REGENERATIVE BRAKES IN A BICYCLE USING KINETIC ENERGY RECOVERY SYSTEM

A final year project report

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by

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ABSTRACT

KERS commonly known as the kinetic energy recovery system that is basically a practical illustration of recovering the energy or in some cases momentum of a system of a moving vehicle that is lost during the braking. KERS basically stores that energy in the form of potential energy and it can be converted back into the kinetic energy when required. During the braking phenomena (when the brakes are applied) the kinetic energy is converted into heat energy (contact surfaces generate heat energy due to friction) and lost into the environment. But with the vehicle designed with the KERS system some part of that kinetic energy is stored in a flywheel as a result vehicle slows down.

The kinetic energy that is stored during this type of braking phenomena can be utilized by again converting it from potential energy into kinetic energy using the proper KERS mechanism. It will help in accelerating the vehicle. So using the concept of KERS system we will be developing the regenerative brakes in a bicycle. We will be using the variable moment inertia flywheel to develop this system.

PREFACE

The aim of this project is to introduce the concept of regenerative brakes and demonstrate the concept of variable moment inertia flywheel using this. And we also know that the bicyclist knows the pain to gain the momentum which it has lost during the braking. He has to push those paddles hard again to regain that momentum. So if the bicycle with KERS system can be designed it may revolutionize this industry. There is not much work done in this field so extensive development and research can be done in this field. As this is pollution free technology and use of flywheel in a bicycle can increase the efficiency of a bicycle. This is also one of the reasons that we are opting for this project.

ACKNOWLEDGMENTS

The project is highly inspired by the practical influence of the innovative designs. It took a lot of effort to unearth the idea of this project. The active participation and collaborative work has blessed us with various learning opportunities. We would like to acknowledge the efforts of our project supervisor **Engr. M. Naweed Hassan**. His diligent advising and supervision helped us to complete our project in allocated time. The efforts of **Dr Mian Ashfaq Ali** can also not be ignored who supported and encouraged us at various stages of this project. The people who were involved with us in this project also hold a significant positon and we would like to thank our family and friend for immense support and best wishes. It gives us great pleasure to complete our final year project with reliable and feasible results.

ORIGINALITY REPORT

We hereby declare that no portion of the work of this project or report is a work of plagiarism and the workings and findings have been originally produced. The project has been done without any partnership and has not been a support project of any similar work serving towards a similar degree's requirement from any institute. Any reference used in the project has been clearly cited and we take responsibility if found otherwise.

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ABBREVIATIONS

KERS Kinetic Energy Recovery System

CVT Continuous Variable Transmission

NOMENCLATURE

v= velocity of bicycle

r= radius of the rear wheel

FR = rolling resistance

Fac= Force required to take the bicycle from rest to 10km/hr. in 5 sec

P= power

FD = aerodynamics drag

CD = drag coefficient

A = frontal area of bicyclist and bicycle.

ρ= density of air

Ff = Other Frictional Force

EF = energy of flywheel

S= sprocket ratio

I= inertia of flywheel

m= mass of flywheel

T = torque transmitted to flywheel

d=center distance

n=no. of units of chain

L=length of chain

P= pitch of chain (length of one chain element)

FCM= minimum force from clutch drive

M.A= Mechanical advantage

$Fspring$= spring force

CHAPTER 1

INTRODUCTION

KERS:

It is a system to recover the Kinetic energy of a moving vehicle under braking. It stores the kinetic energy in the form of potential energy and converts it back to kinetic energy when needed [1].

Types of KERS system:

Now we have discussed the KERS system above. So we should also know that there are two main types of KERS system available that are becoming more popular day by day.

- Electrical KERS system
- Mechanical KERS system

Both the systems have their own advantages and disadvantages. One of the main difference between these two systems is that in Electrical KERS system the efficiency is not up to mark but it can successfully be used for the storage of power for a longer duration period. The versatility of storage can also be used for the manipulation of the related variables of torque and rpm. But on the other hand the Mechanical KERS system is more efficient but it does not store energy for the longer duration [2].

We can find many situations in which we wanted to store the kinetic energy for shorter duration of time. And bicycle can be one of the perfect examples for this specific situation. So that is one of the reasons why we have chosen the cycle for our project.

There are some other types of KERS system also available in the market [3].

- Hydraulic KERS
- Hydro-electric KERS

Formula F1:

As the formula one is famous for supporting the environment friendly technology. In 2009 F1 championship they allowed for the first time to use the KERS technology. William F1 was the first team ever to develop the flywheel KERS system. Later on due to some of the packaging issue they couldn’t carry the flywheel KERS system. Later on William Hybrid Technology developed the electrical KERS system on its own [4].

Flywheel:

First of all we will introduce the word flywheel. As most of you will be familiar with this term. Flywheel is energy storing device used for centuries for this purpose. It uses the significant amount of moment of inertia to store the rotational energy. Flywheel is used in different areas of engineering these days. Application of flywheel is widely spread. They are used in the steam engine, when we needed the uninterrupted power supply or in generators. Flywheels can always be known as large spinning masses from industrial age, but now they are finding innovative uses in various fields due to recent development in the field of material science. Now they can be found everywhere in the sea, land almost everywhere. Now a day’s flywheels are replacing the electrochemical batteries because of their environment friendly response. Since it is a developing field so they don’t have much advantage over the electrochemical batteries but they have the promising future for the hybrid technology cars [5].

Variable inertia flywheel:

Variable inertia flywheel is basically the energy storing device in which we vary the inertia of a rotating disk through different techniques. There are different designs of variable inertia flywheel through which the above objective can be achieved. Some of the designs are given below.

- Screw design flywheel
- Spring loaded with lever design flywheel
- Spring loaded flywheel
- Fluidic variable inertia flywheel.

Spring loaded flywheel design was used in which the small masses are attached to the spring. When the rpm is increased the masses will fly out towards the periphery and vice versa.

Organization of report:

Chapter 2 contains the literature review and has all the knowledge and information which would be used in designing the KERS. Whereas design and manufacturing of the project is included in the 3rd chapter. Chapter 4 contains the results obtained through implementing the KERS in the bicycle and the discussion on these results. It also contains the comparison of KERS and simple bicycle. Chapter 5 have the future recommendations for the project and conclusion of this report.

CHAPTER 2

LITERATURE REVIEW

Mechanical KERS:

There are basically different types of mechanical KERS available for bicycles:

- Clutch type KERS system
- CVT type
- Combined type KERS system

Clutch type KERS system:

As we have taken this project we have gone through many ideas after discussion with among ourselves and with the supervisor as well. Initially the idea was to develop the clutch type KERS system. In this system when the rider will apply the brakes it will activate the clutch and clutch would be engaged with the flywheel. As a result KERS system will start charging the flywheel. After few moments the vehicle will slows down and the rider now can disengage the KERS system and can apply the brakes. In this technology the KERS will be connected to the left brake handle and other brakes will be connected to the right brake handles (both front and the rear).

Some of its disadvantages are:

- This may not be very friendly to users. As in this the user has to plan many things when to engage and when to disengage. So as a result it might lose its concentration that could cause a fatal accident.

- No mild brakes can be applied only hard brakes will take place.
- It is a very risky chance to bring this product in the market as many customers will not prefer it

CVT type:

In this idea it was planned not to attach the clutch system. In fact the flywheel would be connected to the rear wheel directly through a chain. During the start the rider always has to keep the high gear ratio to charge the flywheel. And during the discharging the rider should always keep the low gear ratio to get the maximum benefit out of this. Safety factor is included in this design [6].

