NUST College of

Electrical and Mechanical Engineering

Kinetic Energy Recovery System (KERS) Implemented on Bicycle

Project Report

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DECLARATION

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ABSTRACT

Kinetic Energy is wasted when brakes are applied and is converted to heat energy due to friction at the contact surface and dissipated to the atmosphere in the form of thermal radiations. Kinetic Energy Recovery System (KERS) is used to recover the kinetic energy of a moving vehicle when brakes are applied. When KERS system is equipped with a vehicle, it can take some K.E from the vehicle which is used to slowing down the vehicle and is again used for boosting the vehicle.

In this system the energy is not wasted but is stored in a device in the form of potential energy. The stored P.E can be again converted to K.E using a proper mechanism. In the presence of KERS system, the driver will have the option of using any one of the two available sources of power. Mechanical KERS system there are of two types; clutch based and CVT based.

In this project the focus would be to design a KERS system that could function in vehicles like Bikes and other electric vehicles. The KERS system can be automated using PID controllers and servo motors will be used instead of lever arm. Also, the flywheel weight can be optimized by proper material selection and size optimization depending upon the usage. Finally, the complete KERS system will be implemented on a vehicle (bicycle/motorcycle).

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Plan of the Report

This report has 11 chapters and discuss the following,

Chap # 1 – gives introduction to the report contents.

Chap # 2 – discusses the literature on KERS.

Chap # 3 – discusses the methodology which is followed in this project.

Chap # 4 – the design procedure of all components is discussed.

Chap # 5 – feasibility of all components is checked using FEA techniques

Chap # 6 – changes depending on design and market are evaluated

Chap # 7 – the manufacturing processes involved are discussed

Chap # 8 – final components after fabrication are shown and discussed

Chap # 9 – the assembly of all components is explained in detail

Chap # 10 – the complete scope of the project is discussed

Chap # 11 – discusses and explains 2-d drawings of the complete project

Chapter # 1 Introduction

1.1 Why KERS?

Unlike normal braking systems that stop vehicles along with energy losses, KERS (Kinetic Energy Recovery System) brings vehicles to stop while recovering the energy *which would otherwise be wasted due to friction because of braking*. This energy is first stored in an energy storing medium (High voltage batteries or flywheel) which is then utilized in accelerating the vehicle. KERS also dissipate heat energy during its application, but this energy loss is very small compared to normal braking. In this way a part of energy is recovered while also aiding the braking of vehicle.

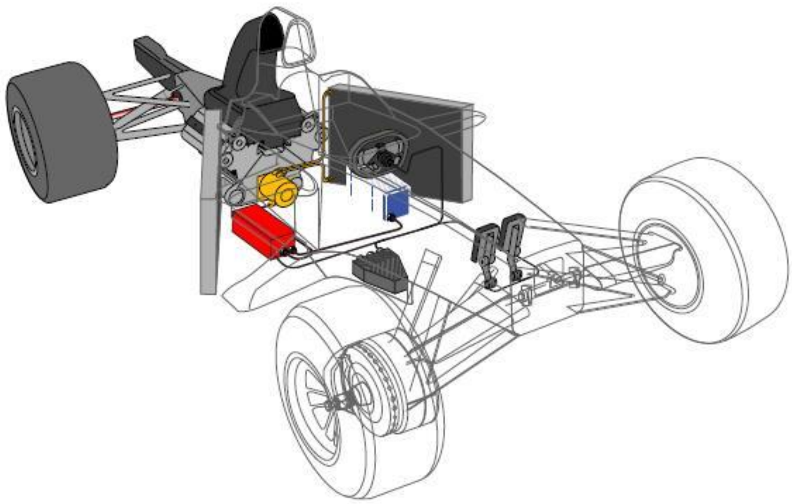


Figure 1: KERS in Formula One Vehicle [2]

In recent past recovering Kinetic energy has become an engrossing area of research for many vehicles. Mainly the KERS system is implemented in formula one vehicles as shown in figure 1. To find out why? There are two major parts of energy, that are potential energy and kinetic energy. Taking example of a vehicle the potential energy part is associated with burning fuels which we know are depleting resources, already we are gulping up the Earth's resources at an unsustainable rate it has become very important for us to think about saving these depleting energy reserves and utilizing them on a sustainable rate. The kinetic energy part is associated with motion of masses which is the result of conversion of potential energy as fuel is burned by engines into mechanical energy. By the utilization of KERS in vehicles we can save a part of Kinetic energy lost in braking which can in turn save the potential energy(fuel) and implementation of KERS on a large scale will decrease the rapidly depletion rate of fossil fuels.

1.2 Elements of KERS

KERS requires two main elements. A way to recover energy and utilize it when needed, and a reservoir to store this energy for later use. Based on these requirements KERS has two main types that are in practice. One is Mechanical KERS and other is Electrical. The Mechanical KERS operates by using a flywheel as an energy storage device whereas Electrical KERS utilizes batteries to store recovered energy. Both types have their specific pros and cons. The Electrical KERS is less efficient way of recovering energy, yet it can store energy for a long time and utilize when needed. It also gives us the ability to control the rpm and torque. The Mechanical KERS, however, is twice as efficient in recovering energy as compared to Electrical KERS. But the nature of flywheel does not allow it to store energy for a long time. The continuous friction in the flywheel will result in energy decay although it’s very small but still its considerable. This stored energy can be used to accelerate vehicle to achieve a certain speed or can be utilized in a single run to provide a boost to vehicle. The flywheel can store energy for as long as half an hour.

1.3 Types of KERS

There are two rarely used types of KERS that include Hydraulic KERS and Hydro-electric KERS. The Hydraulic KERS system uses hydraulic pump/motor together with a hydropneumatics accumulator. This system is well suited to be operated in city buses, however, due to high cost of about 10-15% of vehicle cost, this system was not successful. The hydroelectric KERS makes use of hydraulic accumulator with the characteristics of higher power density which is well suited to situations where frequent acceleration and deceleration is required. However, the relatively lower energy density imposes a limitation to increase in accumulator size. To solve this issue a hydroelectric synergy system is introduced. This combined system Hydraulic/electric synergy system (HESS) was a possible and great kinetic energy recovery system, but high cost of production was not feasible.

Motivation

A lot of energy is wasted during braking and the pain can be felt by the person driving or sitting on the vehicle. Working in NUSTAG automotive group we felt this gap and started searching for the energy saving methods. We came to a point where we came across KERS and its different types. We thought to implement that in our vehicle but weight, cost and all other factors doesn't allow that. We then thought to take this model as our FYP on a basic and implemented scale as it was very fascinating, and all concepts of our ME degree were to be involved in it.

<u>Objectives</u>

1. To study and develop a KERS and implement on a bicycle.
2. To optimize the weight of flywheel.
3. To calculate the maximum distance of travel with implemented KERS on bicycle.

<u>Assumption</u>

This model is limited to bicycles and can be modified for bikes.

Chapter # 2 Literature Review

Regenerative braking is a mechanism of storing energy what would otherwise be lost in surroundings. The process involves the lowering down of vehicle speed and converting the kinetic energy into useful form of energy. There are many ways to store this energy, some of which are via mechanical KERS, electrical KERS, hydraulic KERS and Hydro-electric KERS. It is to note that KERS (kinetic energy recovery system) is an automotive system whose function is to store the kinetic energy of a moving vehicle under braking.

2.1 Electrical Storage System

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.

2.2 Hydraulic Storage System

Regenerative braking in vehicles using a variable displacement hydraulic pump/motor together with a hydro pneumatic accumulator has been of great interest during the last two decades. Such a system is particularly suitable for application in city buses [1]

2.3 Hydro-electric storage system

Hydraulic accumulator has the characteristics of higher power density and is well suited for frequent acceleration and deceleration under city traffic conditions [2]. It can provide high power for accelerations and can recover more efficiently power during regenerative braking [2] in comparison with electric counterparts [3]. However, the relatively lower energy density brings the packaging limit for the increasing accumulator size [3].

2.4 Mechanical Storage System

For mechanical based system, a rotating mass commonly known as a flywheel is used to serve the purpose of a storage device. The transfer of energy for this case needs to be controlled. This is done using a variable drive transmission, a transmission system that seamlessly changes gear ratios as per requirement.

2.4.1 Energy Storage in Flywheel

Energy can be stored in many different mediums like flywheel, battery, and super capacitors. The system that we will focus on our project is mechanical one that utilizes flywheel. The amount of energy the flywheel can store depends on the weight of flywheel and its rpm. The larger the size of flywheel the more energy it will store in the form of angular momentum, but it will also have a huge weight which can be downside of Mechanical KERS however one can find the effective size of flywheel for a particular vehicle to improve vehicle efficiency. Based on proper stress analysis, the flywheels are made, so that they can withstand harsh conditions for a considerable fatigue life.

This transmission controls energy transfer to and from the driveline. [4] During the start of the braking process vehicle's speed is higher while that of flywheel's is low. At the end of braking the vehicle speed drops with an increase in flywheel's speed. The ratio of speed has thus changed during the process of braking. To understand how transfer of energy happens it is to note that in addition to variable transmission and flywheel a clutch is used. The schematic layout of mechanical KERS is shown in figure 2. The clutch connects the system to the primary shaft of the transmission. During the process of braking clutch connecting the flywheel to transmission is engaged thus allowing the transfer of energy to the flywheel. The energy store is called rotational energy. The flywheel can rotate up to a maximum of 60000 revolutions per minute [4]. The clutch disengages allowing the flywheel to rotate independently when the car stops. To use this energy for later use the clutch engages so now the flywheel is again connected with variable transmission but this time the energy transfer is from flywheel to the wheels.

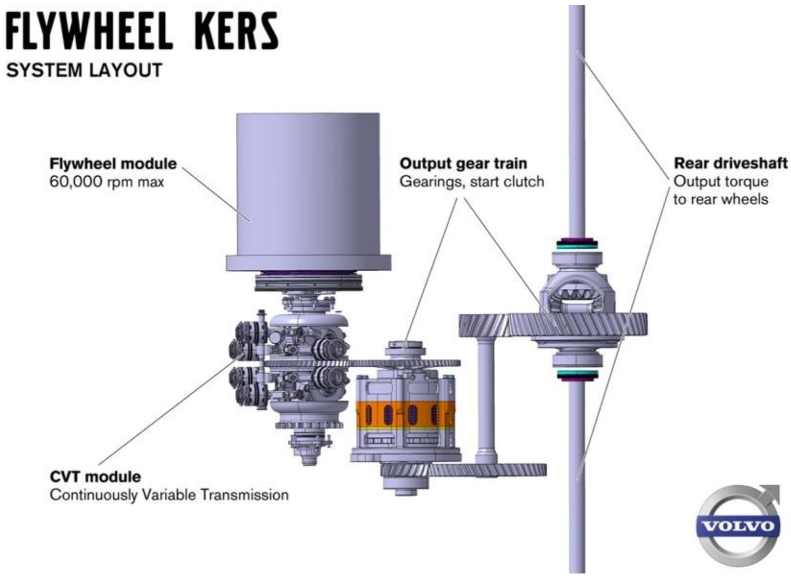


Figure 2: Schematic Layout of Mechanical KERS

2.5 Literature Review on KERS

Kumar et. al. [1] designed and fabricated a flywheel bicycle with mobile charger which attains the kinetic energy produced from the cycle's pedalling power. The Mode of chain arrangement rotates while pedalling which in turn slightly increases the speed of the bicycle. By the rotation of the wheel, the driving wheel of the dynamo also rotates which in turn produces A 5V of AC which is converted to DC. Hence the back wheel rotates while pedalling the bicycle and the kinetic energy produced is recovered as the extra movement of the back wheel of the bicycle by the rotation of the flywheel.

Kumbhojkar et. al. [2] in their research work found that the flywheel and transmission add weight to the bicycle. The increased weight will add to the energy required to accelerate the bicycle and to ride it uphill. However, once the rider has provided the energy to reach a cruising speed, the flywheel reduces the energy cost of slowing down from this speed since it aids in subsequent acceleration. Roads are optimal environment for the flywheel bicycle because it's flat and there are lots of reasons for the cyclist to slow down. Considering weight criteria author found that optimum weight for better efficiency is 5 kg for normal cycling.

