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Senior Design Project Report

Design of Kinetic Energy Recovery System for Bicycle

In partial fulfillment of the requirements for the
Degree of Bachelor of Science in Mechanical Engineering

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Abstract

The kinetic energy recovery system (KERS) is designed to recover the kinetic energy of a moving vehicle under braking. While the engine is rotating or the vehicle is in motion, the kinetic energy is stored and is utilized at times when it needs a quick acceleration. Flywheels are mostly used for that purpose, with several designs coming up over the years. KERS converts the kinetic energy often using an electromagnetic system, to electrical energy. The development of a mechanical system of storing energy leads to the prevention of incidents in the use of batteries such as shock and fires. Furthermore, the mechanical system of KERS involves harvesting kinetic energy during braking. The brake energy is harvested and used to turn a flywheel which acts as the reservoir as it continues to turn. Thus, when the stored energy is needed, the flywheel is connected to the wheels through a system of gears to provide the acceleration boost. Through further design and modifications, a fitting mechanical KERS can be developed for a bicycle as well. The electric type of KERS is not recommended due to the dangers stated above and its poor efficiency due to the several forms of energy conversions. In this project, an efficient mechanical kinetic energy recovery system is designed for a bicycle using a combination of clutch based and continuously variable transmission system to connect to the wheels. The relevant steps in research, design, and prototyping will be mentioned.

Acknowledgments

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List of Acronyms (Symbols) used in the report:

v	= Final velocity of the bicycle at the end of discharging cycle (m/sec)
u	= Initial velocity of the bicycle at the starting of the discharging cycle (m/sec)
a	= Acceleration of the bicycle (m/sec^2)
E	= Total energy of the system (Joules)
D_R	= Diameter of the bicycle wheel (m)
R_R	= Radius of the bicycle wheel (m)
F_a	= Inertia force (N), force required to accelerate the bicycle a rate of “a”
F_R	= Rolling resistance (N)
F_A	= Aerodynamic drag (N)
C_d	= Coefficient of drag
ρ	= Density (Kg/m^3)
A	= Projected area of a bicycle
F_f	= Frictional resistance (N)
F	= Total force (N)
T	= Torque (Nm)
E_{Ω}	= Energy of the flywheel (Joules)
s	= Sprocket ratio = $\frac{\text{rear}}{\text{front}}$
m	= Mass of the flywheel (Kg)
μ	= coefficient of friction
ω_1	= Maximum angular velocity of the flywheel (rad/sec)

List of Figures:

Figure 1. Isometric view of the KERS.....	8
Figure 2. A picture of the total flywheel system. The flywheel is represented as a simple disc instead of a wheel rim (a) The system in its default state. (b) The charging phase for the flywheel [2]	12
Figure 3. Flywheel rotor of storage subunit [3]	13
Figure 4. Product Subsystem	19
Figure 5. Design of Flywheel on SolidWorks	22
Figure 6. Design of Sprocket	23
Figure 7. Design of Central Shaft	23
Figure 8. Design of Clutch Actuator.....	23
Figure 9. Design of Clutch.....	24
Figure 10. Design of Bearing.....	24
Figure 11. Exploded Assembly of Overall Design	25
Figure 12. Final Assembly of the Design with Bicycle	26
Figure 13. Bill of Materials	26
Figure 14. Experimental Setup Showing Speedometer	31
Figure 15. Graph for the Experiment.....	33
Figure 16. Pie Graph Depicting Contribution of Group Members	34

List of Tables:

Abstract.....	2
Acknowledgments	3
List of Acronyms (Symbols) used in the report:.....	4
List of Figures:	5
List of Tables:.....	6
Chapter 1: Introduction.....	7
1.1 Project Definition.....	8
1.2 Project Objectives	8
1.3 Project Specifications.....	8
1.4 Applications	10
Chapter 2: Literature Review.....	10
2.1 Project background.....	10
2.2 Previous Work.....	11
2.3 Comparative Study.....	13
Chapter 3: System Design	15
3.1 Design Constraints and Methodology.....	15
3.2 Engineering Design Standards.....	16
3.3 Theory and Theoretical Calculations	16
3.4 Product Subsystem and Selection of Components.....	19
3.4.1 Selection of Components	19
3.5 Manufacturing and Assembly	22
Chapter 4: System Testing and Analysis	31
4.1 Experimental Setup, Sensors and Data Acquisition System.....	31
4.2 Result, Discussion Analysis.....	32
Chapter 5: Project Management	34
5.1 Project Plan.....	34
5.2 Contribution of Team Members	34
5.3 Project Execution Monitoring.....	35
5.4 Challenges and Decision Making	35
5.5 Project Bill of Materials and Budget	35
Chapter 6: Project Analysis	36
6.1 Life-long Learning	36
6.2 Impact of Engineering Solution	37
6.3 Contemporary Social Issues Addressed.....	37
Chapter 7: Conclusion and Recommendations	38
7.1 Conclusion	38
7.2 Recommendations	38
8. References	39

Chapter 1: Introduction

The flywheel has been used since prehistoric times. It utilizes the moment of inertia to store energy by rotating. When this cylinder disc rotates, the energy it stores can be utilized by connecting it to a medium we want to provide energy to. Commonly, flywheels are connected to engines to provide energy to drive a machine or vehicle. They can also be used in bicycles to recover the kinetic energy during breaking, it stores the kinetic energy as potential energy, which can be converted back when needed. Their high efficiency can lead to replacement of electrochemical cells for storage of kinetic energy generated during motion or rotational energy. In our project, we are planning to apply the knowledge we have into designing a flywheel that will be integrated into a bicycle.

The most plausible feature of the flywheel is its high-power density and storage capacity. The development of material such as carbon fiber and light anodized aluminum alloys has increased the power densities of the flywheels and at the same time reducing their weight and amount of force required initially to overcome their stationary inertia. The use of such materials makes it even easier to apply it to a bicycle.

Flywheels as kinetic energy recovery systems has first taken root in the formula one industry. In 2009, the rules were changed allowing vehicles to be fitted with such systems. This came as a relief as the manufacturers know the benefits of using flywheels in engines and other propulsion systems. It provides continuous energy supply during intermittent cycles in the piston firing system in the engine. Hybrid vehicles are also rolling out the use of flywheels in the engine. This is used to complement the engine and fuel propelled system with an extra source of energy. Since it has already been established that the flywheel is more efficient and cheaper, the electrochemical system will be supplemented by one or a series of flywheels.

1.1 Project Definition

Our design philosophy is to build a KERS flywheel energy storage unit as a proof of concept, which hopefully be optimized by ourselves and others in the future. The reason why a system like this is feasible is that globally, roads have many impediments such as intersections, cars and turns which prevents a cyclist from maintaining a constant speed. This system will help with recovering the lost energy from braking caused by these impediments.

1.2 Project Objectives

1. Identifying the potential of KERS for bicycle.
2. Summarizing key technologies used for recovering kinetic energy.
3. Optimizing the existing design for KERS and purposing a new design.
4. Testing the newly designed KERS for bicycle under different conditions.
5. Identifying the external and internal parameters that have increased or decreased the efficiency of KERS.
6. Citing the limitations of the purposed design and suggesting future work for the KERS design.

1.3 Project Specifications

The isometric diagram of the purposed designed project is depicted in Fig.1.