Some of the disadvantages are:

- This would require a large initial torque.
- The system might go under the wear and tear because of the continuous engagement.
- Friction loss would be high in this case.

Combined type:

So, as a result we discussed a lot on the above two ideas and we came up with the solution that why not we should combined the both of the above concept and make a hybrid of the above two ideas. If we combine the above two system in a way then we can eliminate all of the above limitation given and we can produce a much better product. This is the idea that we will be using in this project. The advantages of this type are many, few of them we would like to mention here.

- This is a very user friendly technology.

- Cost effective
- This idea is more marketable.
- Jerks are removed in this concept.

Design and Working Principal:

We will use different types of component in making the KERS bicycle. We would like to mention few of them here. SolidWorks 2015 is used to model these products and modeling of those products is shown in the later stage of this report.

- Clutch Plate
- Variable Inertia Flywheel
- Front Sprocket
- Clutch Drive
- Rear Sprocket
- Ball bearing
- Driving Chain
- Shaft
- Clamps
- Thrust

To have a better understanding how this KERS bicycle will work the working principal is as follows:

So, first thing is to actuate the KERS system and for this we have a lever attached near the handle. So, this lever basically pulls the wire that is connected to the clutch drive as a result it will undergo the rotational motion. A translational motion is also induces because of the counterpart that is fixed. Due to this motion clutch drive will push the clutch plate upwards so that the clutch plate could come in contact with the variable moment inertia flywheel. It is to be noted that clutch plate is a continuous rotating part that is connected with the front sprocket. The front sprocket is attached with the rear sprocket through a chain drive [7]. There are different sprockets attached to the rear sprocket so that the chain can change its position and it can attain the different gear ratio when required. One thing to be noted here is that these all are interconnected and they rotate with the same rpm of the rear wheel.

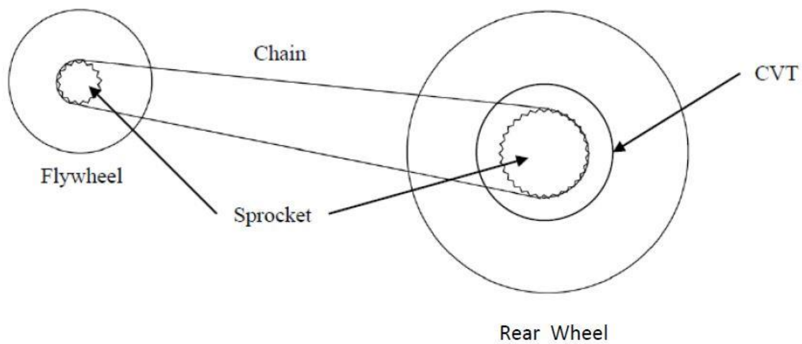


Figure 1: KERS Parts

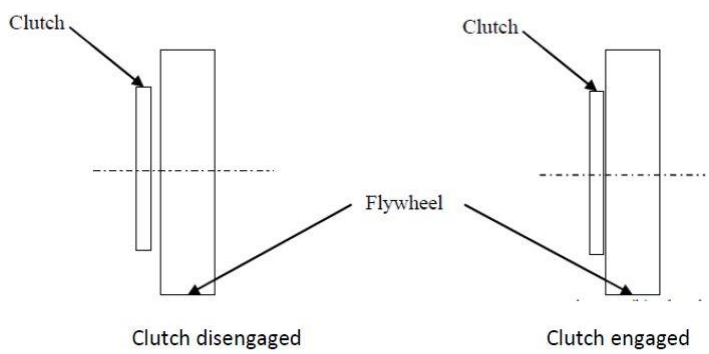


Figure 2: Clutch Engagement

We will use the higher gear ratio when we have to charge the flywheel but this will produce the initial jerk. So to remove this initial jerk we will engage the clutch initially with the lower gear ratio. And gradually we will move to the higher gear ratio. Another additional advantage of this mechanism is that the relative velocity of the variable inertia flywheel will decrease if we compare this value with the real value. As a result it will increase the torque on the flywheel and that will increase the acceleration of the flywheel. And the desired RPM could be attained smoothly.

During the discharging we will keep the gear ratio low. We have to reduce the gear ratio in successive intervals to avoid the jerk. This could be done for the longer duration of time and this could be attained by keeping the sprocket ratio (rear: front) low. One of the advantages of this is that when the gear ratio is low the relative velocity of flywheel will be more than the rear wheel which will subsequently accelerates the cycle.

We are using the variable moment inertia flywheel in this system to remove the remaining jerks in this mechanism. As in variable moment inertia flywheel it will gain momentum or charge the flywheel gradually by slowly allowing the masses to move outwards attached to the flywheel during the charging phase subsequently decelerating the bicycle. And during the discharging phase the masses are allowed to move towards the center of the flywheel gradually as a result accelerating the bicycle. The advantage of using the variable inertia flywheel instead of the constant inertia flywheel is to further smoothen the process and eliminating the jerks from the system.

The design we will be following of the variable inertia flywheel in this project will be similar to this figure:

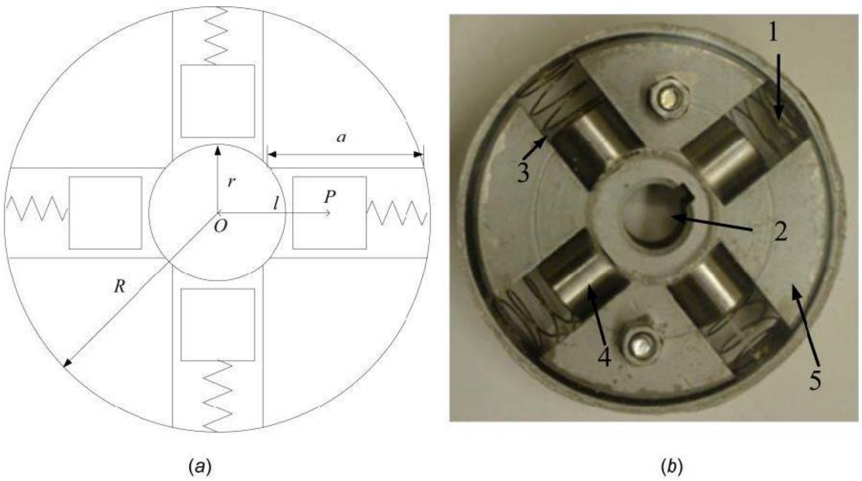


Figure 3: Spring Loaded Variable Inertia Flywheel

Working:

The major components of the system are shown in the figure [8].