Mugunthan and Nijanthan [3] conducted an overdrive test to find out the efficiency of their flywheel based KERS installed 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.

Menon et. al. [4] in their research work found that the flywheel and transmission add weight to the bicycle. The increased weight will add to the energy required to accelerate the bicycle and to ride it uphill. However, once cruising speed is reached, the flywheel reduces the energy cost of slowing down from this speed since it helps in subsequent acceleration. Roads are desired environment for the flywheel bicycle because it's flat cyclist tends to slow down frequently. 5 kg for normal cycling was found to give the best efficiency.

2.6 Flywheel

Based on the rotational speed requirements, flywheel can be fabricated using the right materials. High strength carbon fibre is used for flywheels with speeds above 3000 rpm [3]. A large mass is not desired for high-speed flywheels because extra mass means more energy will be needed to accelerate the vehicle. On the other hand, low speed flywheels with speed values below 20000 rpm, are generally made of steel or other metals for low cost. The weight of the flywheel is a very important factor in determining the efficiency of the system.

2.6.1 Energy Transfer in Flywheel

In this section the analytical calculations for energy and flywheel are performed. As discussed earlier in section 2.3, rotational K.E is stored in flywheel. The formula is given as:

$$E = \frac{1}{2} I\omega^2 \qquad 2\text{-}1$$

Here "I" is the mass moment of inertia of the flywheel while "w_1" is the rotational speed. I can be written as,

$$I = \frac{1}{2} m(r_1^2 - r_2^2) \qquad 2\text{-}2$$

Where r_1=outer radius of flywheel and r_2=inner radius of flywheel. Substituting the equation results in:

$$E = \frac{1}{2} m(r_1^2 - r_2^2)\omega^2 \qquad 2\text{-}3$$

It is to note that increase in rotational speed increases the energy transfer by squared.

2.7 The flywheel vacuum chamber

The vacuum chamber is another very essential part of the flywheel hybrid system. The major function of the vacuum chamber is to minimize the air resistance as the flywheel rotates. The decrease in air resistance thus increases efficiency, Without the vacuum chamber, the friction caused by air resistance is enough to cause significant energy losses and heat the carbon fibre rim to its glass transition temperature [5]. Vacuum chambers for KERS systems are commonly made of metals like stainless steel and aluminium since these metals can provide required strength to withstand variable stresses.

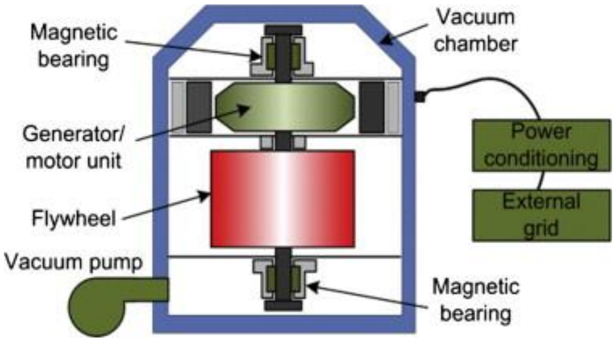


Figure 3: Flywheel Vacuum Chamber

Methodology

Kinetic energy recovery system is used in modern vehicles and mostly in some formula cars. The motivation for doing this project is like most of the energy is wasted during the working of a vehicle. That energy can be stored in many effective ways like in batteries, flywheel etc. There are such practical vehicles in which KERS system is used commonly except formula vehicles. In this project the focus will be to improve the working of kinetic energy recovery system in bicycles by using optimized, proper handling and energy transfer ways and will be implemented on the bicycle. It is a modern concept and is just similar like regenerative breaking. Kinetic energy recovery system uses a flywheel, clutch and gear mechanisms to transmit the power from the tires to the flywheel. When the brake is applied the mechanism is engaged and now the whole system works as a brake and the storing system, storing the energy in flywheel in the form of KE.

In this project we will start from the designing phase of the flywheel, clutch, and gears. Then the CAD modeling of the kinetic energy recovery system (KERS) and latterly the fabrication would be performed. Firstly, the working of the KERS would be tested on Ansys in actual conditions and the FOS would be calculated and the results would be analyzed. If the results are feasible then the model would be fabricated and implemented on an automobile. We are thinking to implement the KERS on a bicycle like a hand model. The final project can also be implemented on a bicycle, but a motorbike can also be used taking into consideration the cost of the whole project.

Chapter # 3 Designing Procedures

For the application of the KERS system, a bicycle is chosen with large area under the seat for the adjustment of flywheel with other components.

By looking at the space available in the bicycle the result is concluded that at max 25 cm flywheel can be used.

The complete designing of all required components is shown below,

3.1 Design of Flywheel

Calculation for the energy stored in the flywheel is shown.

Assumptions:

Mass of the person riding the bicycle = 70kg
Mass of bicycle = 10kg
Other payloads = 10kg
Allowance for flywheel weight = 10kg
Total weight =100kg

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

$$v = 10km/hr = 50/18 = 2.78m/sec$$

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

$$E = \frac{1}{2}mv^2 = 385.8 \text{ joules}$$

Calculate the rpm or speed of the wheel and the flywheel

D_r = Diameter of the bicycle wheel = 29inch ≅ 750mm

Note: We are not considering the resistance due to gradient as we are doing the calculation for the straight road.

Aerodynamic drag = F_a

$$F_a = C_d \rho A v^2 \quad \text{4-1-1}$$

Where C_d = coefficient of drag = 0.75(considering the worst case)

ρ = density of air = 1.25 kg/m3 at 25°C

A = projected area = 1m^2 (let us assume)

v = velocity of bicycle = 2.78m/sec

by using equation 4-1-1, drag is given as

$$F_a = 6.94N$$

But we cannot underestimate the fact that this force is proportional to square of velocity. So, this factor is not much pronounced in the beginning but comes into play in later stage.

Taking weighted avg. over time and velocity will be equal as v is proportional to t

F_A = 2.313 N

Other frictional resistances

F_f = 2N

Total requirement of force = F

F = Fa + Fr + F_A + F_F

= 71.69N (Taking upper limit)

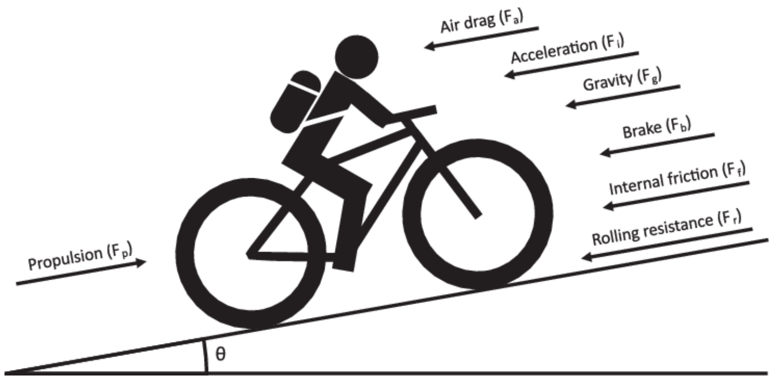


Figure 4: Forces acting on bicycle

Torque required at the centre of the wheel to get this required force = Tw

$$T_w = F \times r = 71.69 \times 0.75 \div 2 = 26.884 \text{ Nm} \quad \text{4-1-2}$$

When our system reaches 10kmph our flywheel should have a speed directly in proportion with the wheel speed (rpm)

Let the Sprocket ratio = s

Flywheel rpm = 70.74s rpm = 1.18rps

Energy released by the flywheel = E_{fl}

$$E_{fl} = \frac{1}{2} I (\omega_1^2 - \omega_2^2) \quad 4\text{-}1\text{-}3$$

$$\omega_2 = 2\pi \times RPS = 7.41s$$

ω1 is constrained by the top speed of the bicycle ω1 = 22.22s

So, $E_{fl} = ½ I (\omega_1^2 - \omega_2^2) = 219.63 \times I \times s$^2

E_{fl} will be consumed in bringing in bringing the cycle into motion 10kmph and also overcome the resistances.

$E_{fl} = F \times$ displacement

$= \frac{F \times (v2 - u2)}{2a}$

- $219.63 \times I \times s^2 = 71.69 \times (2.782 - 0) / (2 \times 0.556)$
- $219.63 \times I \times s^2 = 497.85$
- $I \times s^2 = 2.267$

s is constrained by the choice of chain drive and force that can be applied comfortably by the driver.

I is constrained by the availability of space and maximum mass of flywheel that is allowed.

Note: We are using a circular disk flywheel

Max dia. = 25cm,

Max thickness = 5cm

$$m = \rho \times \pi \times d_2 \times t = \rho \times 2.4544 \times 10^{-3} \text{ Kg} \quad 4\text{-}1\text{-}4$$

$$I = \frac{1}{2} mr^2 = \rho \times 1.9175 \times 10^{-5} \text{ Kgm}^2$$

Putting the value of ‘I’ in above equation mentioned, we get

$\rho \times 1.9175 \times 10^{-5} \times s^2 = 2.267$

$\rho \times s^2 = 118228.34$

Choosing flywheel material as structural steel (ρ = 8000 Kg/m^3)

$S^2 = 14.77$

$s = 3.84$

Now putting the value of ρ in Eq. 4-1-4 we get

$$m = 8000 \times 2.4544 \times 10^{-3} = 19.64 \text{ kg}$$

As weight is more than 10kg and less than 20kg, we must compromise with the payload to have a comfortable ride with the system.

Let us try some other material say Aluminium (Density = 2700Kg/m^3)

$S^2 = 43.79$

$s = 6.62$

Now Eq. will yield

$$m = 2700 \times 2.4544 \times 10^{-3}$$

$$m = 6.63 \text{ Kg}$$

As $m < 10$Kg

This material is allowed for the flywheel design. For this design we don’t have to compromise with the payload.

Another point is that we can simply reduce the sprocket ratio keeping the flywheel mass and dimensions constant, this will only lengthen the time of acceleration. This calculation is for the maximum energy storage of the flywheel. For convenience of fabrication, we can reduce the sprocket ratio to 3:1.

Now the time is to design the design of the additional parts that will make the product a working one.

3.2 Design of the clutch

Clutch is the most vital part of this system. It is constantly subjected to axial and twisting forces due to constant engagement and disengagement with the flywheel.

T = torque transmitted by the clutch plate = TF

P = intensity of axial pressure with which the contact surfaces are held together

R_1 = internal radii of friction surface

R_2 = external radii of friction surface

r = mean radius of the friction surface

μ = coefficient of friction

Consider an elementary ring of radius r and thickness dr on the friction surface of the clutch.

The area of the friction surface or contact surface

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

Normal or axial force on the ring = dw

$$= \text{pressure} \times \text{area} = P \times 2\pi r \times dr \qquad \text{4-2-1}$$

The frictional force acting on the ring acting tangentially at the radius r is

= Fr

$= \mu \times dw$

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

Figure 5: Clutch Plate

Frictional torque actin on the ring

= Tr

= Fr×r

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

$= \mu \times P \times 2\pi r^2 \times dr$ 4-2-2

We shall now <u>consider two cases</u>

1. When there is uniform pressure

2. When there is uniform wea

Considering uniform pressure:

When the friction force is distributed uniformly over the entire area of friction surface, the intensity of pressure will be,

$$P = \frac{W}{pi(r1^2 - r2^2)} \quad \text{4-2-3}$$

Here,

W= axial force with which the clutch and the flywheel are held together

We have discussed above that the frictional torque on the elementary ring of radius r having thickness dr

= Tr

= 2πμPr^2dr

Integrating the equation with the limits r2 to r1 for the total frictional torque

= > Total frictional torque acting on clutch

= T

Considering uniform axial wear:

In machine parts, which are subjected to wear due to sliding friction, the normal wear is proportional to work done by friction. The work done by the frictional force is again proportional to product of sliding velocity (V) and normal pressure (P).

Therefore, Normal Wear $\propto$ work of friction $\propto$ P. V

P.V = Const.

P = Const /V

While new a friction surface exerts uniform pressure over the entire contact area. Gradually the pressure will vary at different locations due to wear. Wear will be more where the velocity is high.

This wearing process will continue until the P.V becomes constant over the entire surface. Then the wear is minimum.