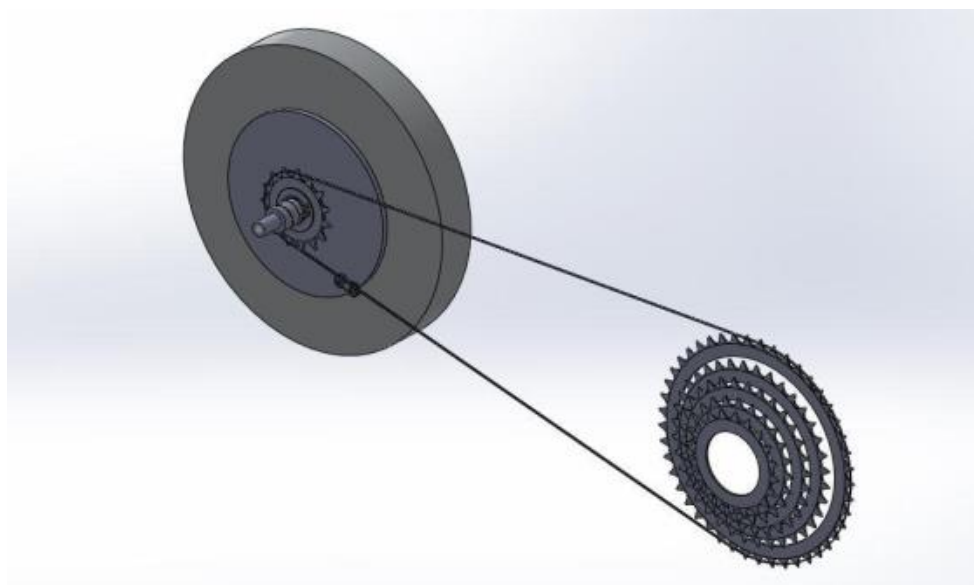


Figure 1. Isometric view of the KERS

a. The technical and non-technical requirements of the designed KERS system are as follow:

- Store energy while braking- This is the main requirement and the overall objective of the device and must be suitable to meet the rider's needs.
- Return energy to start up- Once the energy is stored in the device, it is necessary to have a simple way to release this energy back to the user in positive way. This can be accomplished with an innovative chain drive system.
- Must fit on a bicycle- This is one of the most difficult constraints to achieve and most important because we are dealing with such confined spacing. The objective is to fit the flywheel and accessories in the bicycle.
- Light weight- The importance of having a light weight design is driven by the rider's desire to have a bicycle that is more maneuverable and more portable. This is also a direct trade off with how much energy can be stored in the flywheel.
- Good stopping range- The stopping range is important because this product needs to be usable in real life situations. This component can be optimized to have the shortest stopping distance using dynamic analysis.
- Good stopping force- The force required to stop is dependent on the stopping range and the comfort levels of the rider. It is also related to the possible flywheel features.
- Inexpensive and affordable- This product must be able to make a profit and be desirable.
- Safe to user and environmentally friendly- Safety is always a very important aspect whenever there is a consumer product.
- Economical- The product economical and the products for this design must be cheaply available.
- Reliable

b. Engineering standards

Codes are generally the top-tier documents, providing a set of rules that specify the minimum acceptable level of safety for manufactured, fabricated or constructed devices. The project will be designed and fabricated by considering the code of conduct and standards of OSHA which is the Federal agency under the U.S. Department of Labor, the OSHA has a mission to provide a safe environment, protect public safety and health.

1.4 Applications

- The design has the potential to be used by cyclist in order to apply less energy and cover long distances.
- The design can be also used in the automobiles and in high speed racing vehicles to decrease their fuel consumption and increase their mileage without decreasing their speed.

Chapter 2: Literature Review

2.1 Project background

The introduction of Kinetic Energy Recovery Systems (KERS) is one of the most significant technical introductions for the Formula One Race. Formula One have always lived with an environmentally unfriendly image and have lost its relevance to road vehicle technology. This eventually led to the introduction of KERS. KERS is an energy saving device fitted to the engines to convert some of the waste energy produced during braking into more useful form of energy. The system stores the energy produced under braking in a reservoir and then releases the stored energy under acceleration. The key purpose of the introduction was to significantly improve lap time and help overtaking. KERS is not introduced to improve fuel efficiency or reduce weight of the engine. It is mainly introduced to improve racing performance.

1. In development since 90's. It was first introduced to the general public through the 2009 series of Formula One motorsport.

2. KERS builders, Flybrid Systems demonstrated a working Formula One-spec device at the Autosport International Show. (24kg , 400kj energy capacity, power boost-60kW.
3. FIA introduced KERS in 2009 GP series to increase overtaking and as defensive tool to block a faster car.
4. But many F1 teams opposed it, as it was an expensive system, so it was banned in the 2010 season.
5. But with improvements and increase in manufacturers for KERS it was reintroduced in 2011.
6. At the 2011 North American International Auto Show, Porsche unveiled an RSR variant of their Porsche 918 concept car which uses a flywheel-based KERS.
7. A motorcycle racing company called KTM Racing, secretly tested this kinetic energy system in their vehicle, but they were banned as that system was illegal and unstable for motorcycles.

2.2 Previous Work

Alberto. Boretti also named the mechanical KERS as M-KERS and electrical KERS as E-KERS and in his research they he found that M-KERS on the rear non-motored wheels, the thermal engine powering the front wheels has to supply 0.31 MJ/km or 30.82 MJ/100 km for a 1000 kg vehicle of standard rolling and aerodynamic resistances covering a modified version of the new European driving cycle [1].

Kevin Ludlum displayed a fairly simple design with implementation of a kinetic energy recovery system with a non-negligible increase in the efficiency of a bicycle. Also reasoned to use a flywheel that, flywheel has an environmental impact only at its time of production and has the potential to heavily outweigh those costs through its use. Bikes do not have the pollution problems that cars and other modes of transportation have, but they can serve as a good analogy for how a kinetic energy recovery system can increase the efficiency of a vehicle [2].

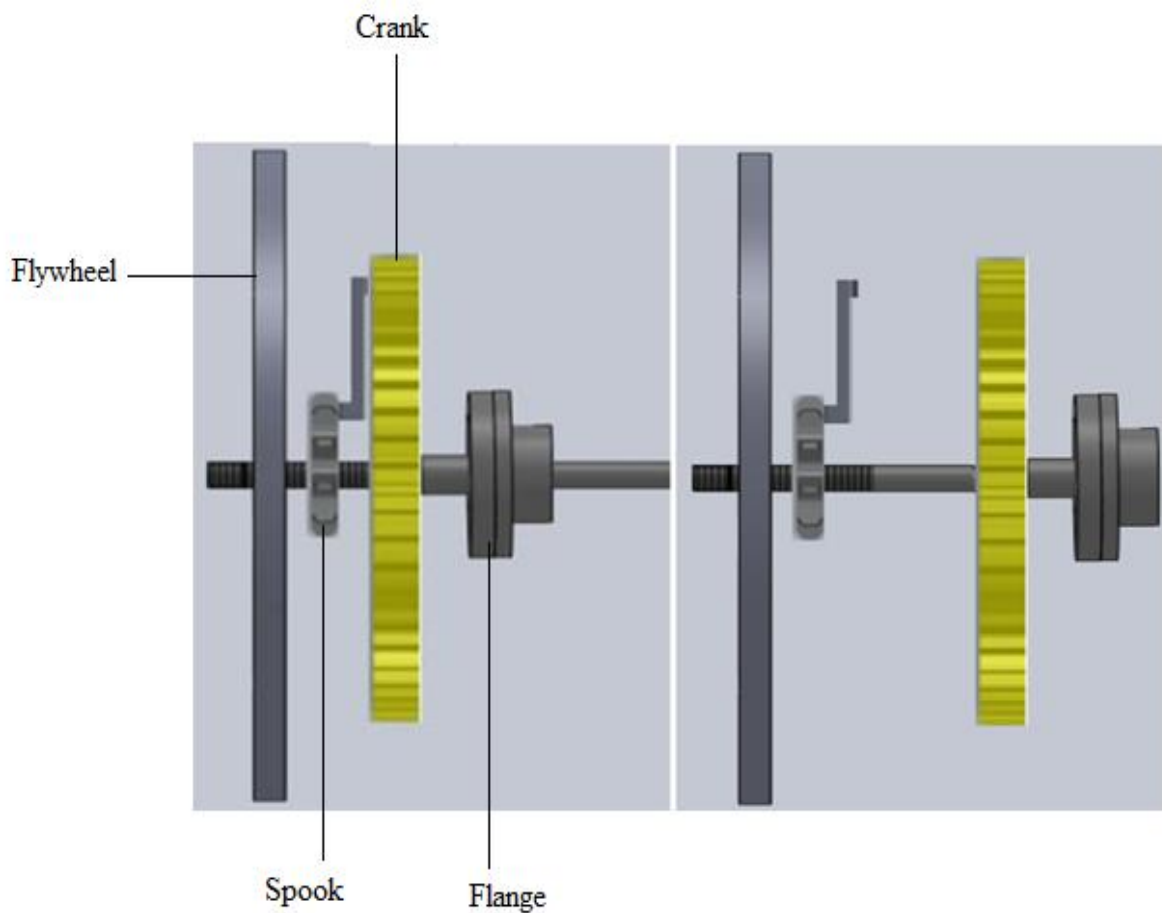


Figure 2. A picture of the total flywheel system. The flywheel is represented as a simple disc instead of a wheel rim (a) The system in its default state. (b) The charging phase for the flywheel [2]

A comparison of other battery energy storage and regenerative braking with KERS and observed by Cibulka, J. [3] that in comparison with other battery storage technologies, KERS offers: Cycle durability- 90% efficiency of flywheel (including power electronics) in both directions during KER reference duty cycle. Extensive operating temperature range. Steady voltage and power level, which is independent of load, temperature and state of charge. High efficiency at whole working speed range. No chemistry included thus, no environmental pollution and great recycling capability.