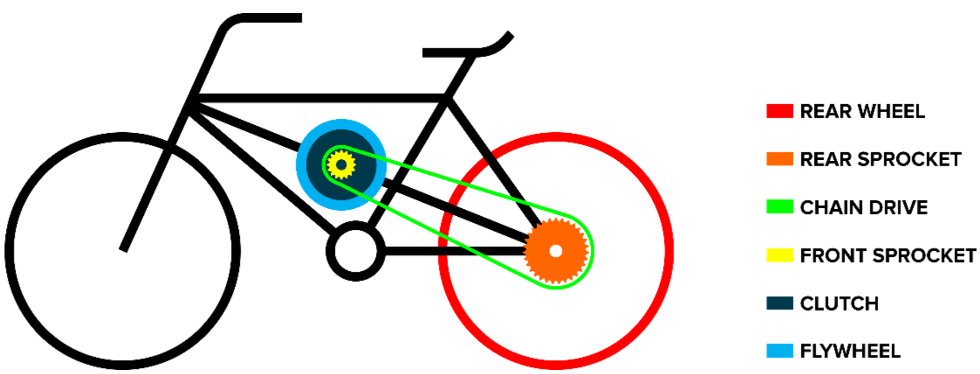


Figure 4: Components of Bicycle

CHARGING:

1. The rear sprocket is fixed with the rear wheel. Kinetic Energy of the rear wheel is transmitted forward chain drive.

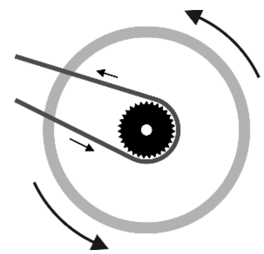


Figure 5: charging cycle (a)

2. The chain drive rotates the front sprocket which is welded with the clutch plate. This assembly is held on an axle and rotates freely on it with the rear wheel.

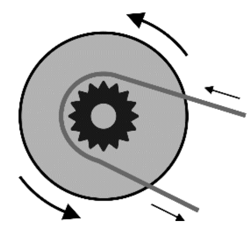


Figure 6: charging cycle (b)

3. The clutch plate can move in translation on the axle. This motion is controlled by a lever on the bike handle.

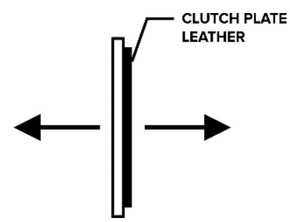


Figure 7: charging cycle (c)

4. When braking is required, clutch is engaged to flywheel using the lever. Power is transmitted from the rear wheel to flywheel through the chain assembly. It starts rotating and builds up inertia. The bicycle is slowed down and the flywheel is charged.

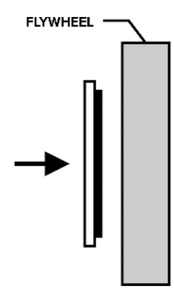


Figure 8: charging cycle (d)

DISCHARGING:

1. When acceleration is needed, clutch is again engaged to the charged flywheel using the lever.

2. Power is transmitted from the flywheel to the rear wheel through the chain assembly.

3. The bicycle speeds up and the flywheel is discharged.

CHAPTER 3

METHODOLOGY

Our methodology to achieve the objects of this projects was based on these following steps:

- Design and Calculations
- Modeling and Simulation
- Manufacturing

Design and calculation parameters:

Following are the calculation of this project to see that this project is feasible or not. Some of the values are taken best possible assumption near to realistic [9] [10] [11].

CALCULATIONS OF FLYWHEEL:

These calculations are for discharging cycle of KERS.

Weight of a person = 75 kg

Weight of a person (globally) = 62 kg

Other payloads = 10kg

Flywheel weight = 12kg

Total weight = 107 kg

Let us assume that the whole bicycle would move from rest to 10km/hr in 7 sec.

v = 10 km/hr.

$v = (10 \times 1000/3600)$

$= 2.78\ m/s$

Average acceleration = 2.78/7

$= 0.39\ m/s^2$

Energy of the system when it reaches 10km/hr.

$=1/2 \times m \times v^2$

= 440.67 joules

Now no of revolution of wheel would be = $v/2\pi r$

= 1.264 rps

= 75.8486 rpm

Force required to take the bicycle from rest to 10km/hr in 5 sec

$F_{ac} = m \times a$

$= 41.73\ N$

Now considering the rolling resistance of the bicycle

P = 20 watt at 10km/hr

$P = F_R \times V$

$= 20/2.78$

$F_R = 7.2\ N$

Now we are considering the aerodynamics drag = FD

$FD = CD \times A \times V^2 \times \rho$

Density of air = 1.25 kg/m^3 *at STP*

$A = 1/2 \times m^2$

V = 2.78 m/s

Co-efficient of Drag =CD *= .88*

$FD = 8.5012\ N$

We know that the drag force is significant when the body is moving the drag would increase as the velocity would increase. We have the discharging cycle starting at rest (v=0) and it reaches the 10 km/hr., so the drag would be average.

$\int FA2.780 \times dv = CD \times \rho \times A \times \int V22.780 \times dv$

$= CD \times \rho \times A \times V2/3$

$= 2.8337$

Other Frictional Force = Ff *= 2N*

Total Requirement of Force = F

$F = Fac + FD + FR + Ff$

F = 60 N

Now $VF \propto Vw$

Let us consider the sprocket ratio to b = s

So flywheel rpm = 75.8466 rpm

$EF = ½ \times I \times (w1\char`^2 - w2\char`^2)$

Top speed $w1 = 22.22s$

And $w2 = 2 \times \pi \times rps = 7.9419$

$EF = 215.32 \times I \times s^2$

$EF = F \times displacement$

$215.32 \times I \times s^2 = 60 \times ((2.78-0)/ (2 \times .39) \times (0.78))$

$I \times s^2 = 0.99$

Now consider that we are not using variable flywheel inertia and inertia of the flywheel is constant.

Dimensions: (assumed)

Max diameter =25 cm

Mass thickness = 5 cm

$m = \rho \times d^2/4 \times \pi \times t$

$m = 2.45 \times 10^{-3}$

$I = ½ \times m \times r^2$

$I = 87.66 \times 10{-}5kgm^2$

$\rho \times 1.9168 \times 10{-}5 \times s^2 = 0.99$

$\rho \times s^2 = 51648.35$

Suppose, material of flywheel to be structural steel (density= 7800 kg/m3)

s^2 =6.6215

s =2.5732

$m = \rho \times d24 \times \pi \times t$

m =19.14 kg

Let us try some other material and we are using the aluminum

(Density of aluminum 2700 kg/m^3)

m = 6.62 kg

So, for the convenience of manufacturing can use the ratio of 3:1

Now we have to also design the components that would be necessary to complete the system.

CALCULATIONS FOR CLUTCH:

Area of friction surface = $2 \times \pi \times r \times dr$

Normal or axial force = *pressure* × *area*

Frictional force = $Tf = Tr = \mu \times dn = \mu \times P \times 2 \times \pi \times r \times dr$

$Tr = Fr \times r$

$Tr = \mu \times P \times 2 \times \pi \times dr \times r$^2

UNIFORM PRESSURE THEORY:

This theory is mostly applied to new clutches. Using springs at different position pressure could be considered constant.

Now, using uniform pressure theory we have

As $P = w/ (\pi \times (r1\text{^}2 - r2\text{^}2))$

$Tr = 2/3 \times \mu \times ((1\text{^}3 - r2\text{^}3)/ (r1\text{^}2 - r2\text{^}2))$

UNIFORM WEAR THEORY:

This theory have its bases on the fact that wear is distributed uniformly over the friction surface of the clutch. This theory is used when the clutch is in use and old.

Uniform axial wear we have

$P \times V = constant$

$P = constant/V$

$P \times r = C$

$P = C/r$

$dN = P \times 2 \times \pi \times r \times dr$

$N = 2\pi (r1 - r2)$ *Where N = force*

$= c/v \times 2 \times \pi \times r \times dr$

$C = N/ (2 \times \pi \times (1 - r2))$

$Tr = \mu \times P \times 2 \times \pi \times dr \times r\text{^}2$

$Tr = \mu \times N \times ((1 + r2)/2)$

Now as we have calculated $TR=F\times R$

$TR=37.45\ Nm$

Which was the required torque at the center of the wheel.