Let p be the nominal intensity of pressure at a distance r from the axis of the clutch. Since the intensity of pressure varies inversely with the direction, therefore

$$P.r = C$$

$$P = C/r$$

And the normal force on the ring

$$dW = P.\ 2\pi r.\ dr$$

$$= (C/r).\ 2\pi.\ r.\ dr$$

$$= 2\pi.\ C.\ dr \qquad 4\text{-}2\text{-}4$$

We know the friction torque acting on the ring

$$Tr = 2\pi\mu Pr^2 dr$$

$$= 2\pi\mu \times (C/r) \times r^2 dr$$

$$= 2\pi\mu C r dr \qquad 4\text{-}2\text{-}5$$

In our case we have

I. The torque to be transmitted.

II. The inner radius is fixed due to the size of shaft and bearing.

III. We have the COF (μ) from the table.

IV. W can be varied in suitable range adjusting the spring constant and displacement.

As we have found out the torque required at the centre of the rear wheel is

$$Tw = 26.884$$

And the Maximum gear ratio for the Al flywheel = s

Torque transmitted by the clutch

T = 26.884/ s

Again, r_2 has its upper limit as 25/2 = 12.5cm

3.3 Calculation of the Chain Length

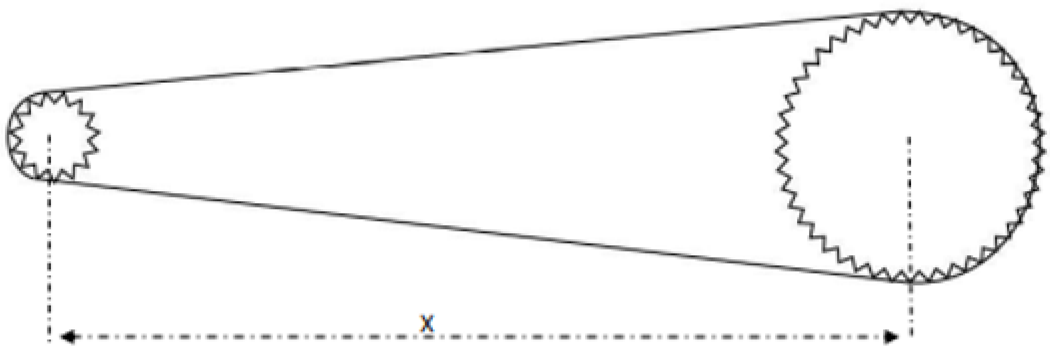


Figure 6: Chain Length Calculation

T_1 = Number of teeth on the smaller sprocket

P = Pitch of the chain

T_2 = Number of teeth on the larger sprocket.

X = Centre distance

K = Number of units of the chain links used.

L = Length of the chain.

p = Pitch of the chain

The length of the chain can be found out by multiplying the number of units with the pitch of the chain.

L= K×p

Number of chain links can be found from the following formula as mentioned in the book of "Machine Design" by Khurmi & Gupta

$$K = \frac{T1+T2}{2} + \frac{2X}{P} + \left(\frac{T2-T1}{2pi}\right)^2 * \frac{P}{X} \qquad 4\text{-}3\text{-}1$$

The value of K obtained from the above equation can be approximated to the next/ nearest even number.

The looseness can be compensated by using an idling gear.

First let us consider the following set of data

$T_1 = 15$

$T_1 = 60$

X = Distance between centres = 1m (approximately, because this distance varies from cycle to cycle.)

p = 12.7mm

The corresponding value of K is given as,

K = 195.63

K ≅ 196

L = 196 × 12.7 = 2489.2mm

Now to calculate the gear shifter/ idler gear arm length:

$T_1 = 15$

$T_2 = 20$

K is calculated as follows,

K = 174.98

K ≅ 176

Length of the chain required for the minimum gear ratio = 176 × 12.7

= 2235.2mm

Length to be compensated = 2489.2 – 2235.2

= 254mm

We can get the length of the shifter arm by triangular approach,

Y = √ (12542 − 10002) = 756mm

this length is very difficult to achieve.

So, the gear ratio is reduced to 3:1 and the procedure is redone.

T_1 = 15

T_2 = 45

X = Distance between centres = 1m (approximately because this distance varies from cycle to cycle.)

Pitch= p = 12.7mm

K = 188 (calculated using the previously mentioned steps)

L = 188 × 12.7 = 2387.6mm

Now to calculate the gear shifter/ idler gear arm length:

T_1 = 15

T_2 = 20

K = 176

Length of the chain required for the minimum gear ratio = 176 × 12.7 = 2235.2mm

Length to be compensated = 2387.6 – 2235.2 = 152.4mm

We can get the length of the shifter arm by triangle approach,

Y = √ (1152.4^2 – 1000^2) = 572.7mm

Converting this length into number of links

No. of links = 572.7/12.7 = 45.09 ≅ 45

Which implies we have to compensate 45 no of links at the lowest gear ratio.

This can be easily achieved by models readily available in the market.

3.4 Design of the clutch drive system:

From previous calculation we know

T = 26.884/s Nm.

As we have found out,

s=3

T = 8.96 Nm.

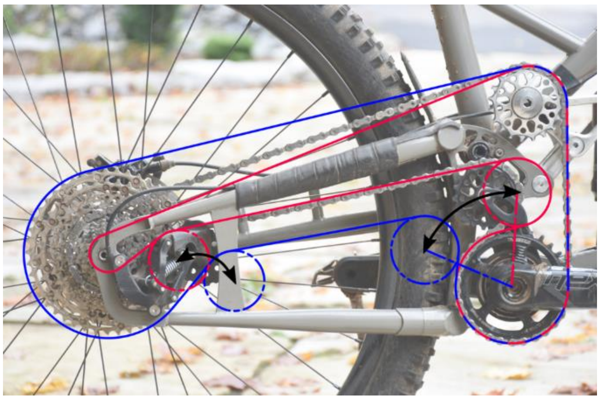


Figure 7: Clutch Drive for Bicycle

Let us assume the outer radius of the clutch = 10cm (less than 12.5cm) and inner radius of the clutch = 2cm

First calculating **the threshold spring force** required to actuate the clutch so that whenever the clutch is applied at whatever sprocket ratio to discharge the energy from the flywheel, the energy will be discharged, and the bicycle will move.

Threshold torque means the minimum amount of torque that the front sprocket must provide in order to bring the system into motion, i.e. the bicycle + rider system will come into motion.

For this the force required at the rear wheel = F_t

$F_t = F_r + F_a + F_f$

Fa is neglected here. Even, FA won't come into picture if there is no relative flow of wind.

$F_t = 7.2 + 2.313 + 2$

= 11.513N

Now considering F_t = 12N so that it will just accelerate the system with minimal acceleration. Threshold Torque required at the rear wheel centre.

$$TTW = 12 \times (\text{radius of the rear wheel}) = 12 \times (0.75/2) = 4.5Nm \qquad 4\text{-}4\text{-}1$$

We generally engage the flywheel at high sprocket ratio s.

$$TTF = 4.5/ s$$

But if the clutch is actuated to discharge energy at lowest gear ratio the system should be able to do that.

$$TTF = 4.5/1.25 = 3.6Nm$$

The clutch should be able to transmit torque more than this limit.

- Mean radius of the clutch surface = (10+2)/2 = 6cm =0.06m
- Minimum force applied by the clutch drive = FTC
- FTC = 3.6/(μ×0.06) = 3.6/ (0.4×0.06) = 150N
- The mechanical advantage at the clutch drive = n
- Linear travel of the clutch drive = 3mm
- Rotational travel of the outer periphery point = 150/180 × 2πR = 150/ 180 × 2π × 10 = 52.36mm
- The mechanical advantage = n = 52.36 3 = 17.454 ≅ 17.5
- Threshold force applied by the spring = FTS = 150 17.5 = 8.6N

The spring force should be greater than 8.6N. With requirement of higher acceleration, required spring force will also increase.

For maximum acceleration:

$$T_f = 26.884/ s\ Nm. = 26.884/3\ Nm. = 8.96Nm.$$

(Because maximum acceleration can be achieved when the sprocket ratio is maximum s = 3.)

Force applied by the clutch drive = F_c

F_c = 8.96/ (μ×0.06) = 8.96 0.4×0.06 = 373.39N

Spring force

F_s = 373.4/17.5 = 21.33N

To disengage the clutch driver has to apply a force equal to or more than 21.33N

Mechanical advantage at the left brake handle = x1/ x2

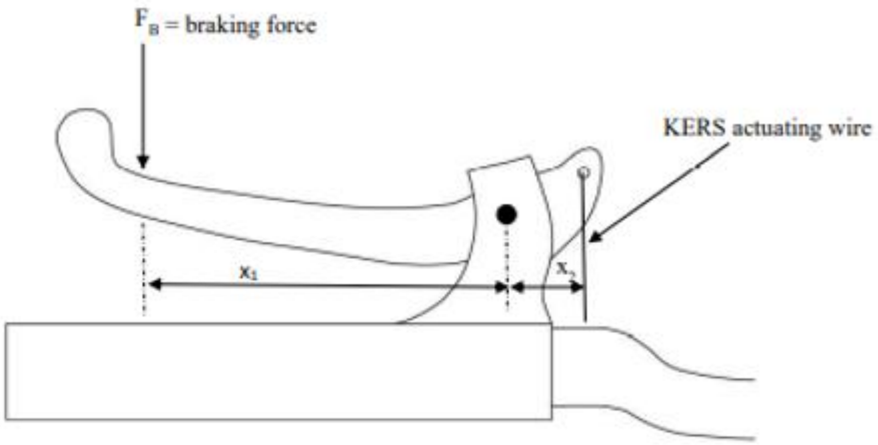


Figure 8: Clutch of Bicycle

Comfortable force that the rider can apply = 0.5 Kg = 4.905N
Mechanical advantage at the left brake handle = 4.35
The left handle is to be designed with a mechanical advantage of 4.35.

Chapter 4 Computer Aided Designs

CAD, or computer-aided design and drafting (CADD), is technology for design and technical documentation, which replaces manual drafting with an automated process. If you're a designer, drafter, architect, or engineer, you've probably used 2D or 3D CAD programs such as Solid Works or AutoCAD softwares.

The different CAD models that are used in our project are as follows,

4.1 Smaller Gear:

This gear is to be mounted on the center of the clutch plate and is designed accordingly by looking at the parameters of the plate. The model of the gear was imported to solid works and then changes were done accordingly.

- This gear has 12 teeth.
- The pitch diameter is according to the meshing with the larger gear.

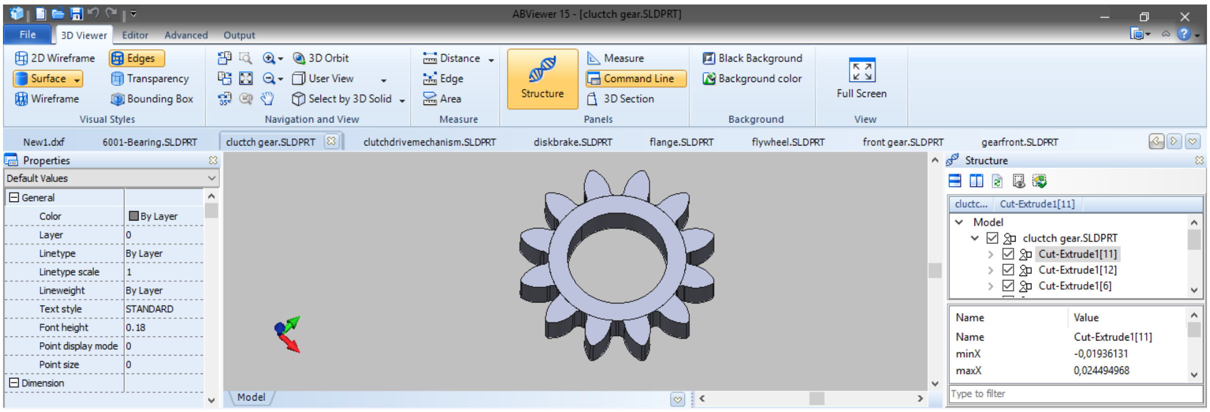


Figure9 : Small Gear attached with Clutch Plate

4.2 Clutch Drive Mechanism:

This model is created on solid works and by using circular and line commands followed by the corresponding equation. This was one of the most difficult models in SW. Two of these models are created and they move with eachother.