Figure 3. Flywheel rotor of storage subunit [3]

U. Mugunthan, U. Nijanthan have been performed an overdrive test to observe the efficiency of bicycle. It has been found out that the flywheel supplies an energy with which the cycle could move forward by 10% of the given input. Depending upon the input given, the efficiency varies. But only 10% can be obtained by this principle. This system when installed in vehicles would save a greater amount of energy lost during the braking of the vehicle. This energy can be stored and can be reused when needed [4]. It is more efficient when compared to the conventional braking system. We would conclude that, this recovery system has to be developed further and has a wide range of research which can be conducted in the future.

2.3 Comparative Study

a. Mechanical KERS

In this system the energy is stored by means of either flywheel or spring. Here the braking energy is used to turn a flywheel or spring and when extra power is needed the wheels are coupled up to the spinning flywheel to give a boost in power or springs are released to restore the energy into the main. The system is completely based on a carbon flywheel in a vacuum that is linked through a CVT transmission to the differential. With this a huge storage reservoir can store the mechanical energy and the system holds the advantage of being independent of the gearbox. The braking energy is used to turn the flywheel and when more energy is required the wheels of the car are coupled up to the spinning flywheel. This gives a boost in power and improves racing performance.

b. Electrical KERS

With this system when brake is applied to the vehicle a small portion of the rotational force or the kinetic energy is captured by the electric motor mounted at one end of the engine crankshaft. The key function of the electric motor is to charge the batteries under braking and releasing the same energy on acceleration. KERS components for battery storage systems are: Electric Propulsion Motor /Generator. Power Electronics – Inverter, and the Quad Flywheel Storage. Electric Propulsion Motor and Generator in one are also known as an MGU – Motor Generator Unit. Capacitors are fundamental electrical circuit elements that store electrical energy in the order of microfarads and assist in filtering.

Electrical KERS brake consists of a driving wheel linked with a rotary shaft, a motor, a battery charging circuit, a set of batteries or another storing device.

c. Hydraulic KERS

In a hydraulic accumulator the potential energy is stored in the form of a compressed gas or spring, which is used to exert a force against an incompressible fluid. Accumulators store energy when the hydraulic system pressure is greater than the accumulator pressure and releases hydraulic energy in the opposite case. Regenerative braking in vehicles using a variable displacement hydraulic pump/motor together with a hydro-pneumatic accumulator has attracted considerable interest during the last 20–25 years. Such a system is particularly suitable for application in city buses. Despite the significant gains in the efficient use of energy that can be brought about by hydro-pneumatic regenerative braking, its use has not attained great popularity. The added cost, which may represent 10–15% of the total for the vehicle, is undoubtedly a deterrent.

d. Hydro-Electric KERS

In this system the combination of electric and hydraulic system is used to store the energy. Hydraulic accumulator has the characteristics of higher power density and is well suited for frequent acceleration and deceleration under city traffic conditions. It can provide high power for accelerations and can recover more efficiently power during regenerative braking in comparison with electric counterparts. However; the relatively lower energy density brings the packaging limit for the increasing accumulator size. The regenerative component consists of, 1. A fixed displacement hydraulic pump/ motor. 2. A hydro-pneumatic accumulator. A hydraulic-accumulator/battery hybrid energy system, called hydraulic/electric

synergy system (HESS), is designed to overcome the drawbacks of existing single energy storage sources used in heavy hybrid vehicles.

Chapter 3: System Design

3.1 Design Constraints and Methodology

- Time constraints- To achieve the goal and objectives, the design should be in working condition in five weeks. All the requirements should be fulfilled within the limit specified.
- Economic constraints-The cost of this design should be minimum to make it feasible and cost should be less than SR2500. The cost includes the estimated cost of the components price of equipment and installation cost.
- Safety Constraints- The design should be safe to implement, and it should not affect the health of the inhabitants. Safety is foremost priority in this design to ensure the protection of lives and properties. The design system should operate accurately to ensure safety constraints.
- Geometrical Constraints- The dimension of the project should be within the bounded limits of the bicycle. Appropriate size will be selected for the flywheel so that it can be fitted to bicycle on both sides easily.
- Sustainability- Only those components will be selected that are environment friendly. Any material that can disrupt the eco system or can have severe consequences on the health of people should not be selected.
- Manufacturability- The design should be feasible to manufacture, and it should be easily manufactured by using the machines available in the laboratory. Such as Lathe and milling machine.
- Social and Environmental impact- The design will have direct influence on the lives of people as it will provide a comfortable room environment. The design should have no impact on the environment as all the material and equipment used are safe for the environment and it emits no pollutant which can disrupt the eco-system as in case of air conditioner which emits harmful byproducts.
- Ethical Constraints- All the finding of the project will be presented in objective and truthful manner. The fabrication of data will be discouraged at all the phases of the project, whether project is in working condition or not.

3.2 Engineering Design Standards

The engineering design standards of ASME will be followed, such as the performance tests codes to evaluate the working performance of flywheel. ASME performance test codes states that Performance test codes provide a “level playing field” for both manufacturers and users of the equipment or systems. Purchase specifications are greatly strengthened by citing the results of PTC tests. When buying new equipment, purchasers may specify that the equipment guarantee will be based on the results of a specific ASME PTC test. The other standard that will be used in this project is ASME Y14.5 which incorporate technical innovations making it compatible with electronic systems, such as Computer Aided Design (CAD), Computer Numerical Controlled (CNC), and Coordinate Measuring Machines (CMM), as well as computerized dimensional tolerance analysis systems. The Y14.5 standard is considered the authoritative guideline for the design language of geometric dimensioning and tolerancing (GD&T.) It establishes uniform practices for stating and interpreting GD&T and related requirements for use on engineering drawings and in related documents’ is an essential tool for communicating design intent — that parts from technical drawings have the desired form, fit, function and interchangeability. By providing uniformity in drawing specifications and interpretation, GD&T reduces guesswork throughout the manufacturing process — improving quality, lowering costs, and shortening deliveries.

3.3 Theory and Theoretical Calculations

For the flywheel, when it rotates it will cause gyroscopic forces which can cause imbalances when riding the bicycle. Positioning, weight and size altogether can affect these gyroscopic forces and at the same time affect the performance of the flywheel.

Calculation for the energy stored in the flywheel:

Weight of the person riding the bicycle	= 70kg
Weight of bicycle	= 10kg
Other payloads	= 10kg
Allowance for flywheel weight	= 15kg
Total weight	=104kg

Let us assume that the flywheel stores enough energy to take the whole system from rest to 10km/hr in 5sec.

$$v = 10\text{km/hr} = 50/18 = 2.78\text{m/sec}$$

$$u = 0\text{km/hr} = 0\text{m/sec}$$

$$\text{Time} = 5\text{sec}$$

$$a = (v - u) / \text{Time}$$

Energy of the system when it reaches 10km/hr = E

$$E = \frac{1}{2}mv^2 = 401.876 \text{ joules}$$

The diameter of the flywheel will be 10 inches.

The gain we get from a flywheel must be measured against the extra power required to move the bicycle from the extra weight of the flywheel. Extra work is needed to accelerate the bike because of the flywheel. Therefore, the efficiency gained from the flywheel can be shown as:

$$\epsilon_{total} = \epsilon_{gained} - \epsilon_{lost}$$

The efficiency gained can be expressed as the energy stored in the flywheel (from the above section) over the total energy in the bike. The efficiency lost can be expressed as the energy required to push the extra weight of the bike over the total energy in the bike.

$$\epsilon_{total} = \frac{E_{flywheel}}{E_{total}} - \frac{E_{fly accel}}{E_{total}}$$

The equation for the rotational kinetic energy for the flywheel is given as:

$$E = \frac{1}{2} cmr^2 \omega^2$$

So, equation for the total energy becomes.

$$\epsilon_{total} = \frac{\frac{1}{2}\eta cm_f \omega^2 r^2}{\frac{1}{2}m_{total}v^2} - \frac{\frac{1}{2}m_f v^2}{\frac{1}{2}m_{total}v^2}$$

where ϵ is the efficiency, η is the efficiency of the transmission, m_f is the mass of the flywheel, and v is the velocity of the bike.