The torque transmitted to the flywheel by the clutch can be written as:

$T=37.45/s$

CALCULATION FOR THE CHAIN DRIVE:

T1 =no. of teeth on the smaller sprocket

T2=no. of teeth on the larger sprocket

P=pitch of chain

The chain is used of 40 no. which has pitch of 12.7mm or 1/2 inch.

d=center distance

n=no. of units of chain

L=length of chain required $L=nP$

From the literature we know that: $n= (T1+T2)/2+2d/P+ (T2-T1/2\pi)\ 2\times P/d$

For s=3 we have

T1=15

T2=45

D is assumed to be 1m as it varies with cycle to cycle.

Putting all the values in the above equation

$n = (15+45)/2 + (2\times1000)/12.7 + (45-15/2\pi)^2\times12.7/1000$ $n \cong 188$ $L = 188\times12.7$ $= 2387.6mm$

Now for gear shifter and idler.

$T1 = 15$ and $T2 = 20$

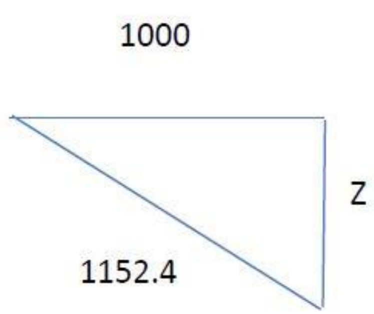
$n = 176$

$L = 176 \times 12.7 = 2235.2$ mm

Now, length to be compensated

$L = 2387.6 - 2235.2$

$L = 152.4$ mm



Now, $Z = (1152.42-10002)$ ^ (1/2)

= 572.7 mm

No of links = 572.7/12.7 =45

We have to compensate 45 no of links at lower gear ratio.

CALCULATION OF CLUTCH DRIVE:

As we have calculated earlier

Tr= 37.45

T = 37.45/s Nm

As s = 3

T = 12.483 Nm

Assumption

Outer radius of clutch = 10 cm

And inner radius = 2cm

Now to calculate the actuating force that is required for discharging cycle at any gear ratio for spring. Now the torque that front sprocket must give in account to bring in KERS motion that can be calculated using the minimum force. Therefore, minimum force at rear wheel.

Fmin=Fr+FD+Ff

= 7.2 + 2.833 + 2

= 12.033 N

Now $Tmin$ = $Fmin$ × radius of rear wheel = 12 × 0.35

$Tmin$ = 4.2 Nm

We engage the flywheel at generally high sprocket ratio s

$Tmin$ = 4.2/s

But if the clutch is actuate at lower gear ratio i.e. 1.25 then

$Tmin$ = 4.2/1.25 = 3.36

Mean radius = 10+2/2 =6cm = 0.06m

Now minimum force for clutch drive will be

*FCM= minimum force from clutch drive μ=0.4 FCM=3.36μ*0.06*

= 140N

Mechanical advantage at clutch drive would be M.A

M.A = $Rotational\ travel\ by\ drive/translational\ travel\ of\ clutch\ \ drive$

Linear travel of clutch drive = 3mm

Rotational travel = 150180×2 × π × 10

= 52.36 mm

Mechanical advantage = 52.36/3

= 17.5

$Fmin$Applied by spring = 140/17.5

= 8N

As the acceleration increases required spring force also increase

For maximum acceleration s = 3

T_{max} = 37.45/s

T_{max} = 37.45/3 Nm

T_{max} = 12.488 Nm

F_{clutch} Force applied by the clutch drive

= 12.483/ (μ × 0.06)

F_{clutch} Force applied by the clutch drive = 520.14 N

F_{spring} = 520.13/17.5 = 29.722 N

This is the force which would be applied by the clutch drive

Comfortable force that the rider can apply on brake handle = 0.5kg = 4.905 N

Now, M.A = $E_{spring}/F_{comfort}$ = 29.722/4.09

= 6.059

The brake handle would be made with the mechanical advantage of 6.05.

Mathematical model of variable inertia flywheel:

Table 1: Values for Calculation of variable inertia

No	Name	Notation	Specification
1	Radius of inner hole	r	0.012m
2	Outer radius of flywheel	R	0.25m
3	Length of slots	a	0.09082m
4	Width of slots	d	0.04m
5	Length of slider	ls	0.02m
6	Mass of slider	ms	198.55 g
7	Mass of flywheel(including slots)	mf	19.39 Kg
8	Mass of the removed slots material	mo	5.81 Kg

$I_{slider} = \frac{1}{12}\ m_s(\frac{3}{4}d^2 + {l_s}^2\ ) + m_s l^2$

$I_{solid\ circular\ disk} = \frac{1}{2}m_f(r^2 + R^2)$

$I_{slot} = \frac{1}{12}m_0(d^2 + a^2) + m_0(\text{R} - \frac{1}{2}\text{a})^2$

$I_{af} = I_{SCD} - \ 4\ I_{slot} + 4I_{slider}$

$I_{max} = 2.055*10^{-3}\ Kgm\text{^}2$

$I_{min} = 1.18015*\ 10^{-3}\ Kgm\text{^}2$

We have selected the **spring loaded design flywheel** because of following reasons:

- Required Specification
- Cost effective design
- Easy to manufacture

There are four slots in the circular plate. In each slot, there is a slider and spring. The rotation of the flywheel will cause slider motion along the slot. The moving sliders will compress the springs to a certain extent, depending on the rotational speed of the flywheel. The variable location of the sliders in the slot leads to variable moment of inertia of the flywheel.

As the rotational speed of the variable inertia flywheel changes, the distance between sliders and rotation center changes, leading to a variable equivalent mass.

Modelling and Simulation:

For modeling of the KERS system, the software used was SolidWorks. 3D models of different parts were made separately using Extrude, Cut Extrude, Revolve, Sweep, Loft commands. These parts were then put together in the Assembly work area of SolidWorks using appropriate mates and constraints.

The 3D models of the parts and the assembly is shown below:


Figure 9: Flywheel Cover

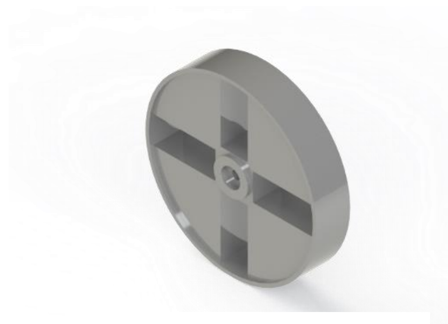


Figure 10: Flywheel

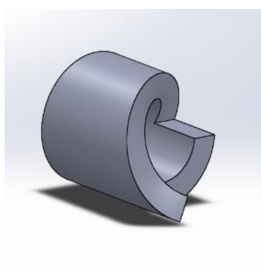


Figure 12: Clutch Drive

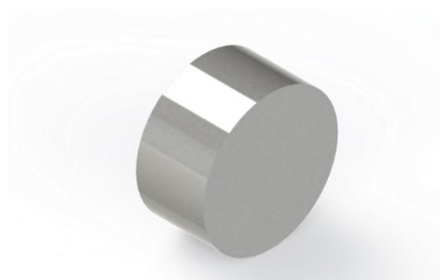


Figure 11: Slider Mass

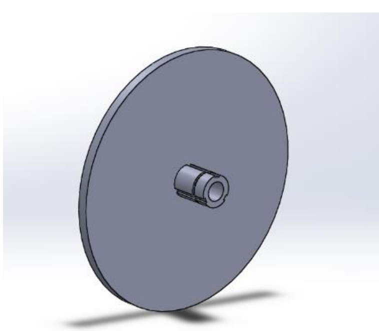


Figure 13: Clutch plate

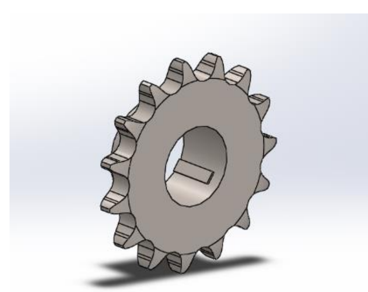


Figure 14: Front Sprocket

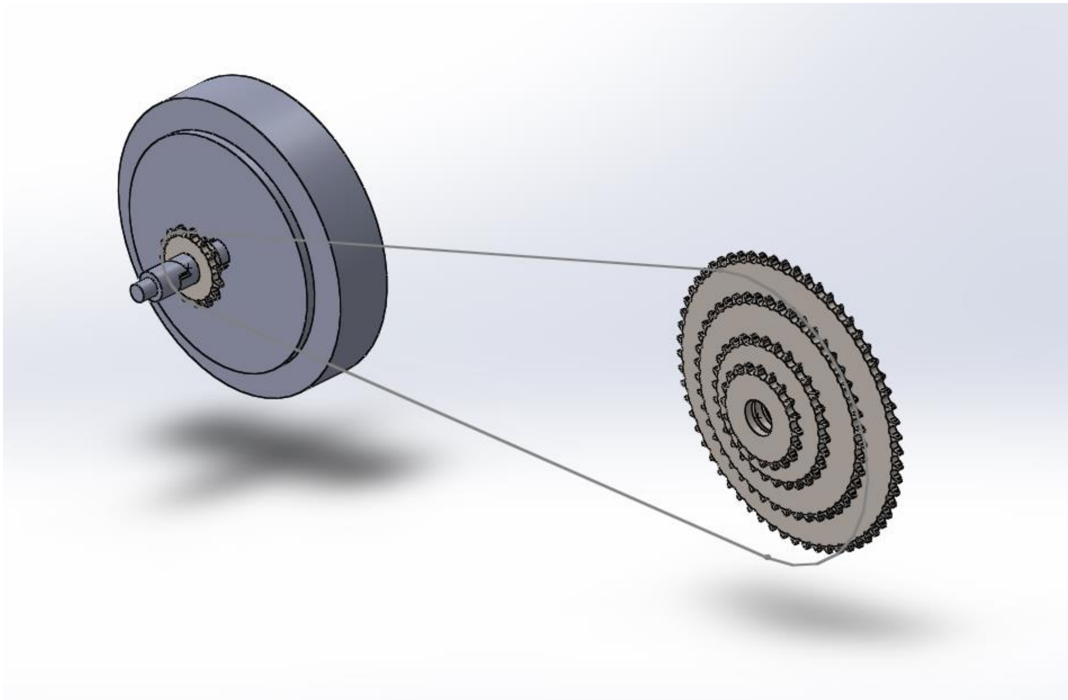


Figure 15: KERS Assembly

Figure 16: KERS Assembly – Side View

For the static simulation of the flywheel SOLIDWORKS simulation tool was used. Torque was applied on the periphery of the flywheel as input parameter. Whereas fixed relation was applied at the center hole of the flywheel. The value for torque, which was taken from the theoretical calculations, was 12.48 Nm.

Following are the plots generated by the software.