- The mass of the mechanism is very less and no such strength is required.

- This part just moves the clutch plate forward and backwards for the utiization of flywheel

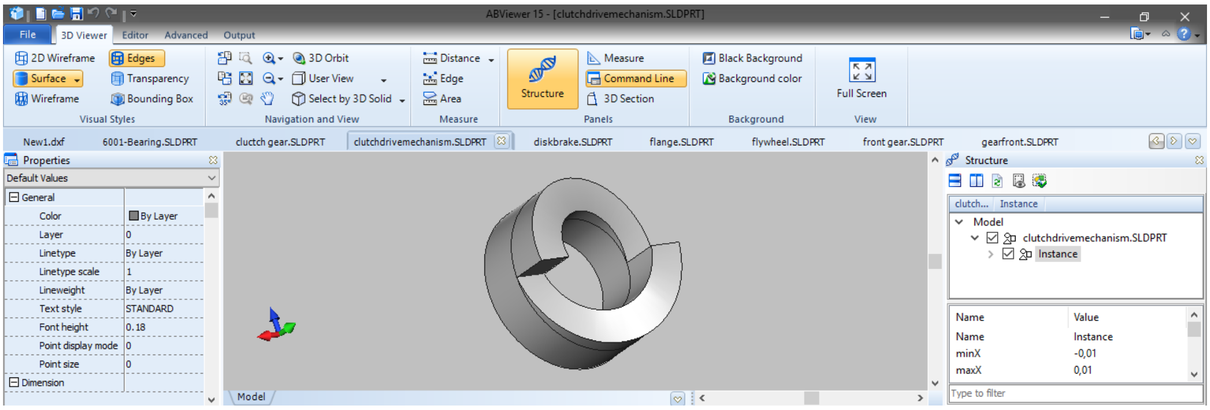


Figure 10: Clutch Drive Mechanism

4.3 Brake Disc attached with flywheel:

This model was created in solid works and was designed accordingly with the disc available in the market. The parameters were taken from the disc and they were followed fot the modeling.

We has a custom brake disc that might be created by CNC or laser cutting but fortunately it was available in the market.

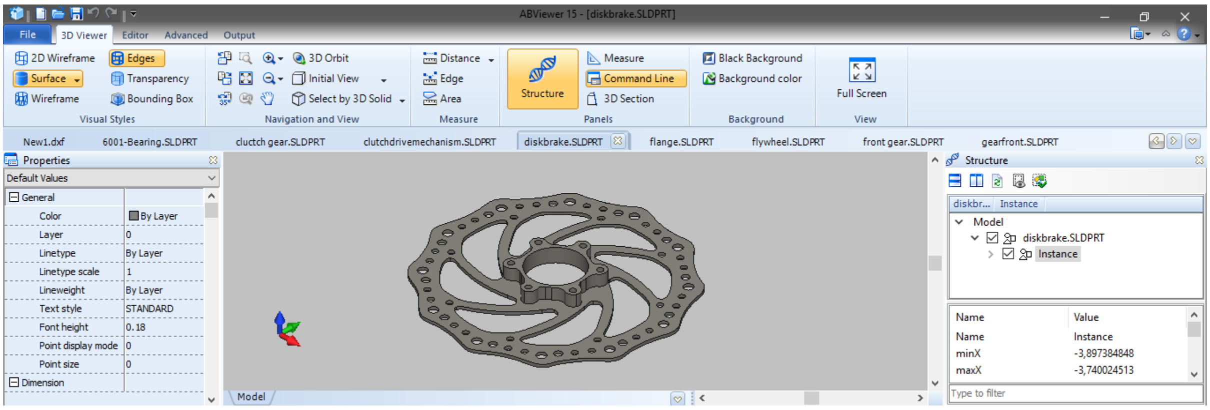


Figure 11: Brake Disc attached with flywheel

4.4 Bearing:

The bearing is also used at various locations in the project where we are using the shaft and axles. This bearing is taken from the pool available on the internet and was implemented on the SW final assembley.

Many changes were done on the bearing design as sometimes holes, skrews, bolts and shafts were not available in the market accordingly.

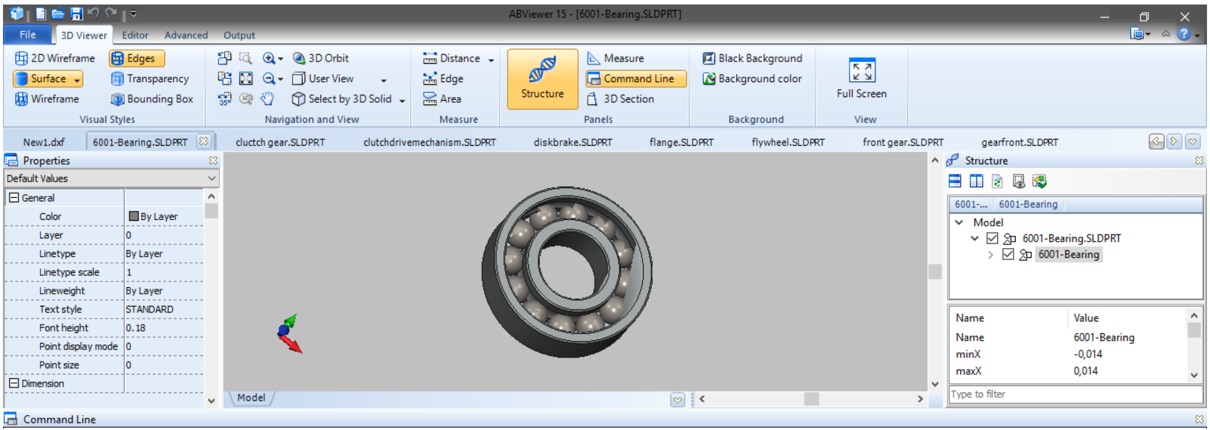


Figure 12: Bearing attached at various locations

4.5 Circular Mounting:

This model is a very simple model and is created on solid works by just following the following commands,

- Circular
- Extrude
- Depth extrudes for the holes on the side for the mount fixation.

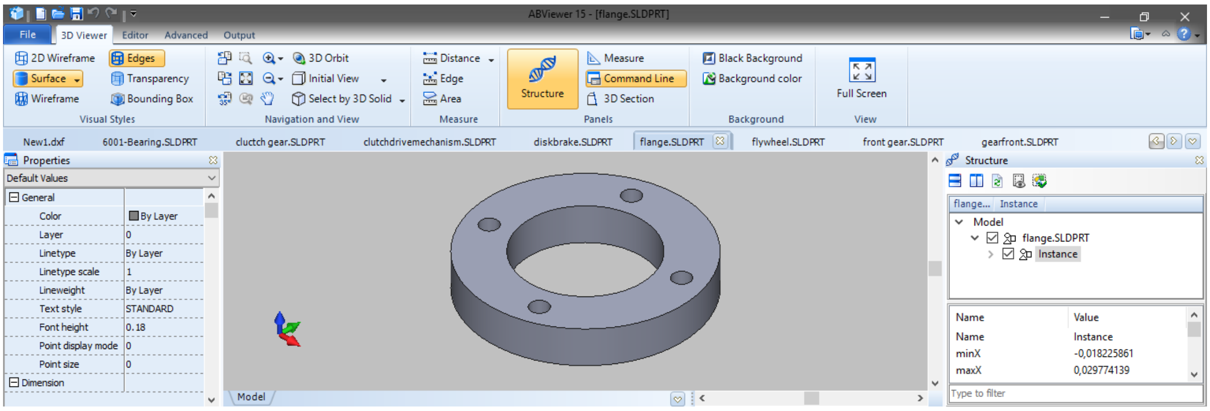


Figure 13: Aluminum Circular Mounting

4.6 Flywheel:

This model is created by following the mentioned steps,

- Dimensions are taken from the theoretical calculations and from the alterations depending on the market availability.
- A circle of 23cm diameter is created and the extruded.
- A hole is created at the center for the axle and then extruded cut.
- A depth of 8mm is also created for the bearings on both sides.

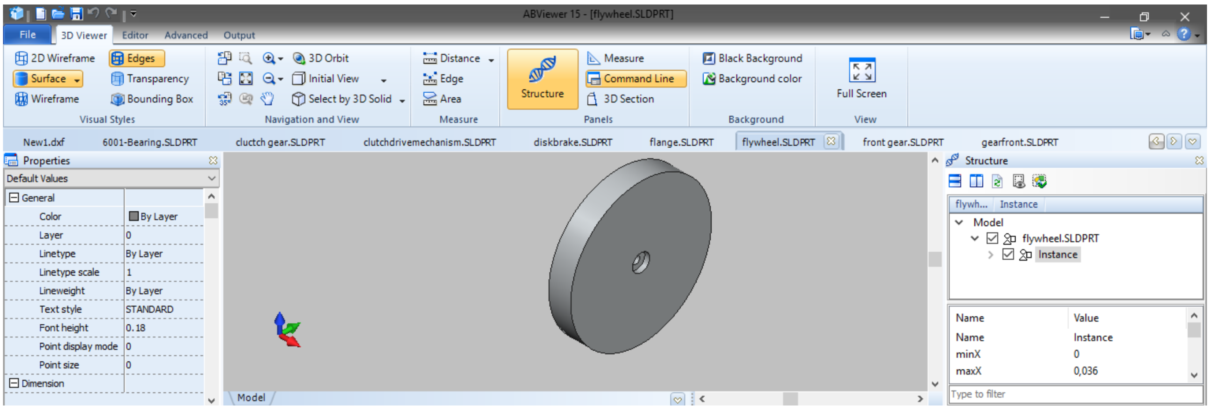


Figure 14: Aluminum Flywheel

4.7 Front sprocket:

This model is created by following the mentioned steps,

- This gear is custom made for our project so the dimensioning was taken firstly.
- A gear was imported for the pool available on internet and the gear teeth and size was changed.
- Hole in the centre was created for the passing of the transmission shaft. The holes at the side of the central one are for the fixation with the transmission shaft.

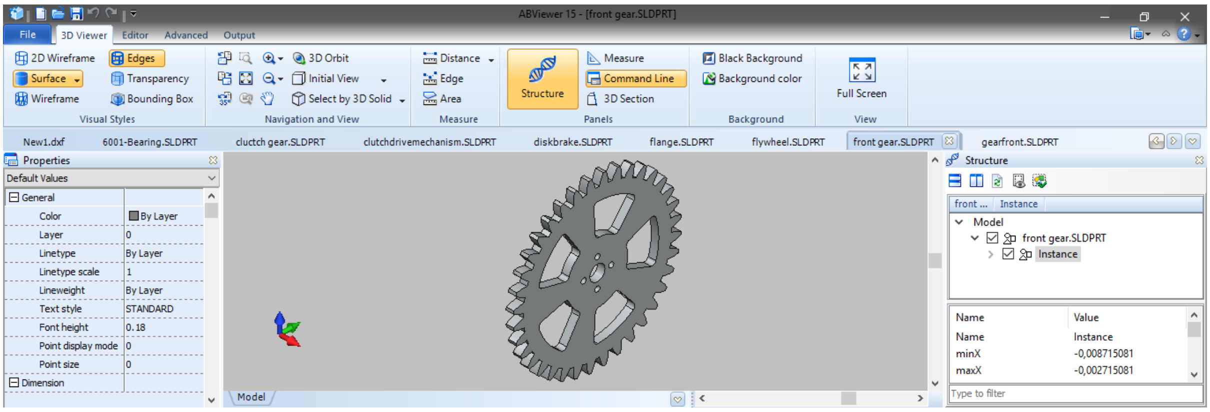


Figure 15: Large Gear attached with the smaller gear

4.8 Gear:

This model is created by following the mentioned steps,

- All gear models are imported from the outside sources mentioned in references section and changes are done accordingly.

