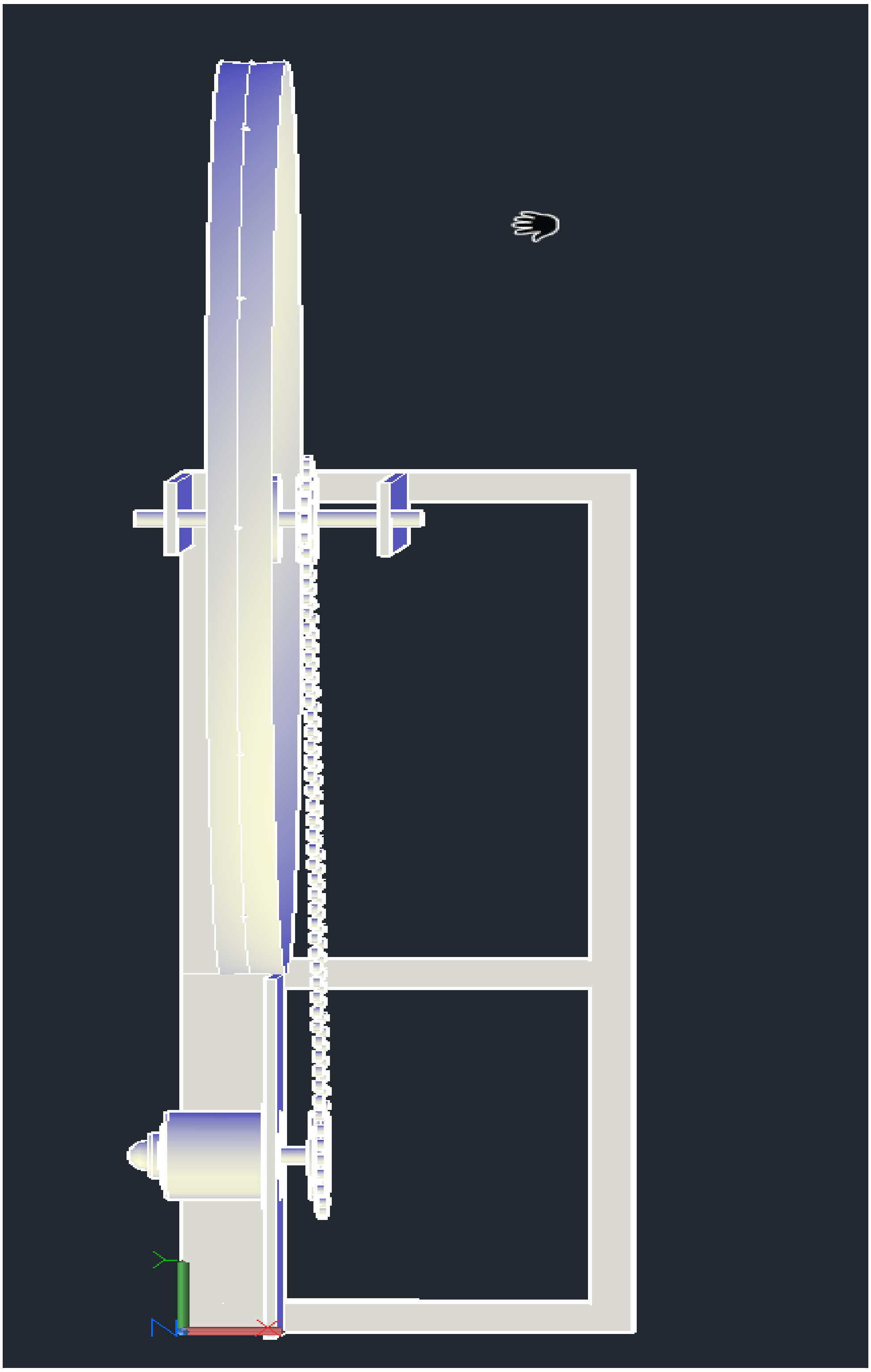

Figure A6: Top View of RBS Prototype