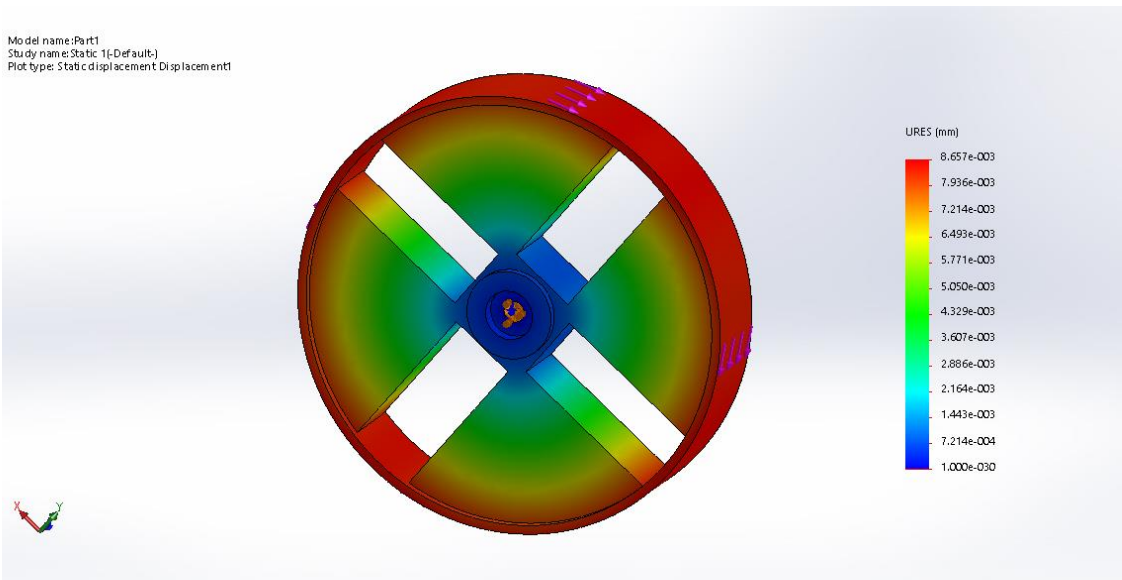


Figure 17: Static Displacement Plot

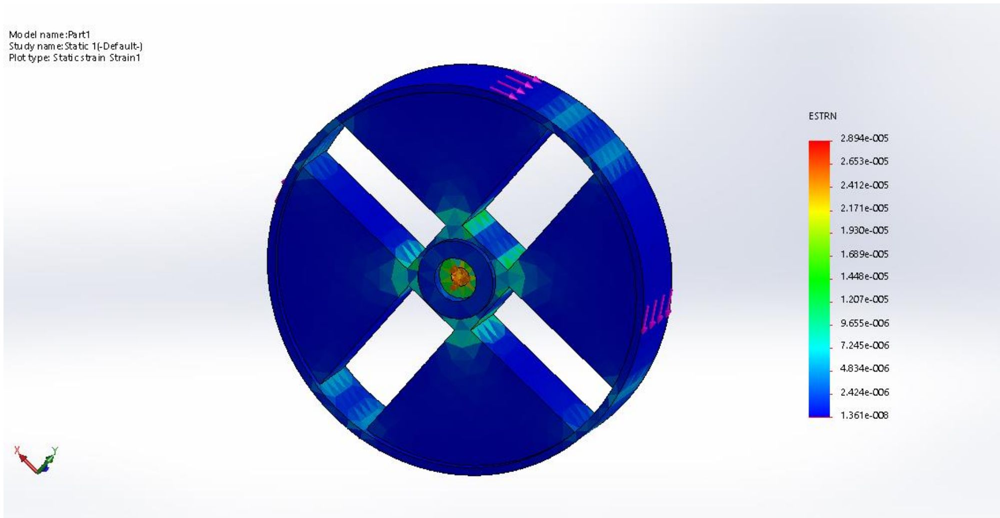


Figure 18: Static Strain Plot

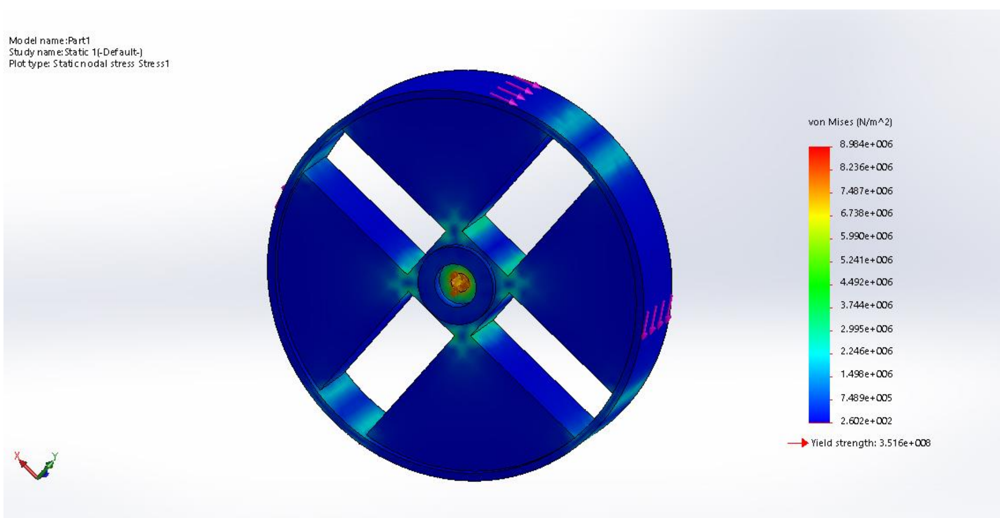


Figure 19: Static Nodal Stress Plot

Static simulation of the flywheel shows that material will not fail.

Manufacturing:

Fabrication is the most important part of any project. In any project whenever you come to the manufacturing phase, you will see some of the practical limitation in the manufacturing phase. So you have to alter your design accordingly. As we have said that you have to change your design during the manufacturing phase due to some of the problems you have to face. Similarly we also have to overcome those hurdles to achieve our goal. We have also divided the manufacturing in different phases

- Frame modification
- Flywheel manufacturing
- Clutch drive manufacturing
- Clutch plate manufacturing
- Axle machining

FRAME MODIFICATION:

Basically we have to install the flywheel in between the frame of the purchased bicycle. So, for that we have to alter the original frame to make space and to balance that flywheel. For that different kind of manufacturing process was used to modify the frame of a bicycle.

- Bending
- Welding

Bending:

It is a manufacturing process that produces a V-shape, U-shape, or channel shape along a straight axis in ductile materials, most commonly sheet metal. Commonly used equipment include box and pan brakes, brake presses, and other specialized machine presses.

Welding:

The method of joining two metals by the help of another metal is called as welding. The fusion of the filler metal is used to join the two metals. The other methods of metal joining that usually take place at lower temperatures such as brazing. These techniques can be used for joining without melting the parent material.

The material that are employed for the frame modification was the steel pipes. Gas welding and arc welding was used for the frame modification.

FLYWHEEL MANUFACTURING:

The material used to manufacture flywheel is the mild steel. And the diameter of the flywheel was 250mm and the thickness of flywheel is 50mm.

The main components that were required in the manufacturing of the flywheel are as follows:

- Main disk
- Cover
- Slider masses
- Springs
- Supporting rods

Following are the part drawings that are used for the manufacturing of the flywheel.

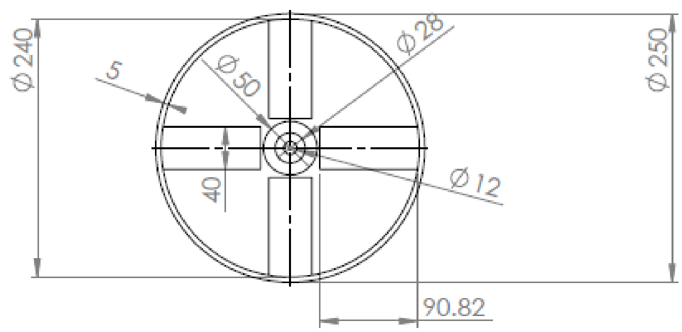


Figure 20: Flywheel Front View

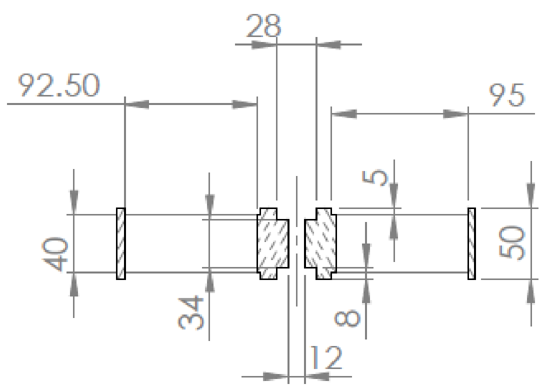


Figure 21: Flywheel Sectioned View

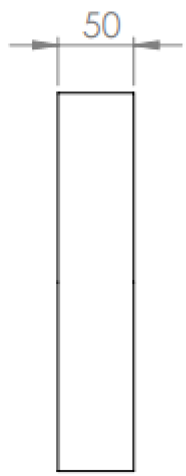


Figure 23: Flywheel Side view

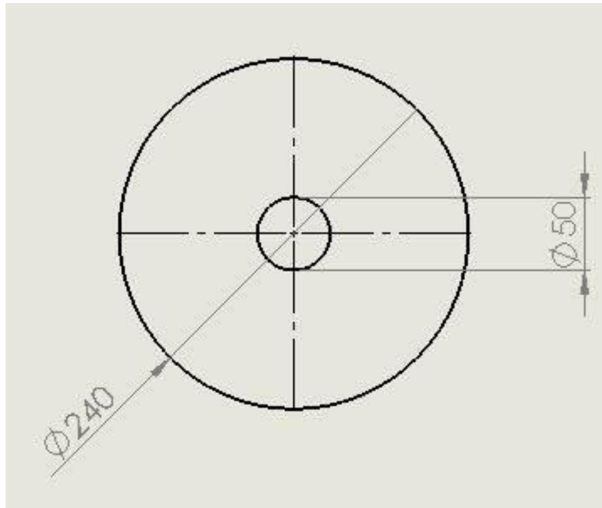


Figure 22: Cover

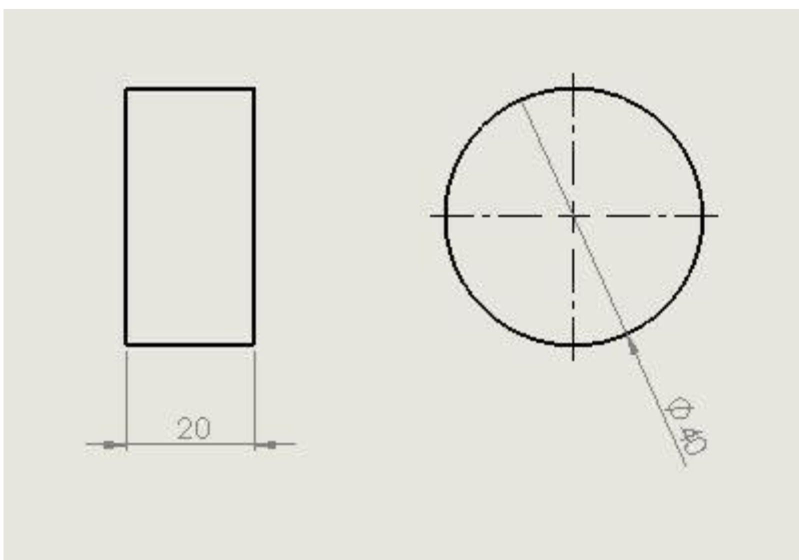


Figure 24: Slider mass Drawing

Some of the manufacturing process that was used in the fabrication of the flywheel is as follows:

- Milling
- Turning
- Drilling
- Threading

Milling:

Milling is the machining process that have been used for removing the material from the workpieces by the help of the rotary cutters. The axis of tool and the work piece need to be in the right direction which would results in the desired cutting and finishing.