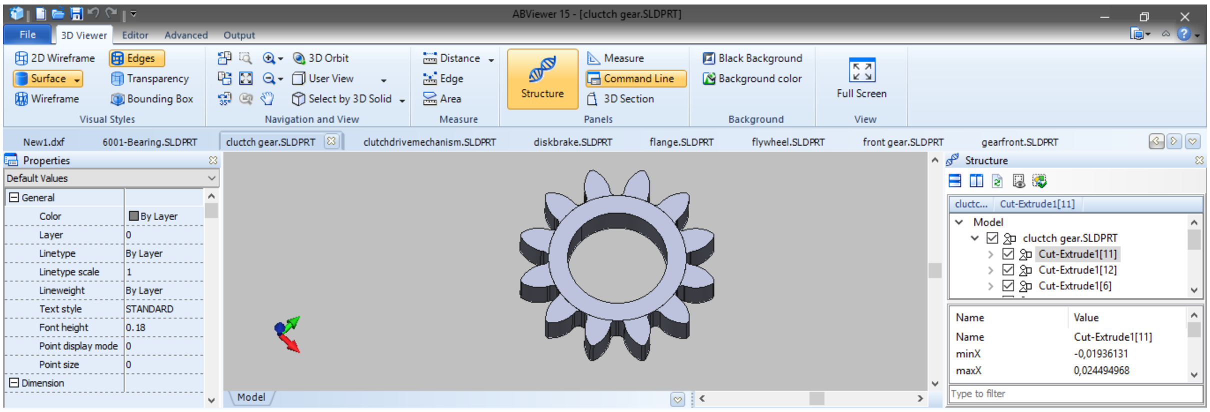


Figure 16: Gear

4.9 Aluminum Mounting part 1:

This model is created by following the mentioned steps,

- A sketch was drawn depending upon the bicycle frame.
- The sketch was then extruded
- 6 holes were cut for proper mounting.
- Corners were filleted.
- A gear was imported for the pool available on internet and the gear teeth and size was changed.

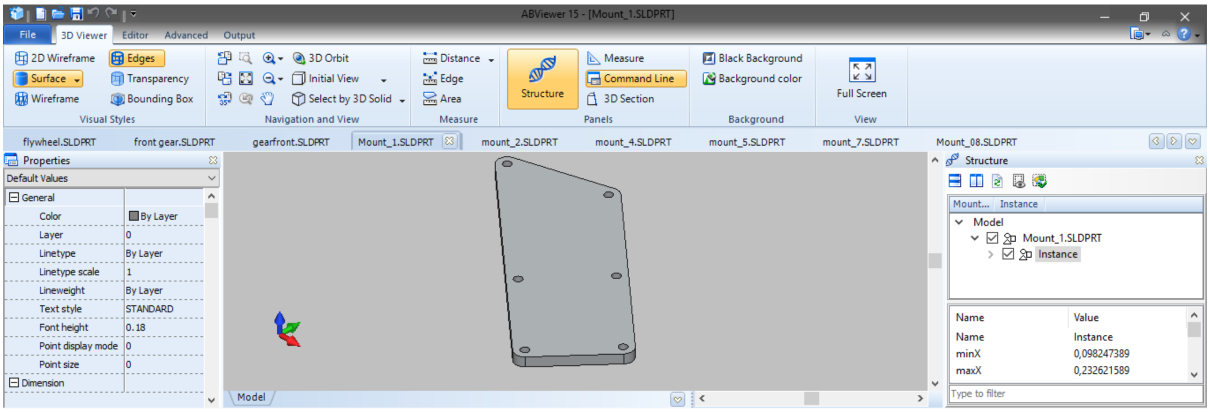


Figure 17: Central Aluminum Mounting between two mounts

4.10 Aluminum Mounting part 2:

This model is created by following the mentioned steps,

- A Sketch was drawn based on the bicycle frame.
- Sketch was exruded to 5mm.
- Hole of 12mm was made for the axle mounting.
- 4 holes were made for mounting on the frame.
- The holes in between were generated for mounting of flanges in which the front sprocket is to be mounted.
- All sharp corners were given a fillet.

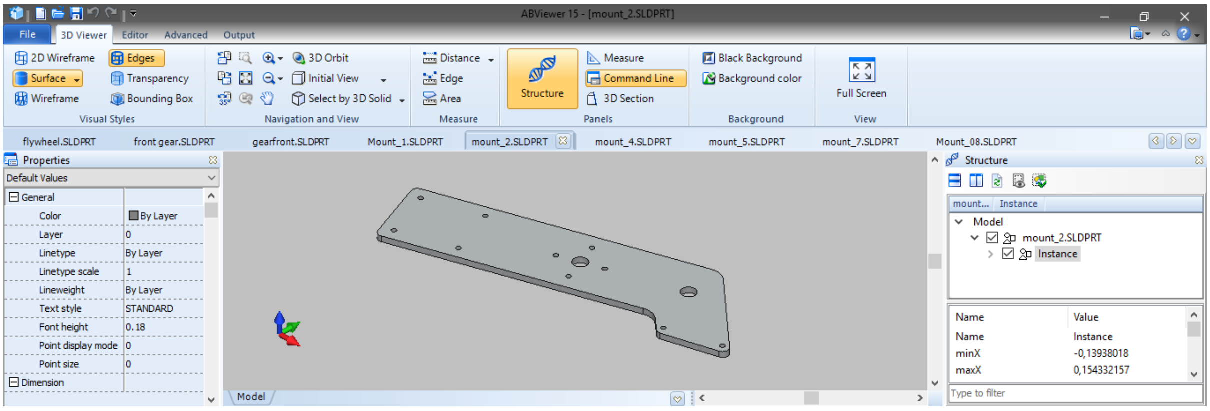


Figure 18: Larger Aluminum Mounting attached with Bicycle Frame

4.11 <u>Teflon Mounting 1:</u>

This model is created by following the mentioned steps,

- A sketch was made based on bicycle frame and aluminum mounting.
- Sktech was extruded.
- 4 holes were generated for mounting using bolts.
- Hole in the centre was created for the passing of the transmission shaft. The holes at the side of the central one are for the fixation with the transmission shaft.

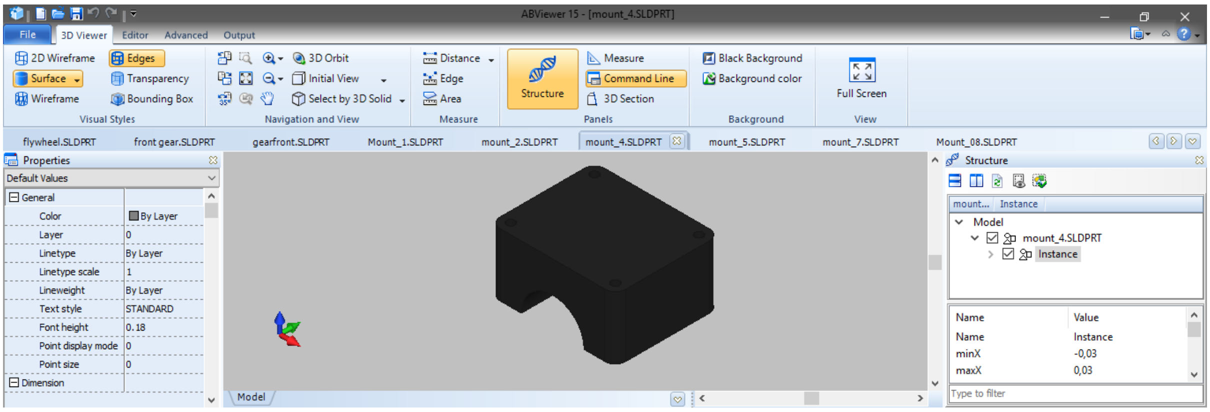


Figure 19: Smaller Teflon Mounting

4.12 <u>Aluminum Mounting part 3:</u>

This model is created by following the mentioned steps,

- A sketch was made based on bicycle frame and this was made for the back plate.
- Sketch was extruded.
- 8 holes were made for mounting properly.
- A hole in centre is intended for axle.
- All the sharp corners were filleted.

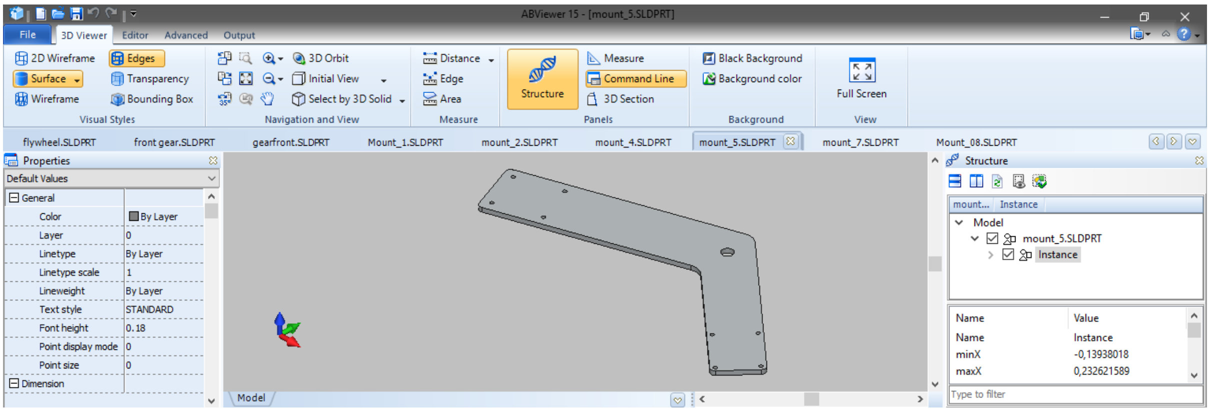


Figure 20: Larger Aluminum Mounting

4.13 <u>Larger Teflon Mounting:</u>

This model is created by following the mentioned steps,

- A sketch was made based on bicycle frame and aluminum mounting.
- Sktech was extruded.
- 4 holes were generated for mounting using bolts.
- Hole in the centre was created for the passing of the transmission shaft. The holes at the side of the central one are for the fixation with the transmission shaft.

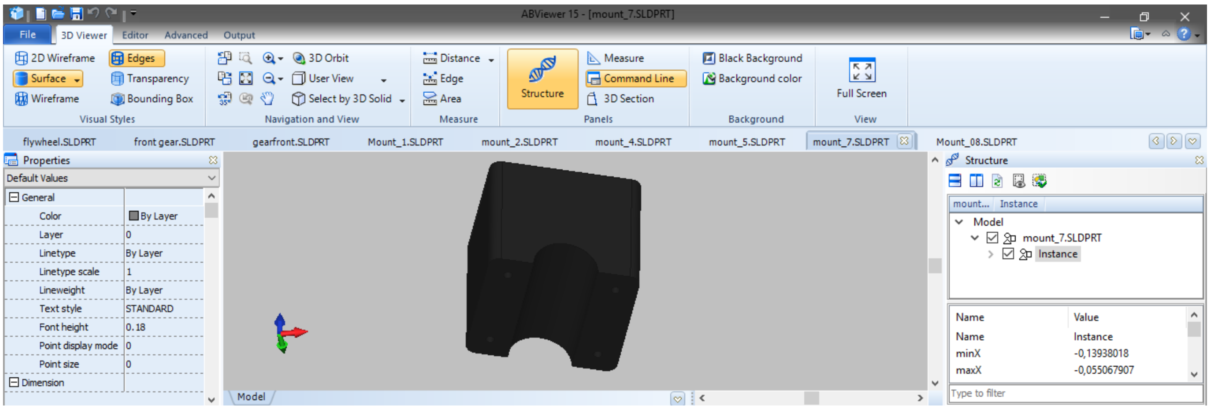


Figure 21: Larger Teflon Mounting attached with Bicycle Frame

4.14 Smaller Teflon Mounting:

This model is created by following the mentioned steps,

- A sketch was made based on bicycle frame and aluminum mounting.
- Sktech was extruded.
- 4 holes were generated for mounting using bolts.
- Hole in the centre was created for the passing of the transmission shaft. The holes at the side of the central one are for the fixation with the transmission shaft.