The flywheel design should minimize the mass of the flywheel in favor of a larger radius or faster speed, since the total efficiency will be much higher. The considerations of stress are also accounted in the design. The stress is given by the following equation:

$$\sigma = \frac{1}{2} \rho r^2 \omega^2$$

Where ρ is the density of the material.³ Usually the key for material selection of a flywheel is the highest possible tensile strength over density. The maximum stress a bike can handle is the tensile strength, so

$$\sigma_{max} > \frac{1}{2}\rho r^2 \omega^2$$

The stress analysis for the design will be performed on the software using finite element analysis. All parts of the design will be subjected to different loads.

The equations for the flywheel design are as follow:

$$E = I\omega^2$$

$$E = I\omega^2 - \frac{1}{2}mf v^2$$

$$I_{hollow} = m_f r^2$$

$$I_{solid} = \frac{1}{2} m_f r^2$$

Another consideration when adding a flywheel to a bike is the possible stability issues with the torque the flywheel will create. When making a turn this force could possibly push the bike into the ground. The expression for the gyroscopic moment is:

$$M = I\Omega \times \omega$$

Where M is the gyroscopic moment, I is the moment of inertia, Ω is the angular velocity caused by the bike, either by tilting or turning, that the flywheel is experiencing, and ω is the angular velocity of the rotation of the flywheel.³ Whether or not this force is significant in the stability of the bike, it can easily be avoided by counter rotating flywheels. This stability problem should not be a factor since bike wheels themselves rotate and generate the same force and remain very stable when turning. It has been shown that the gyroscopic moment of a bike is not the reason for its stability. A bike was made with counter-rotating hoops to cancel out the gyroscopic moment of the wheels.

Tests will be done on the bike when the hoops were rotating in the direction opposite of the wheels, with the wheels, and with no rotation at all. In all three cases the bike was rideable, which in our case shows that the added moment the flywheel contributes will not make the bike unrideable.

The clutch that will be used for the flywheel will use a caliper-like system to engage and disengage the two gears, which will shift the gear ratio. The equations for the clutch are as follow:

$$\sum M_A = F_b - N_b + fNa$$

$$F = \frac{p_a(b-fa)}{b}$$

3.4 Product Subsystem and Selection of Components

The product subsystems are shown in the following diagram:

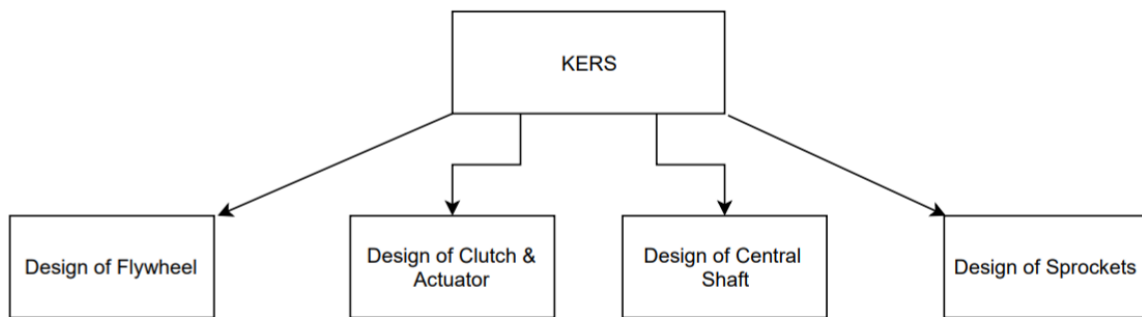


Figure 4. Product Subsystem

From the Figure 4, it can be observed that the design has four main subsystems. The first one is the design of flywheel, second one is the design of clutch and actuator, third one is design of central shaft and final one is the design of sprockets. All the product subsystems will be designed using bottom up strategy. In this strategy all the subsystems will be designed one by one according to the design specifications and dimensions. At the end all the subsystems will be integrated together to make the final product which is the kinetic energy recovery system.

3.4.1 Selection of Components

A. Selection of Flywheel

There are different kinds of flywheel available, but the suitable designs for the flywheel are single mass flywheel and dual mass flywheel. In order to select it the decision matrix will be employed which will select the suitable flywheel based upon the criteria matrix. The Table 1 shows the decision matrix developed to select the best choice for flywheel against criteria. Based upon the criteria the best choice is single mass flywheel due to its less weight and efficiency.

Table 1. Decision Matrix for Flywheel

Criteria	Weight factor	Dual Mass Flywheel		Single Mass Flywheel	
		Rating	Score	Rating	Score
Cost	0.15	3	0.45	5	0.75
Efficiency	0.25	3	0.75	4	1
Less Weight	0.55	2	1.1	5	2.75
Reliability	0.05	4	0.2	4	0.2
Score	1		2.5		4.7

B. Selection of Clutch

The different types of clutches are used in bicycles, such as single plate and dual plate clutch. The selection of clutch will be based upon the decision matrix technique, based upon certain criteria.

Table 2. Decision Matrix for Selection of Clutch

Criteria	Weight factor	Single Plate Clutch		Dual Plate Clutch	
		Rate	score	Rate	score
Reliability	0.668	4	2.672	3	2.004
Efficiency	0.243	5	1.215	5	1.215
Durability	0.088	5	0.44	5	0.44
Score	1		4.327		3.659

The Table 2 illustrate the decision matrix to select the clutch for the design against specified criteria. According to the criteria and the weightage, factor best option is the single plate clutch due to its reliability.

C. Selection of Central Shaft

The two types of central shafts are considered in this project, the first one is the driving shaft and the second one is the propeller shaft. Based upon the design specifications a decision matrix table is developed to select the best component.

Table 3. Decision Matrix for Selection of Central Shaft

Criteria	Weight factor	Driving Shaft		Propeller Shaft	
		Rate	Score	Rate	score
Durability	0.668	4	2.672	3	2.004
Power	0.243	5	1.215	2	0.486
Cost	0.088	5	0.44	4	0.352
Score			4.327		2.842

D. Selection of Sprocket

The alternatives for the sprockets are roller chain sprocket and the differential sprockets. In order to select the best alternative, the decision matrix table is developed shown in table 4. According to the specifications for sprocket, highest score is gained by roller chain sprocket as shown in Table 4.

Table 4. Decision Matrix for Selection of Sprocket

Criteria	Weight factor	Roller Chain Sprocket		Differential Sprocket	
		Rate	Score	Rate	score
Cost	0.668	5	3.34	4	2.672
Durability	0.243	4	2.972	4	2.972
Smooth Operation	0.088	4	0.352	3	0.264
Score	1		6.664		5.908

3.5 Manufacturing and Assembly

The design was made in SolidWorks. The design of flywheel is given in the following figure.

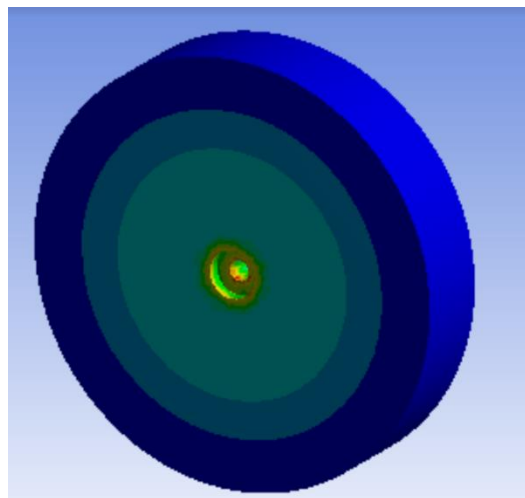


Figure 5. Design of Flywheel on SolidWorks

The design of sprocket is given in the Figure 6.

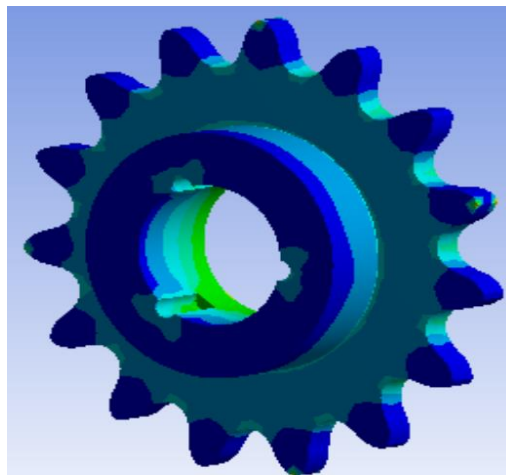


Figure 6. Design of Sprocket

The design of the central shaft is shown in the Figure 7.