Turning:

Turning is a machining process which the workpiece can be cut of fined by the help of a stationary tool. The tool is not rotating in this case.

Drilling:

Drilling is a cutting process which is simply employed in order to make the circular cross section hole in the work piece. This is achieved by the help of the drill bit.

Threading:

Threading is the process of creating a screw thread. More screw threads are produced each year than any other machine element. Cover was attached to the flywheel with the help of screws. And the screws used in this process were M8 type.

CLUTCH DRIVE MANUFACTURING:

The material used in the manufacturing of the clutch drive is the mild steel and the dimension of the outer diameter is 32 mm and the inner diameter is 20mm. And the pitch of helix is 10mm.

Following are the part drawings that are used in the manufacturing of the clutch drive:

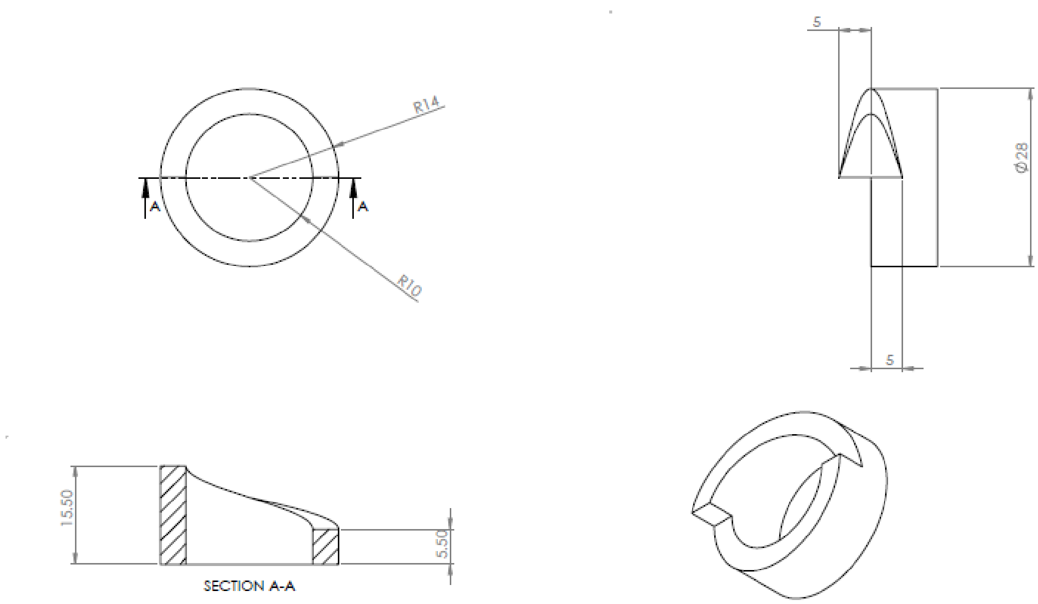


Figure 25: Clutch drive drawing

The manufacturing processes for the clutch drive are as follows:

- Turning
- Milling

CLUTCH PLATE MANUFACTURING:

The material used in the manufacturing of the clutch plate is the aluminum. And the dimension of the clutch plate diameter is 200 mm, thickness is 5mm and the sprocket hub is 24 mm.

Some of the main components of the clutch plate are as follows:

- Clutch plate
- Front sprocket
- Sprocket hub
- Bearing lock
- Key

Following are the part drawings that are used in the manufacturing of the clutch plate:

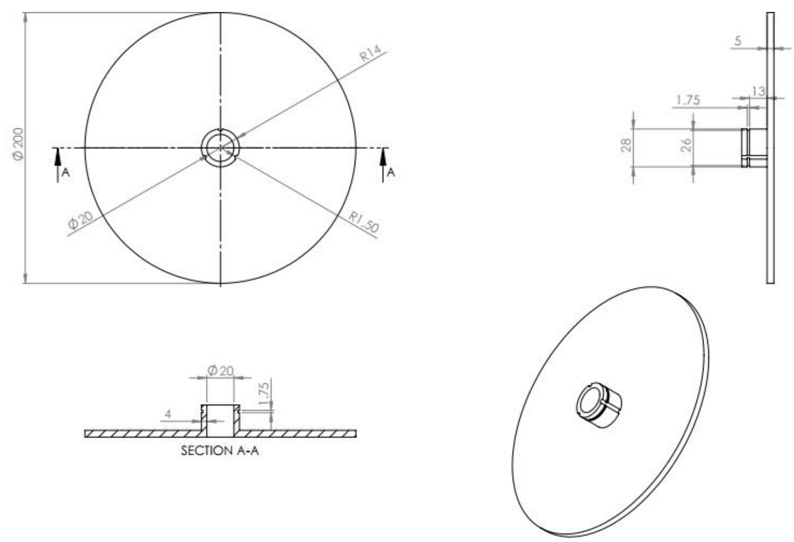


Figure 26: Clutch plate Drawing

A cylinder hub was also manufactured using the following drawing. This hub would fit onto the clutch plate part and front sprocket would be press fitted on it.

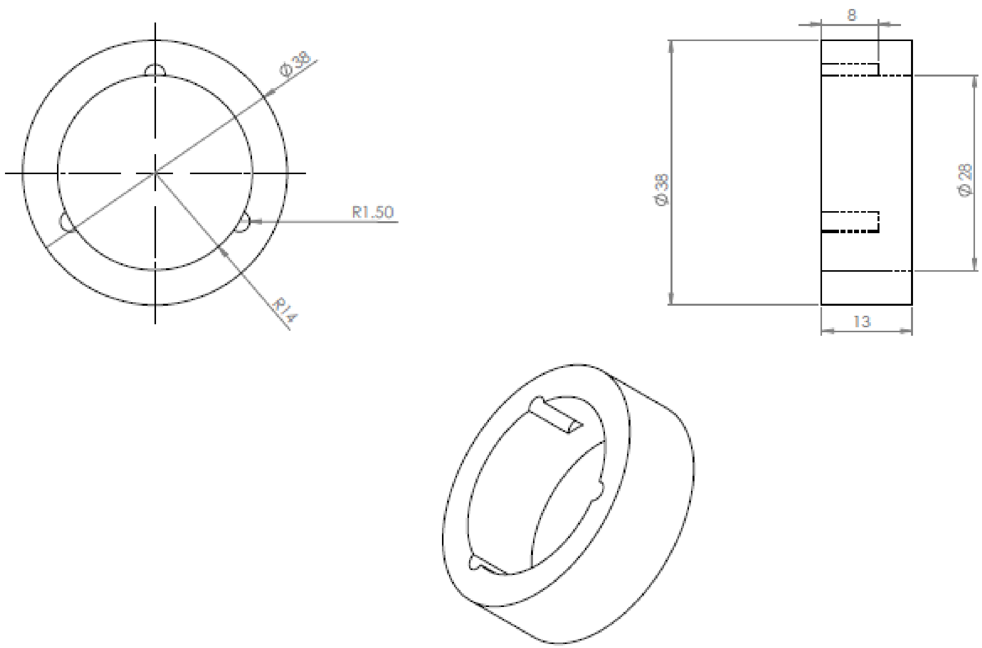


Figure 27: Sprocket Cylinder Hub Drawing

And the manufacturing process that has been used in the fabrication of the clutch plate is as follows;

- Turning
- Milling
- Riveting
- Shaping

Riveting:

Riveting is a forging process that may be used to join parts together by way of a metal part called a rivet. The rivet acts to join the parts through adjacent surfaces.