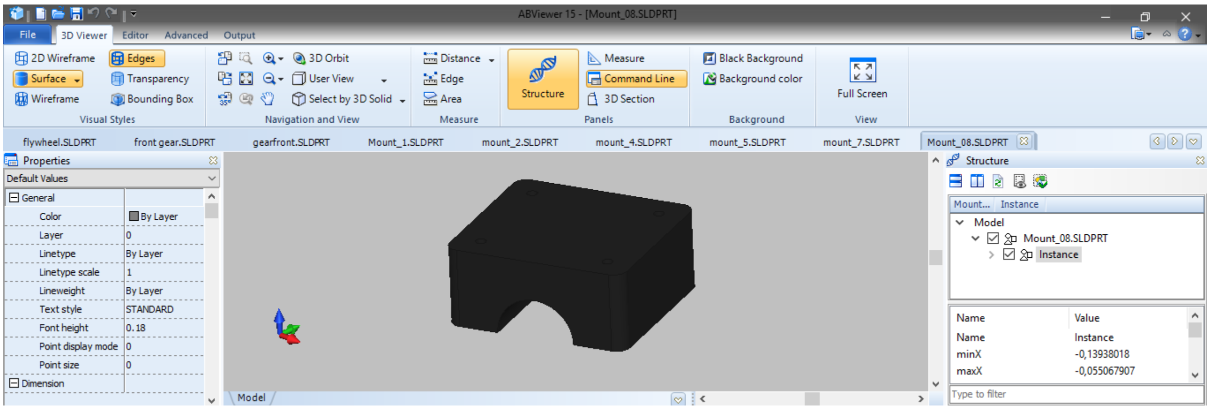


Figure 22: Smaller Teflon Mounting attached with Bicycle Frame

4.15 Aluminum Frame:

This model is created by following the mentioned steps,

- The sketching is done firstly.

- The measurements for the external diameter of the rod are taken from the actual bicycle.
- The circular rod is created and extruded till the required lengths.
- The triangular shape of the rods is created and joined together at the given angles.

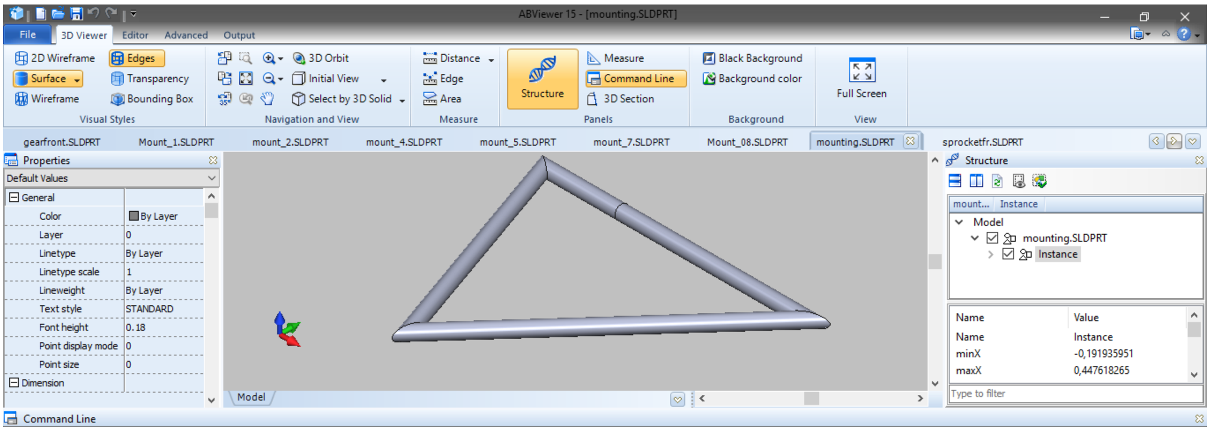


Figure 23: Aluminum Frame of the Bicycle

4.16 <u>Clutch Plate:</u>

This model is created by following the mentioned steps,

- The model is created in accordance with the flywheel and the disc brake.
- The sketch is created firstly.
- It is extruded to its required thickness.
- The holes at the centre are created for passing of the axle.
- The grooves are created for the brake pads.

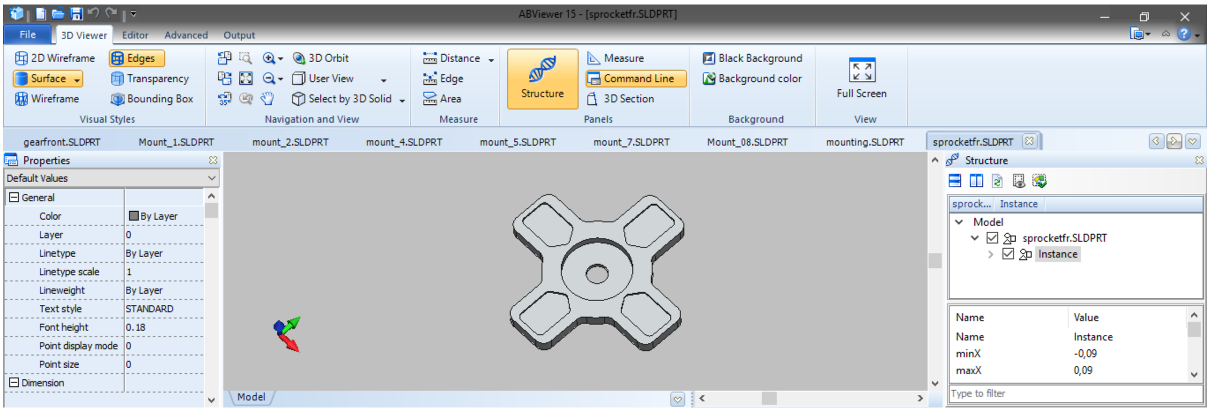


Figure 24: Aluminum Clutch Plate

4.17 Assembly of CAD models:

The following steps were taken for the assembly of the CAD model. The software used was solid work. For starting the assembly, we need to first select a central component. Once that component is selected then different parts are attached to the central component resulting into assembly of the model.

- The central component in our case is flywheel. We attached different component with flywheel.
- Clutch plate was attached to flywheel. We simply went into model and attached it to the assembly keeping in regard the different constraints as for example the constraint of rotation for clutch and flywheel.
- Central rod is the next component and same constraint of rotation was used here that is acle will rotate will correspond to rotation of flywheel and clutch.
- Brake pads are then used on clutch plate to contact clutch plate in solid work. They will rotate together.
- After that disc brake is attached to flywheel and then correspondingly clutch plate, axle, and flywheel will rotate and be in contact.
- A small gear is attached at the opposite side of clutch plate in solid works.
- We used meshing process in solid works to mesh the teeth of larger gear with the other to mesh them properly in the CAD. This will help rotate in rotation of second gear once the first one is rotating.
- With the small gear, we have placed the clutch drive mechanism. When clutch drive mechanism opens, the clutch will start transmitting energy into the flywheel.

- On the other hand, when the clutch drive mechanism closes, the flywheel will transmit energy back to the clutch and corresponding to the wheels afterwards.
- Clutch movement is entirely working on axle
- The larger gear is mounted on another shaft. The constraints are defined accordingly. The constraints define here motion, circular and movement constraints.
- After that mounting of both Aluminium and Teflon are mounted. This was designed simply so that placement will act accordingly. This made our model.
- This is our KERS assembly.

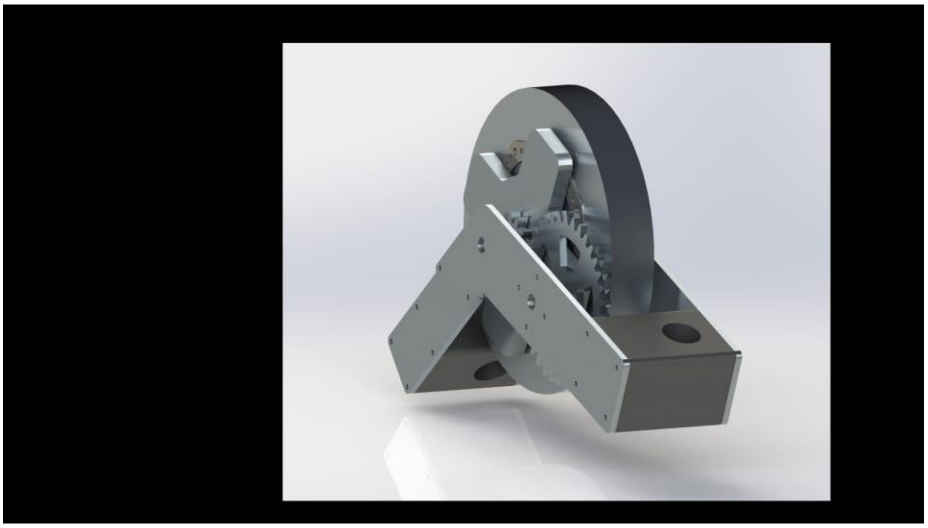


Figure 25: Isometric View of the Assembly

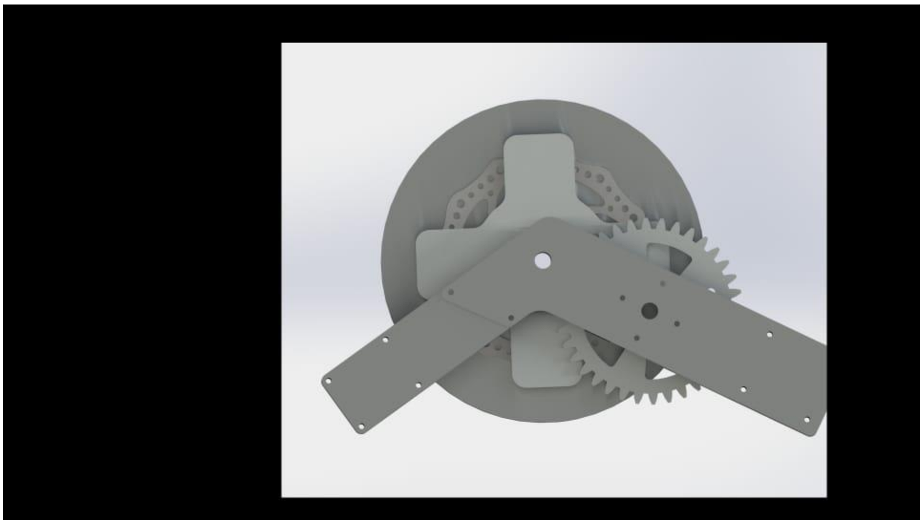


Figure 26: Front View of the Assembly

Chapter # 5 Finite Element Analysis

Finite element analysis of every component has become necessary for any design process. Every designed thing should be checked whether it can take the desired load and sustain the working environment. Product life cycle is an important term coined in this field. FEA helps us to identify the mistakes in our designs. It shows the tress concentration and strain at different desired points. Even it helps to directly find out the factor of safety for a component. The best part is we can change the part material and test as many times as we want without losing any raw material. In this project also extensive FEA analysis has been done on different components to check their integrity and sustainability. All the results of those works have been mentioned below:

5.1 Flywheel

Flywheel is the most rigid component among the components of a KERS system which has the least amount of chance to undergo a failure.

Forces acting on the flywheel are given as,

- Gravitational force
- Rotational inertia force (66.66rps)
- Force due to actuation of clutch (373.4N)

Supports of the flywheel are given as,

- Bearing support.
- Displacement support

After applying the displacements and the supports, the following results have been taken from Ansys.