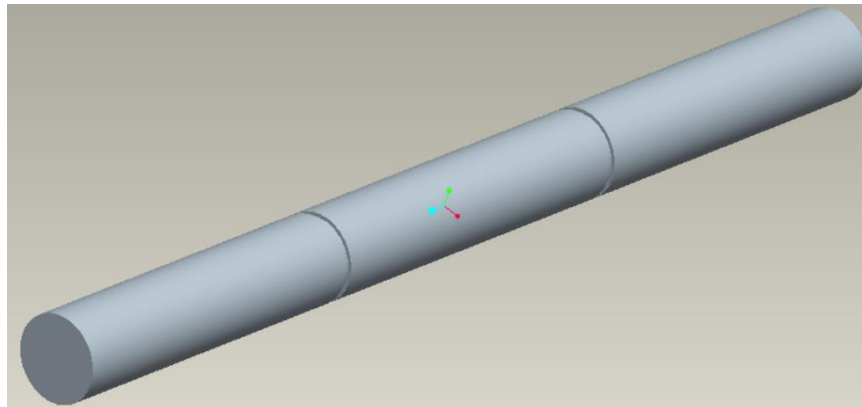


Figure 7. Design of Central Shaft

The design of the clutch actuator is shown in the Figure 8.

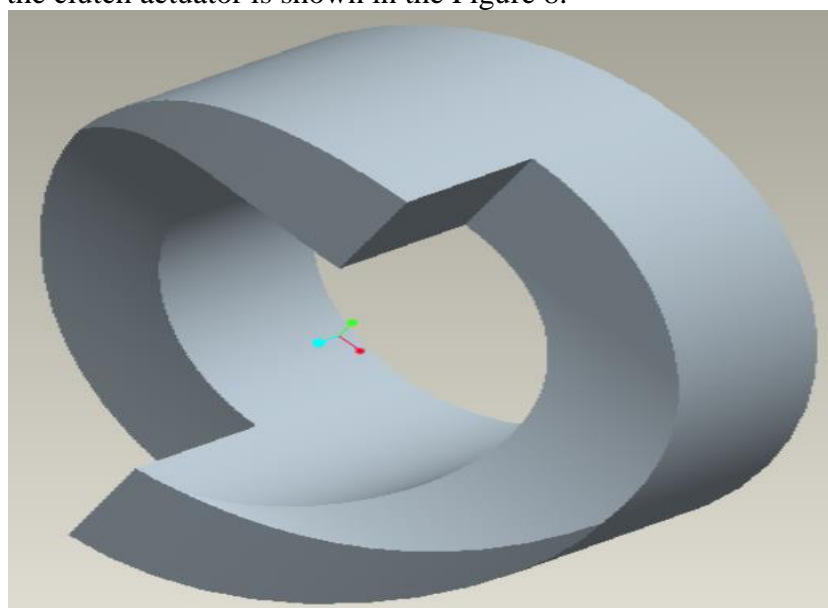


Figure 8. Design of Clutch Actuator

The design of the clutch is shown in the Figure 9.

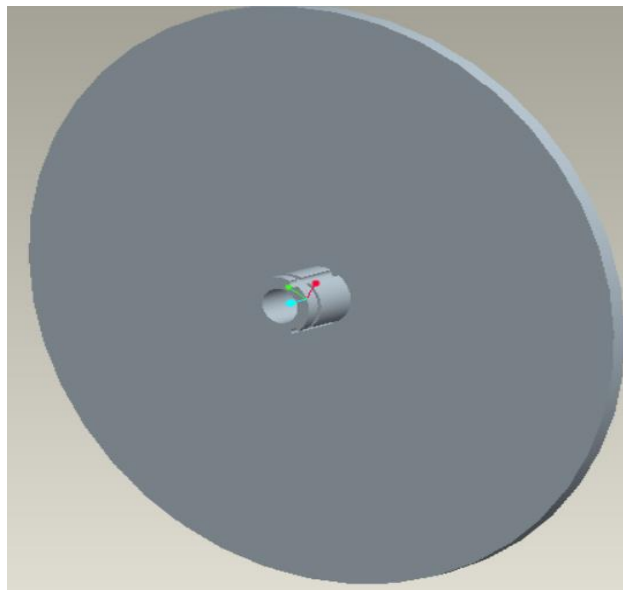


Figure 9. Design of Clutch

The design of the ball bearing is shown in the Figure 10.

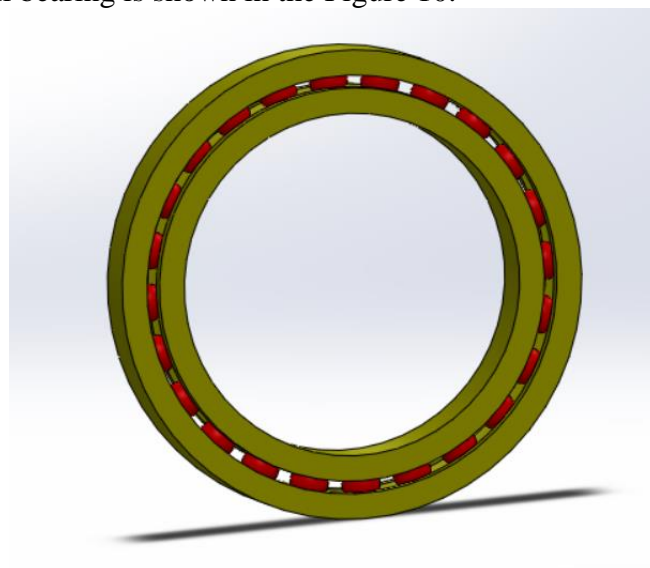


Figure 10. Design of Bearing

The bearing (SKF 6001-2Z) will rest inside the flywheel and will be covered in oil. The purpose of the bearing is to take the torque load from the flange and not transmit it to the endpiece to allow for a successful clutch actuation.

Our Initial Design:

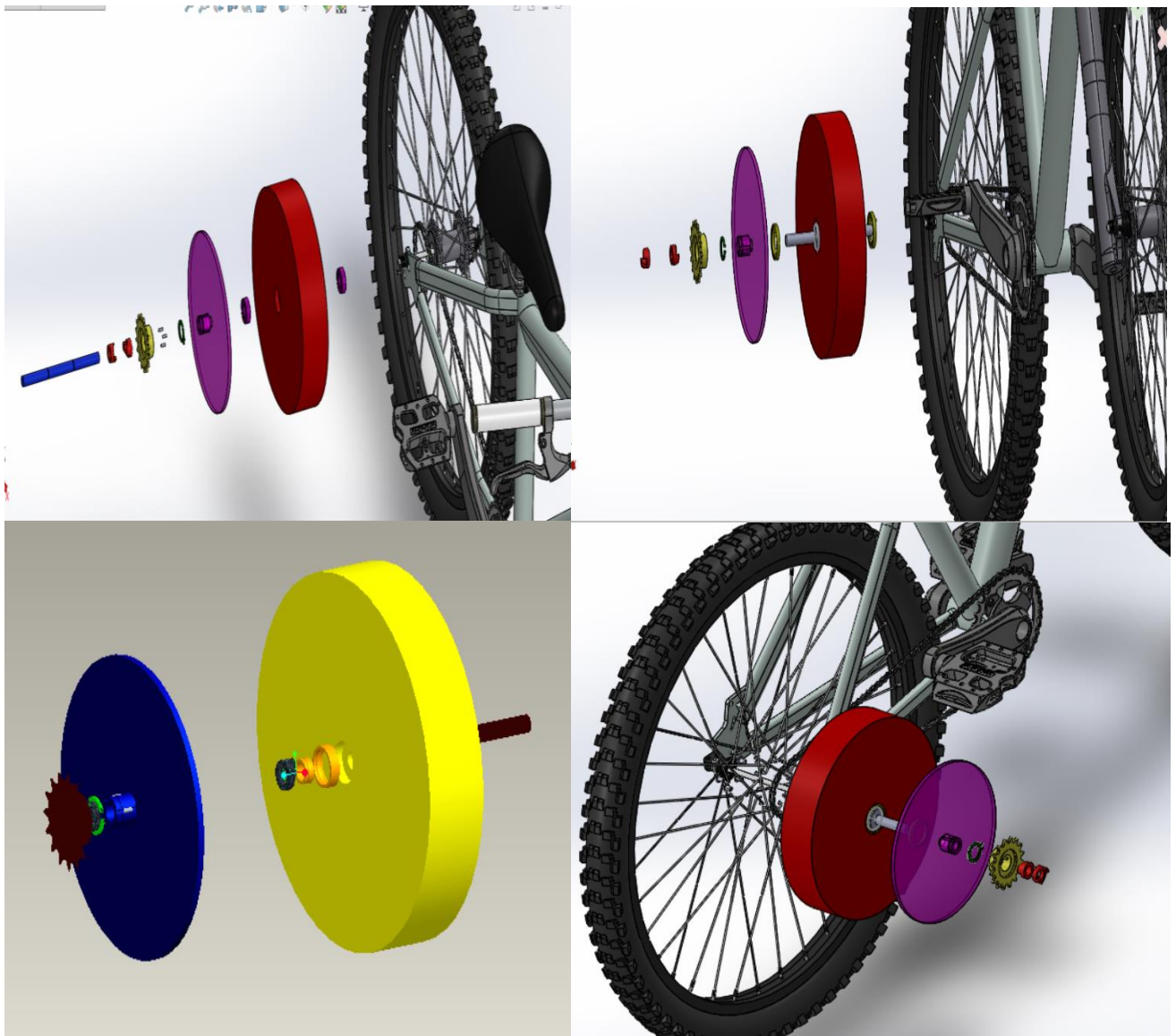


Figure 11. Exploded Assembly of Overall Design



Figure 12. Final Assembly of the Design with Bicycle

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Specialized P1 Jump Bike		1
2	clutch_actuator		2
3	central shaft		1
4	Sprocket		1
5	clutch		1
6	pin		3
7	big_clamp		1
8	Rywheel		1
9	Bearing 27x37		2

Complete Assembly

Figure 13. Bill of Materials

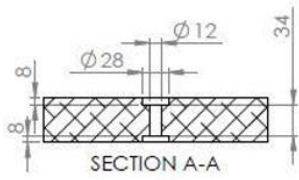
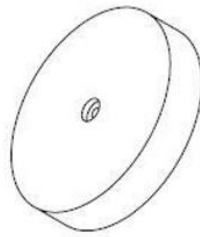
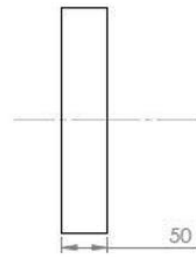
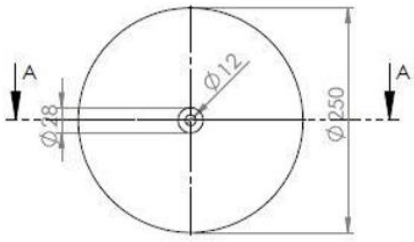
Unfortunately, due to complications we couldn't settle with this design where the flywheel is held next to the rear tire. We have gone to the design on which we based the project on, where the flywheel will be held in the frame of the bicycle underneath the seat.

Diameter of 25cm.

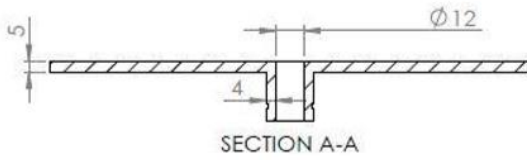
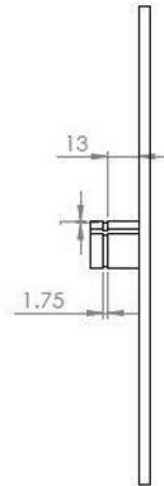
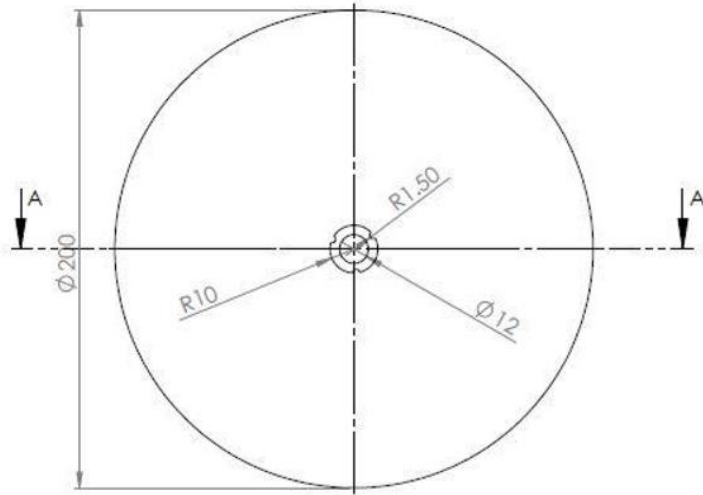


This design still uses the same system and assembly, only the positioning is different. We haven't noticed any major problems with the gyroscopic forces from this positioning of the flywheel.

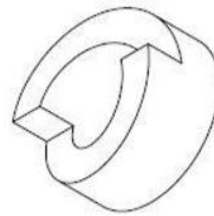
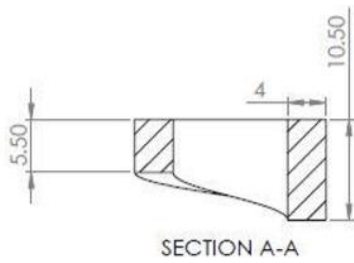
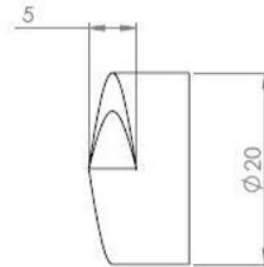
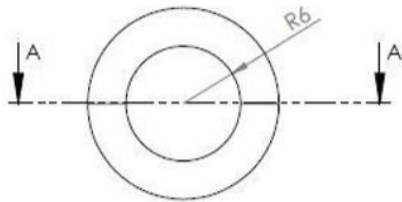
2D Drawings of Parts:



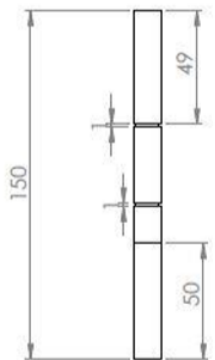
TITLE: Flywheel	
Design of KERS for Bicycle	
MATERIAL: Aluminium	DWG NO. KERS-01
SCALE: 1:5	



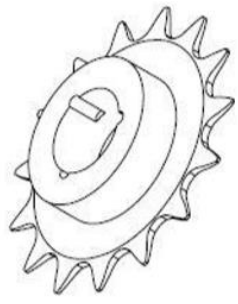
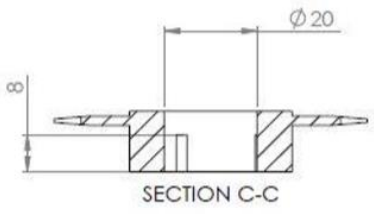
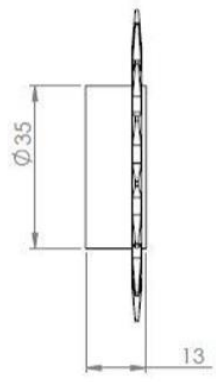
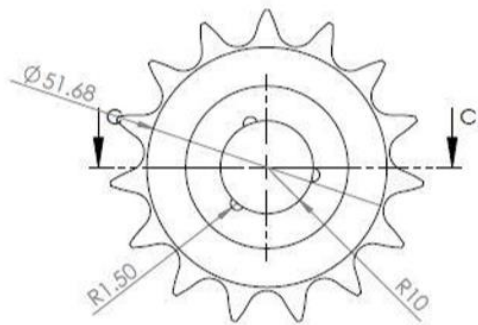
TITLE: Clutch	
Design of KERS for Bicycle	
MATERIAL: Aluminium	DWG NO. KERS-02
SCALE:1:2	



TITLE: Clutch Drive	
Design of KERS for Bicycle	
MATERIAL: SS304	DWG NO. KERS-04
SCALE:2:1	



TITLE: Central Shaft	
Design of KERS for Bicycle	
MATERIAL: SS304	DWG NO. KERS-05
SCALE: 1:2	



TITLE: Front Sprocket	
Design of KERS for Bicycle	
MATERIAL: SS304	DWG NO. KERS-03
SCALE: 1:1	

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and Data Acquisition System

The experimental setup consisted of a speedometer and a stop watch. The bicycle was run between the specific point having same distance. The distance was kept fixed in the whole experimental setup. The distance was kept 0.5km. The speedometer was installed inside the rear wheel of the bicycle to measure the speed of the bicycle. The stopwatch was used to measure the time taken by the vehicle to cover the distance between the two points.