Shaping:

Shaping is a manufacturing process of material removal in which the work piece reciprocates against a stationary cutting tool producing a plane or sculpted surface.

AXLE MACHINING:

The material used in the fabrication of the axle is the medium carbon steel. The diameter of the axle is 20 mm and the length of the axle is 150 mm.

Two manufacturing process was used in the making of axle and they are as follows:

- Turning
- Threading

Threading:

Threading is the process of creating a screw thread. More screw threads are produced each year than any other machine element.

The sprocket ratio for the chain drive was $s = 2.73$

CHAPTER 4

RESULTS

After developing the prototype, we obtained the experimental results by running the bicycle on test bench. We measured the rpm of a flywheel and rear wheel through tachometer. We also calculated the time for which the useful amount of energy that can be extracted from the flywheel.

We also calculated the two different times for the discharging process. In the first process the flywheel was not engaged with the clutch and flywheel was rotating on its own (not helping or transferring the power to the rear wheel) and the time was recorded for this process. In the 2nd process the flywheel was transferring the power to the rear wheel and the time was calculated for this process.

Table 2: Experimental Data

No of readings	**Rear wheel (rpm)**	**Flywheel (rpm)**	**Process 1 time (sec)**	**Process 2 time (sec)**
1	270	800	247	153
2	200	530	167	101
3	150	400	124	66

Another result was obtained by having a practical demonstration of this concept. A 60 kg student was allowed to sit on the bicycle and during his experience the results were recorded by having a reference point. He covered the distance of about 18.5 meters to be approx. when the flywheel obtained the 900 rpm. If we compare these results the bicycle without the KERS system then this energy through which he has travelled would have been lost in that bicycle.

Figure 28: Final Prototype

Our main objective was to conserve the part of a momentum using the KERS system in a bicycle and to improve the overall efficiency of a bicycle during braking process. This objective has been achieved by developing the prototype.

On the bases of the results we obtained from our prototype we could compare the ordinary bicycle and KERS bicycle as follow:

Table 3: Comparison of KERS and Ordinary Bicycle

Ordinary Bicycle	**KERS Bicycle**
Energy is lost during braking.	Energy is stored in the flywheel during braking.
Less initial torque.	More initial torque.
Less efficient during braking process.	More efficient braking process.

FUTURE SCOPE:

From these results and implementing KERS into the bicycle we could deduce the future scope of this project.

- We found that no special material or technique is required to make this product. Manufacturing is very easy with simple modification in the bicycle you can build this new KERS bicycle.
- By using the different material or doing much more research in this field we can make this product much more cost-effective.
- Marketing of this product can be done in an extensive way. Improving the manufacturing techniques we can bring this concept into the mass production and that will have a promising future. This product is recovering the lost energy during the braking process.
- If we do much more research in this field then the regenerative brakes can be brought into the vehicles and can increase their efficiency. This technology has a very promising future in our industries. This mechanical KERS could be used in

motorcycles and could provide a sustainable energy solution by recovering the momentum loss during the braking process [12].

PROBLEMS FACED AND PROJECT CONSTRAINTS:

No project can be completed without facing any problems, whether these are related to the practical or financial limitations or are related to the planning of the project. Moreover as in all projects there are some limitations which we would like to include in this report.

Following are problems that were faced in this project:

- For the clutch drive we need a curved cut with precision and we need a pitch of the helical cut to be 20 mm but due to the unavailability of the CNC and manufacturing limitation we made a cut with 10 mm pitch.
- The design process took more than expected effort because of the unviability of the research on it. No extensive research has been done on mechanical KERS in the past.
- As the cycle was not made according to the specifications of the KERS and its frame was modified to incorporate the KERS, its center of gravity was changed. Due to which the cycle was not stable as it was intended to be. If the cycle was made keeping in mind that the KERS has to be implemented this problem could be eradicated.
- Due to the frame modification another problem which was faced was the chain alignment. Chain alignment is a tricky part of this project as if the chain is loose it would not perform its function and if it is not aligned it would drop from the sprocket.
- The slippage of clutch with flywheel was one of the main problems in the project. To remove this slippage we used a clutch plate leather between flywheel and clutch.

Limitations in this project are listed below:

- This mechanical KERS cannot implemented in the cars or vehicles with heavy mass. Because as the mass of the vehicle increases the mass of the flywheel would also have to be increased to perform its function as in the case of the bicycle. There are other practical limitations too, as in cars space is issue that should be taken into account.
- The weight of the bicycle was increased as result of implementing KERS in it. So going uphill the cyclist would have to overcome this additional weight of this KERS.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The design displayed above is a fairly simple implementation of a kinetic energy recovery system with an increase in the efficiency of a bicycle during braking process. Though there are quite a few parts, many of them can be manufactured easily on lathe machines and milling machines but some parts requires the program cut machines i.e. CNC machines. Due to the non- availability of the resources such as we don't have the access to the CNC machines so we have to manufacture the parts on Lathe machine that has reduced the efficiency of our prototype to some extent. But the ability of this project that sets it apart from the rest is, the freedom of fabrication for the user. The users can easily assemble their own KERS system, which can have the features of their like. It is analyzed that all the parts that are being used are complete safe and are compatible. The parts are capable of survival and functioning even in extreme conditions. The energy can be stored by use of a fly wheel, instead of conventional methods that involve the use of battery. The new and innovative perception of using flywheel in bicycle has great prospects to be used and offers huge future scope.

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Flywheel technology has great prospects and many of other interrelated disciplines are using this technology. It is a pollution free method and hence is highly desired for different practical applications. There is a great void for the environment friendly transportation and industrial solutions. There are numerous applications of the flywheels in our existing industry. The point of energy efficiency is at hand when the transportation sector is concerned. The major concern is the use of flywheel for the regenerative braking. This could help to recover valuable amount of energy that is wasted by each vehicle for each trip. The figures could be astonishing as the valuable energy can be used for various purposes. Flywheel offers great impacts related to environment by avoiding the daily carbon emissions that exist in the conventional transportation sector. The kinetic recovery system can be a turning point that can help in recovering important energy.

We were aiming to build the cost effective and much more efficient bicycle. Improving the manufacturing techniques we can bring this concept into the mass production and that will have a promising future. And these bicycles are aimed to target the mostly those bicyclist those who went on tour for cross – countries.

To further improve the design and losses in our design the following recommendations could be considered.

- KERS system can be automated using micro controllers and PIDs.
- Instead of using levers servo motors can be used to engage and disengage the clutch.
- Different sprocket ratios could be used for power transmission. It would allow the user to use different sprocket ratios for different load requirements.
- Two different sets of springs with different stiffness could be used in the variable inertia flywheel.
- We have attached clutch plate leather with the clutch. Similarly another clutch plate leathers could be attached to the flywheel to further reduce the slippage between clutch and flywheel.

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