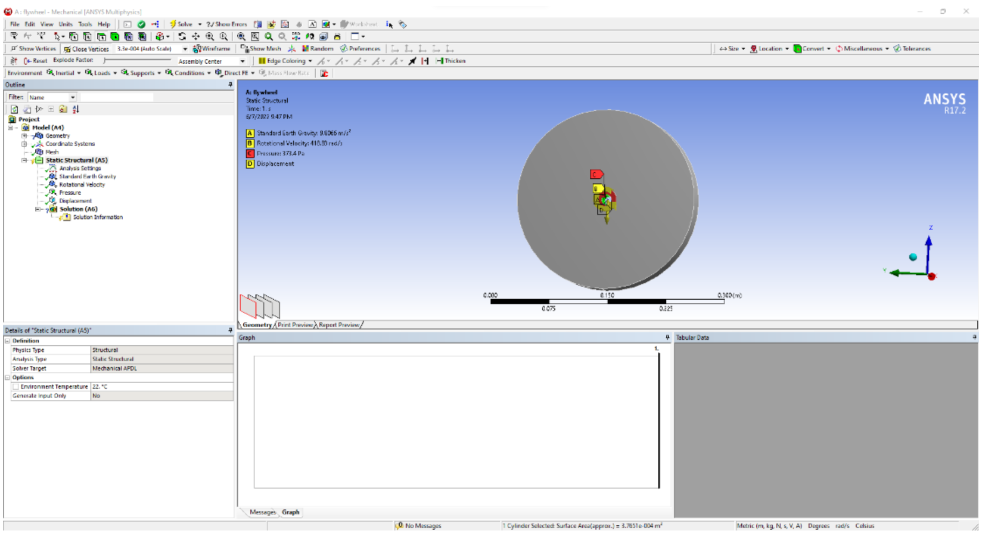


Figure 27: Supports and Displacements on Flywheel

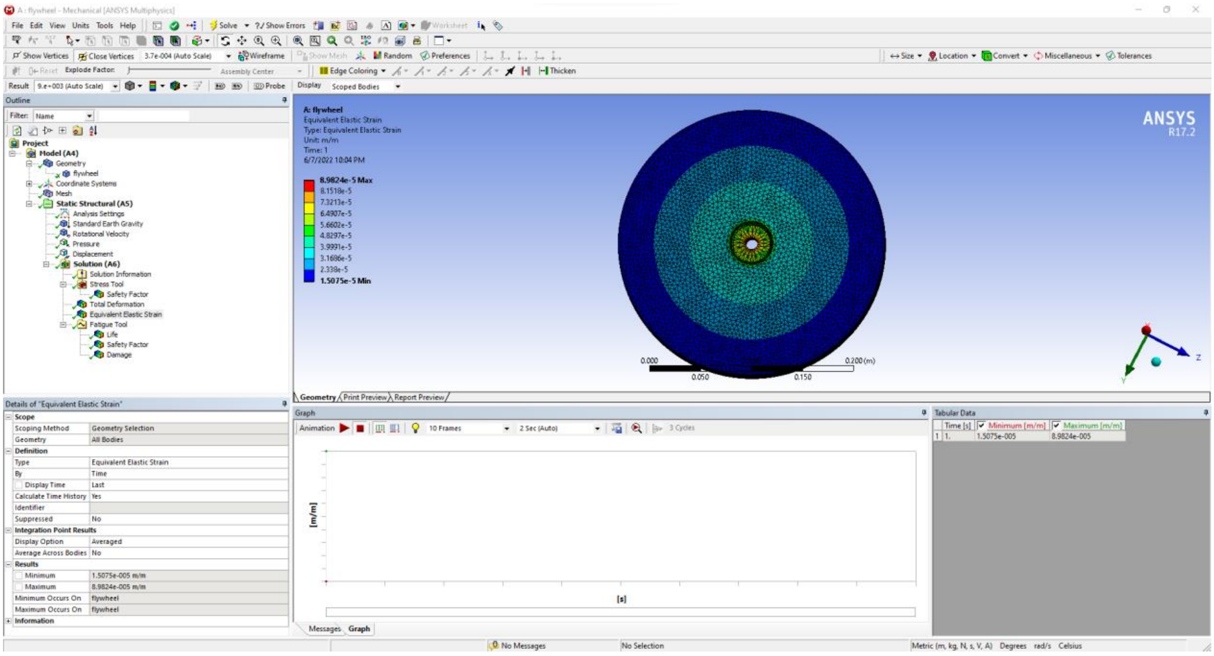


Figure 28: Equivalent Elastic Strain on Flywheel

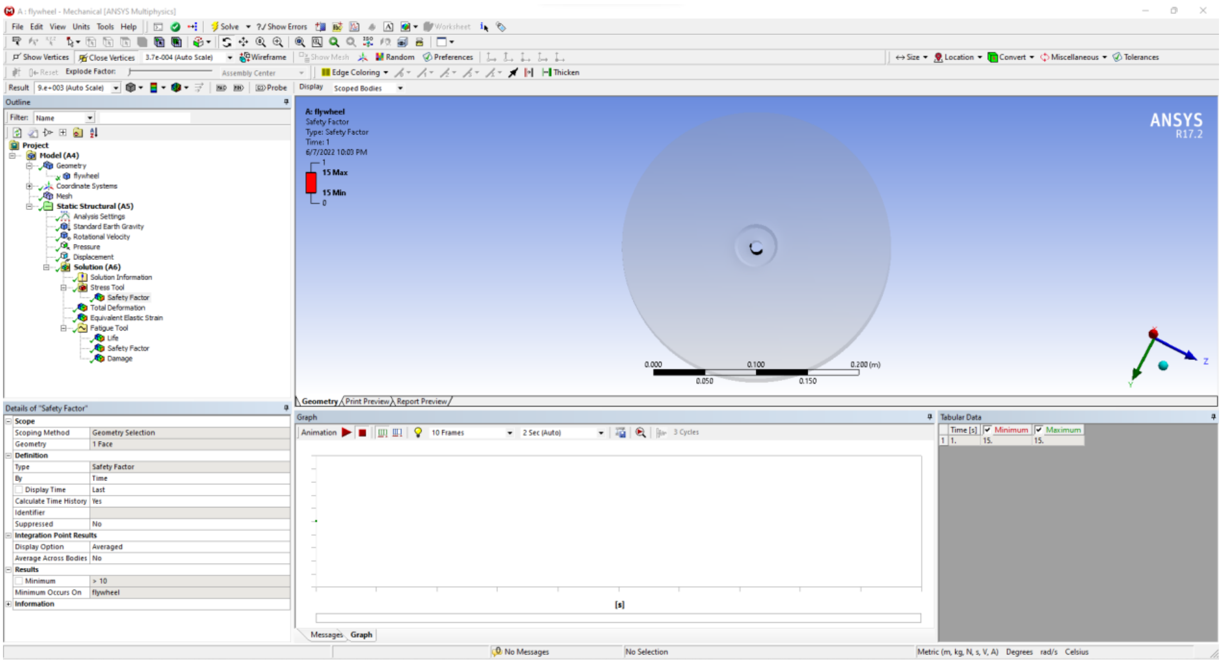


Figure 29: Safety Factor of Flywheel

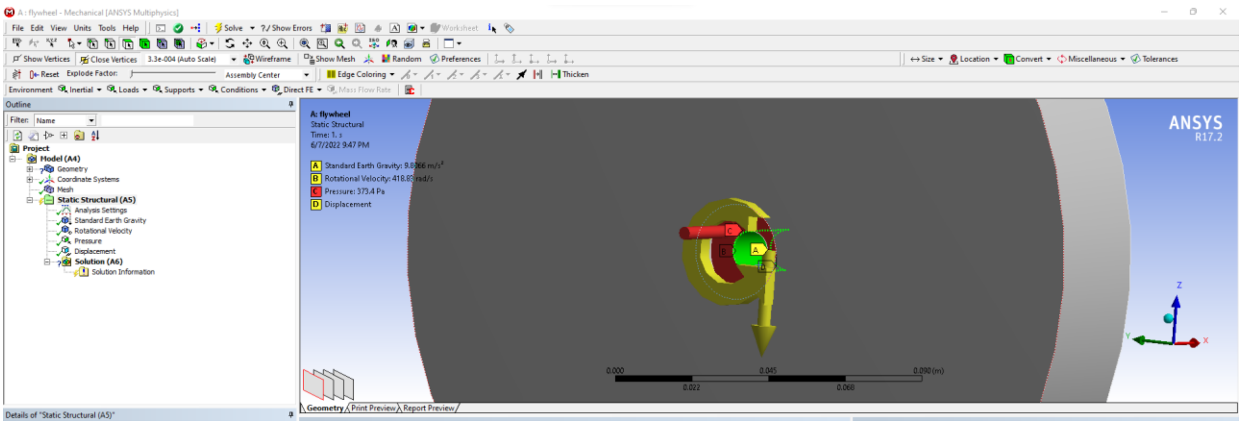


Figure 30: Zoomed View of all Displacements and Forces on Flywheel

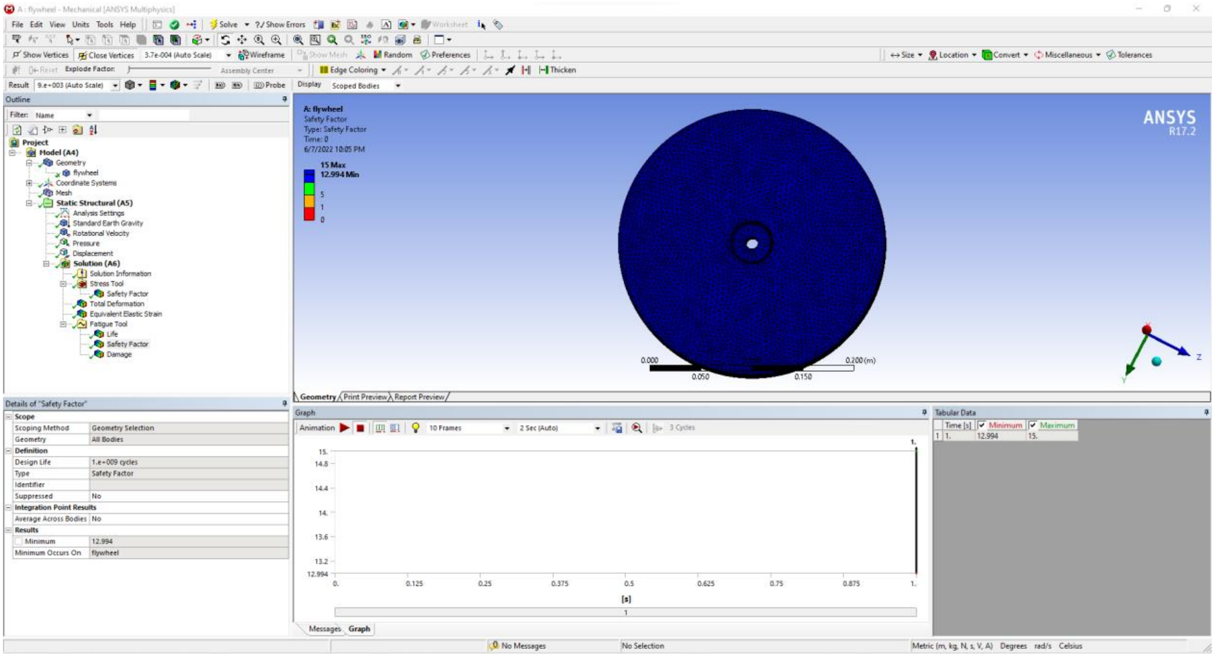


Figure 31: Fatigue Safety Factor of Flywheel

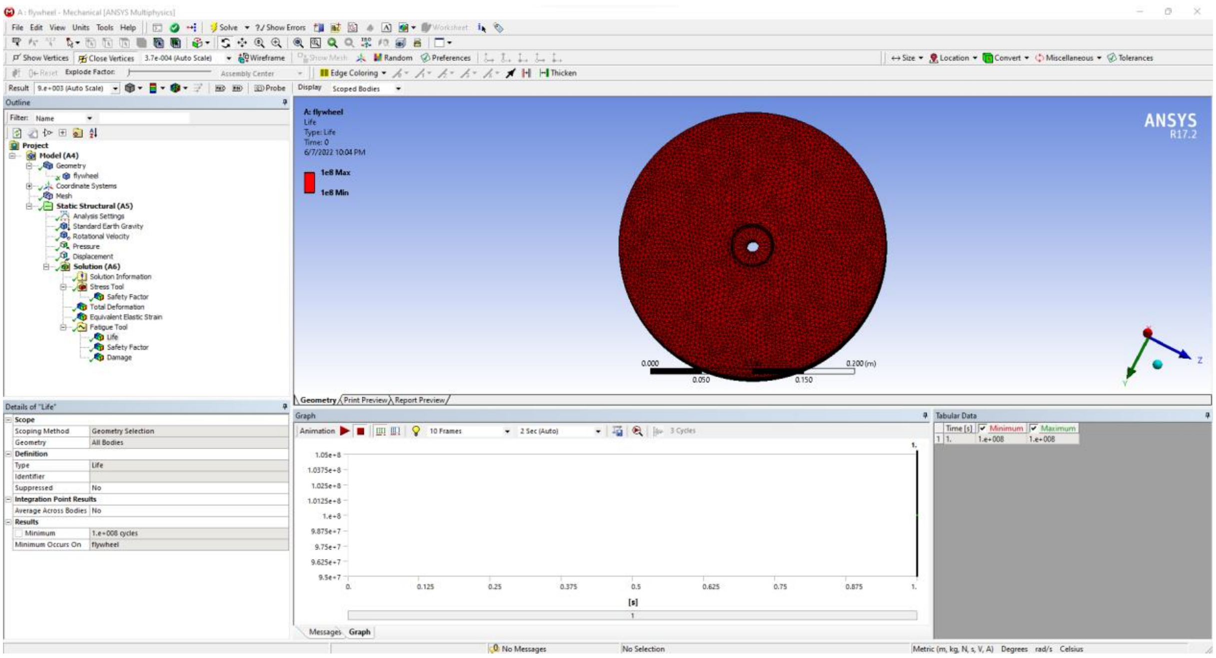


Figure 32: Life of Flywheel

Description:

The above figures are discussed as follows,

5.1.1 Supports and Displacements on Flywheel

The mentioned supports and displacements are applied on flywheel. The points of the application and the direction is shown in the figure 26 accordingly.