Figure 14. Experimental Setup Showing Speedometer

The specifications of the design include its low cost, maximum speed 60 km/h, and the calculation of distance as the bicycle is moved. The installation procedure for this speedometer was also simple and can be connected easily to the rear bicycle wheel or front wheel.

The experiment was performed by taking 6 trials of the bicycle without engaging the flywheel and 6 trials with engaging the flywheel. Maximum speed and the average speed

during each trial was determined. The data was calculated for all the trials for further analysis.

4.2 Result, Discussion Analysis

Experimentation was done using the fabricated bicycle to evaluate the performance of KERS, when used in a bicycle. The findings are shown below in tabular form:

Table 5. Data Recorded with KERS system Engaged

Distance Travelled (km)	Avg. Speed (km/hr)	Maximum Speed (km/hr)
0.5	10.4	15.7
0.5	12.7	16
0.5	12.4	16.8
0.5	13	17
0.5	12.1	17.2
0.5	11.2	17.4

Table 6. Data Recorded with KERS system Engaged

Distance Travelled (km)	Avg. Speed (km/hr)	Maximum Speed (km/hr)
0.5	15.8	20
0.5	16.2	21
0.5	15.4	19
0.5	16.6	22
0.5	15.6	20
0.5	16.4	22

The plot of the data for speed vs trials is given as follow:

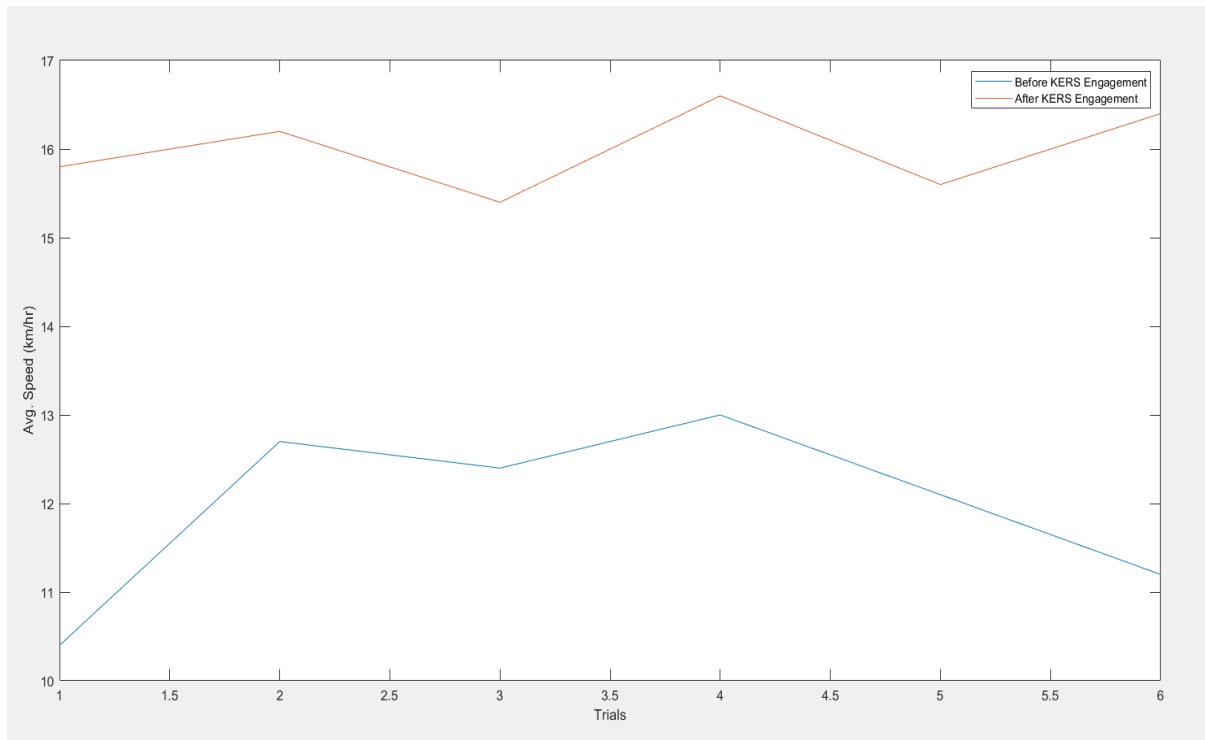


Figure 15. Graph for the Experiment

The table for percent increase in speed is as follow:

Table 7. Analysis of Results

Avg. Speed (km/hr) Before Engagement	Avg. Speed (km/hr) After Engagement	% Increase in Speed
10.4	15.8	34%
12.7	16.2	22%
12.4	15.4	19%
13	16.6	22%
12.1	15.6	22%
11.2	16.4	32%
Average		25%

5.1 Project Plan

Table 8. Project Plan

Task	Start Time	End
Submitting Proposal	11/5/2018	11/10/2018
Select Type of KERS System	11/15/2018	11/23/2018
Theoretical Design of Flywheel	12/10/2018	12/20/2018
Theoretical design of Clutch & Actuator	1/8/2019	1/12/2019
Theoretical Design of Central Shaft	1/14/2019	1/18/2019
Theoretical Design of Sprockets	1/20/2019	1/27/2019
SolidWorks Design of Flywheel	2/8/2019	2/13/2019
SolidWorks Design of Clutch & Actuator	2/15/2019	2/23/2019
SolidWorks Design of Central Shaft	2/25/2019	2/28/2019
SolidWorks Design of Sprockets	3/8/2019	3/16/2019
SolidWorks Design of Bicycle	3/20/2019	3/23/2019
Integration of KERS with Bicycle in Solidworks	3/28/2019	3/30/2019
Selection of Material and Hardware Design of Project	4/1/2019	4/4/2019
Testing of Results	4/6/2019	4/10/2019
Documentation of results	4/10/2019	4/12/2019
Submission of Report		4/14/2019
Final Presentation		4/18/2019

5.2 Contribution of Team Members

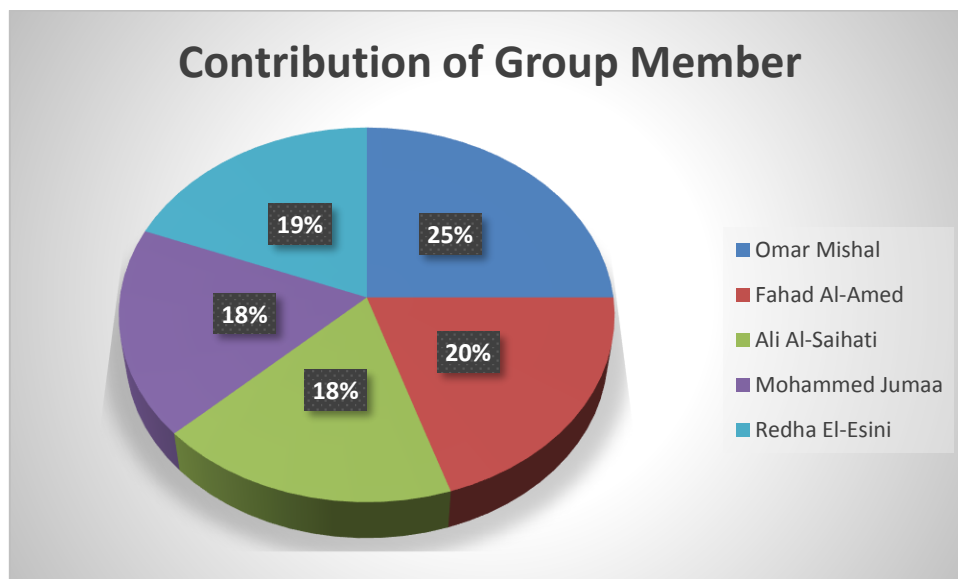


Figure 16. Pie Graph Depicting Contribution of Group Members

5.3 Project Execution Monitoring

Table 9. Project Execution Monitoring Chart

Date	Meeting with Group	Meeting With Supervisor
11/1/2018		
11/6/2018		
1/15/2019		
2/25/2019		
3/18/2019		
3/22/2019		
3/29/2019		
4/1/2019		
4/5/2019		

5.4 Challenges and Decision Making

The first challenge was faced during the theoretical calculation of flywheel regarding the selection of diameter. To solve it finite element analysis was done to see which diameter has more durability. The second challenge was faced regarding the design of flywheel while making hardware, because the flywheel was thick and heavy, this challenge can be solved by boring small holes in flywheel or/and choosing lightweight material to reduce weight without impacting the moment of inertia of the flywheel. Third, the initial design where we wanted to place the flywheel on the rear tire had some problems with how our planned mechanism would work which we had overlooked, this required us to move the position of the flywheel to be under the bicycle's seat. Fourth, although the time and help the university provided was gracious, we still felt as if time was a major challenge.

5.5 Project Bill of Materials and Budget

Table 10. Bill of Materials and Budget

Component #	Description	Cost per Unit	No. of Units used	Total Cost
1	Flywheel	SR500.00	1	SR500
2	Pins	SR2.50	4	SR10.00
3	Bearings	SR20.00	1	SR20.00
4	Sprockets	SR10.00	1	SR10.00
5	Clutch	SR500	1	SR500.00
6	Actuator	SR25.00	1	SR25.00
7	Shaft	SR150.00	1	SR150
8	Chain	SR15.00	1	SR15
9	Speedometer	SR130.00	1	SR130.00
Grand Total Price				SR1360.00

Chapter 6: Project Analysis

Life-long Learning

We acquired lot of new things in this project specially giving a conceptual idea a physical form and how different software and tools can help in converting an idea into a desired shape. The software we work on was SolidWorks which is a good tool to develop a conceptual idea into rendering shape. We use this software to develop our design, we fabricated some parts of our design and bought the rest and then assembled all the parts together. We also learn how to give a virtual design a hardware shape using different machines such as lathe machine, milling machine etc. The other skills we learn in this project consisted of time management and project management. We learn how to utilize our time to build a project in short period of time, in this process we also learn about the efficiency of working in team and how things can be quickly built by assigning different tasks to group members.

Impact of Engineering Solution

Developing a sustainable solution was the core of this project, because wastage of energy is one of the main problems globally. Real-world problems presented through service-learning helped us to engage in active learning and problem solving, which can develop sustainability knowledge, create new perspectives and provide us with exposure to authentic techniques in the practice of engineering.

6.3 Contemporary Social Issues Addressed

The social issues addressed in this project are waste of energy, since there is a waste of energy whenever you use brakes on a bicycle, this system will help with recovering some of the lost energy and redirect it back to the system. Lack of physical activity, we see many innovative designs today for commuting and a system like this may help motivate others to consider a bicycle as a preferred method of transportation, which in return will help with the lack of physical activity. Finally, this design does not emit any harmful gases or byproducts, which will help contribute to reducing global emissions.

Chapter 7: Conclusion and Recommendations

Conclusion

The goal of this project was to develop a project based upon the kinetic energy recovery system. Theoretical calculations were performed for all parts and the constraints and specifications were followed while theoretical calculations. After theoretical calculations design was given a virtual view in SolidWorks software and all parts for the design were made. After, the successful development of software the design was fabricated using steel as the main material apart from the shaft which was SS304. The tools utilized in the projects were lathe machine and milling machine. The final testing of the design was done by performing 6 trials without KERS engaged and 6 trials with KERS engaged. It was found that there was an average 14% increase in speed of the vehicle with KERS system. Hence the design was successful but could be optimized even more.


Recommendations

It is recommended that a dynamo can be installed in the bicycle to convert the mechanical energy into electrical energy which can be used to charge a battery, this battery can have multiple uses, whether to charge a phone or maybe even be used to provide power to a motor for an even easier use of the bicycle.

8. References

- [1] Boretti, Alberto A. "A fun-to-drive, economical and environmentally-friendly mobility solution." *Journal of Power Technologies* 93.4 (2013): 194-201.
- [2] Ludlum, Kevin. "Optimizing Flywheel Design for use as a Kinetic Energy Recovery System for a Bicycle." *Senior Theses, Pomona College, Claremont, California* (2013).
- [3] Cibulka, J. "Kinetic energy recovery system by means of flywheel energy storage." *Advanced Engineering* 3.1 (2009): 27-38.
- [4] Mugunthan, U., and U. Nijanthan. "Design & Fabrication of Mechanism for Recovery of Kinetic Energy in Bicycle Using Flywheel." (2015): 2250-2459.

Appendix A: Progress Reports


	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering Prince Mohammad bin Fahd University

SEMESTER:		ACADEMIC YEAR:	
PROJECT TITLE	Design of Private energy recovery system for vehicle		
SUPERVISORS	Dr. Raga Kammah		

Month:

ID Number	Member Name
Omar Mishal Alghamdi	201301426
Fahad Al-Ahmed	201401314
Ali Al-Saihati	201401357
Mohammed Jumaa	201400992
Redha El-Esini	201402016

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Mid-term Presentation	All team member	100	
2	Collecting all Components	Omar, Fahad And Ali	100	
3	Result and Discussion	Redha and Mohammed	100	

List the tasks planned for the month of April and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Writing all chapters	All team member
2	System testing and analysis	All team member
3	Preparing Final Presentation	All team member

- To be Filled by Project Supervisor and team leader:
- Please have your supervisor fill according to the criteria shown below

Outcome f:
An understanding of professional and ethical responsibility.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d:
An ability to function on multidisciplinary teams.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	Omar Mishal Alghamdi	4	4	4	4
2	Fahad Al-Ahmed	4	4	4	4
3	Ali Al-Saihati	4	4	4	4
4	Mohammed Jumaa	4	4	4	4
5	Redha El-Esini	4	4	4	4

Comments on individual members

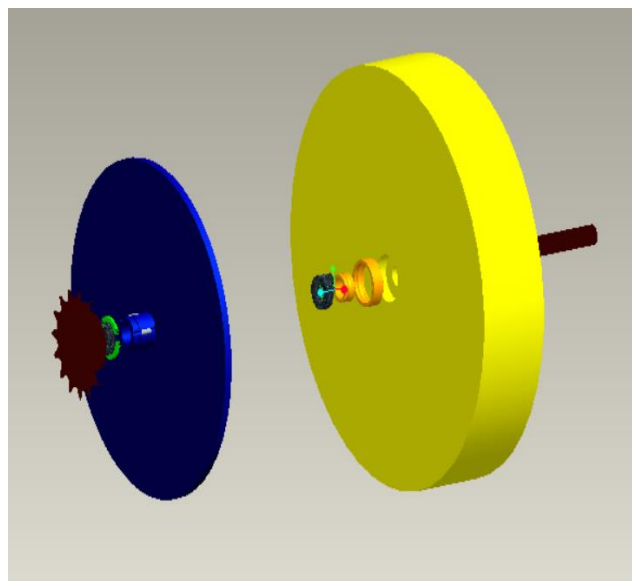
Name	Comments

H. O. Ras

Appendix B: Engineering Standards

Item	Standard
Flywheel	ISO 683-17
Central Shaft	SS304
Clutch	ISO 683-17
Clutch Actuator	ISO 683-17
Sprocket	ISO 683-17
Ball Bearings	SKF 6001-2Z
Clamps	IS 3075 NE-11

Appendix C: CAD DRAWINGS



Appendix D: Bill of Materials and Cost

Component #	Description	Cost per Unit	No. of Units used	Total Cost
1	Flywheel	SR500.00	1	SR500
2	Pins	SR2.50	4	SR10.00
3	Bearings	SR20.00	1	SR20.00
4	Sprockets	SR10.00	1	SR10.00
5	Clutch	SR500	1	SR500.00
6	Actuator	SR25.00	1	SR25.00
7	Shaft	SR150.00	1	SR150
8	Chain	SR15.00	1	SR15
9	Speedometer	SR130.00	1	SR130.00
Grand Total Price				SR1360.00

Appendix F: Operation Manual

- Operate the bike as usual
- When deciding to come to a slow, pull the added handlebar which actuates the clutch
 - The clutch will contact the flywheel and transfer energy from the bike to the flywheel and slow it down.
- Let go of the handlebar, the flywheel will not be in contact with the bike, and it will continue to rotate.
- Apply brakes and slow down to required speed/full stop.
- When you are ready to start moving again, pull on the handlebar again and the flywheel will be connected to the rest of the bike's system and it will give it a boost in acceleration.
- Let go off the handlebar after 2-3 seconds and continue riding the bike as usual.