5.1.2 Equivalent Elastic Strain on Flywheel

As the main force and pressure is applied at the centre of the flywheel that's why the max strain occurs at the center of the flywheel and is very small and negligible. It has to be noticed that its static analysis results.

5.1.3 Safety Factor of Flywheel

According to the static analysis performed the FOS of the flywheel comes to be around 15. It shows that the flywheel is very save and no static stresses can fail it to some level.

5.1.4 Zoomed View of all Displacements and Forces on Flywheel

The earth gravitational force is applied at the center and is facing downwards in the negative z direction. The rotational velocity is applied in the anti-clockwise position. The displacement constraint is also applied.

5.1.5 Fatigue Safety Factor of Flywheel

The factor of safety of the flywheel when it is subjected to fatigue analysis is decreased to some extent and becomes about 12 to its min level. Even then the flywheel is very safe and no such failure is expected out of the mentioned cycles.

5.1.6 Life of Flywheel

If flywheel rotates at the desired rpm for many years, even then its not going to damage due to the large diameter and thickness of this part. The flywheel may experience some damage at its central shaft hole and mounting due to large wear and tear at that location.

5.2 Clutch

Clutch is the most vulnerable component of the KERs system. It is exposed to continuous engagement and disengagement with the flywheel.

Force acting on clutch are given as,

- Force due to actuation of the clutch F = 373.4N
- Gravitational force
- Rotational inertia force
- Speed of rotation when the cycle runs at 30 Kmph and the sprocket ratio is maximum (s=3) $=\omega 2 = 30\times 5\ 18 \times 2D \times s = 66.66$rad/sec

- Torque T = 8.96Nm

Supports are given as,

- Compression only support
- Contact support, no displacement

After applying the displacements and the supports, the following results have been taken from Ansys.

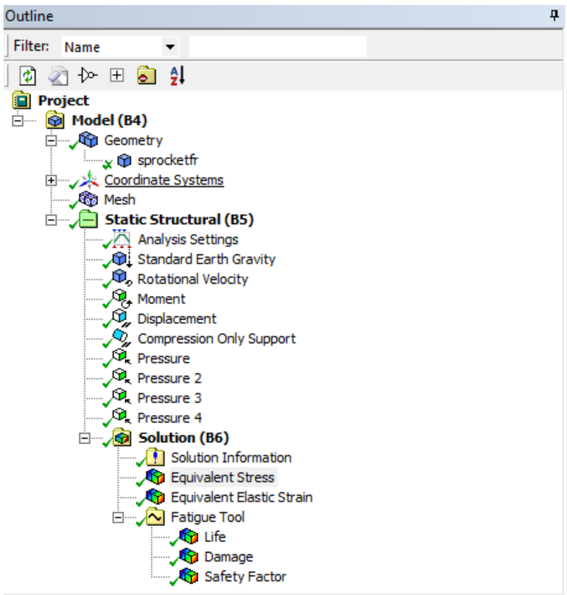


Figure 33: Model Tree of Clutch Plate

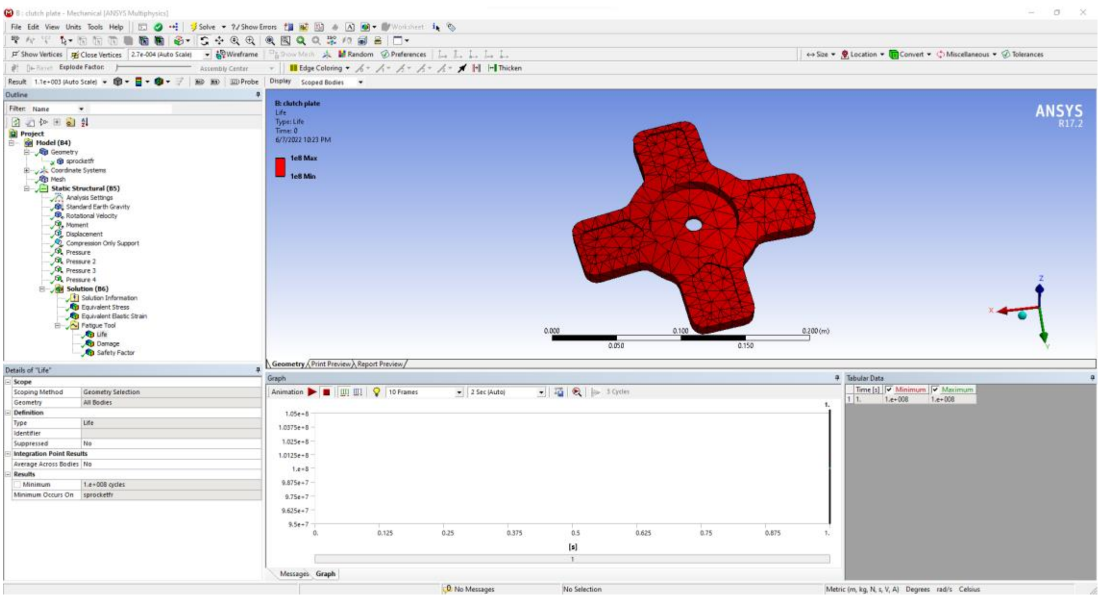


Figure 34: Fatigue Life of Clutch Plate

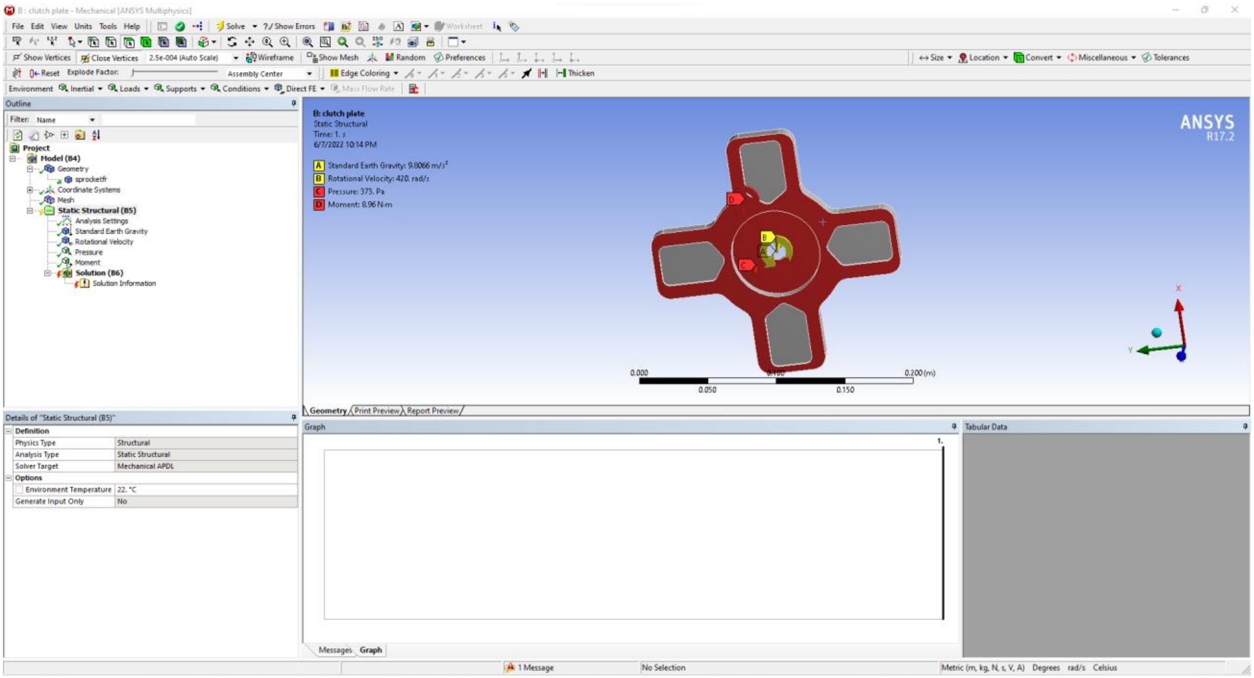


Figure 35: Forces and Displacements applied at Clutch Plate

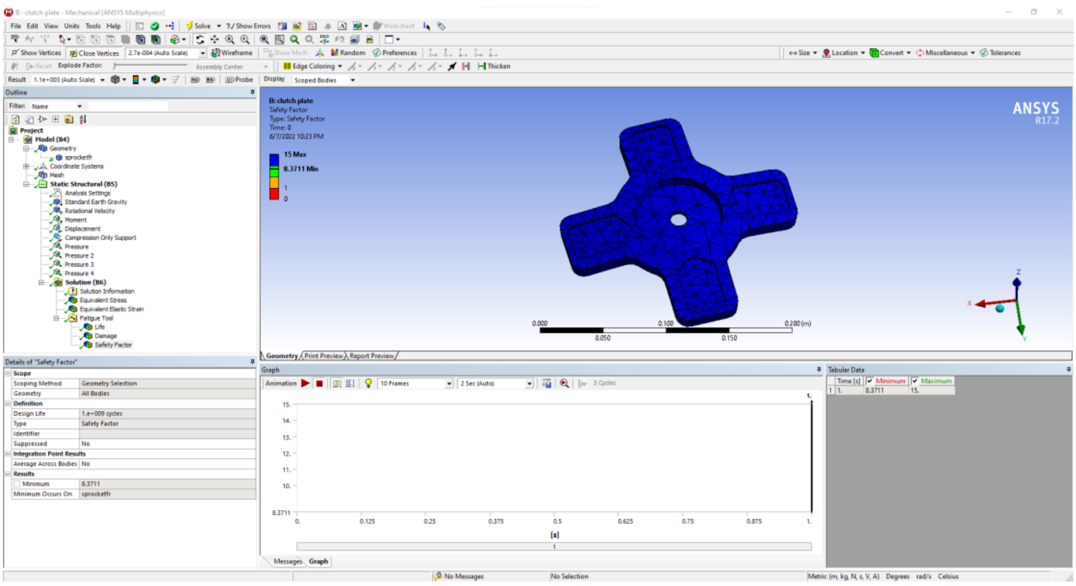


Figure 36: Safety Factor of Clutch Plate

Description:

The above figures are discussed as follows,

5.2.1 Model Tree of Clutch Plate

The model tree of clutch plate shows all the processes to be carries out in the analysis. This tree gives the overview that if any process is missed or not.

5.2.2 Fatigue Life of Clutch Plate

If clutch plate rotates at the desired rpm for many years, even then it's not going to damage due to the large diameter and thickness of this part. The flywheel may experience some damage at its central shaft hole and mounting due to large wear and tear at that location.

5.2.3 Forces and Displacements applied at Clutch Plate

The following forces and displacement constraints are applied at the clutch plate as shown in the figure 34. These forces and constraints are mainly responsible for the working of clutch plate in our desired environment.

5.2.4 Safety Factor of Clutch Plate

The obtained safety factor of the clutch plate is also very large which shows that its capable of working in the bicycle and is not going to be subjected to any failure during its static and fatigue life.

5.3 Front Sprocket

This part is made up of stainless steel so there is a very less chance of damage for this part sill the FEA analysis should be done.

Forces acting on Front Sprocket are given as,

- Gravitational force
- Rotational inertia force
- Torque T = 8.96 Nm

Supports on Front Sprocket are given as,

- Compression only supports and keyway support

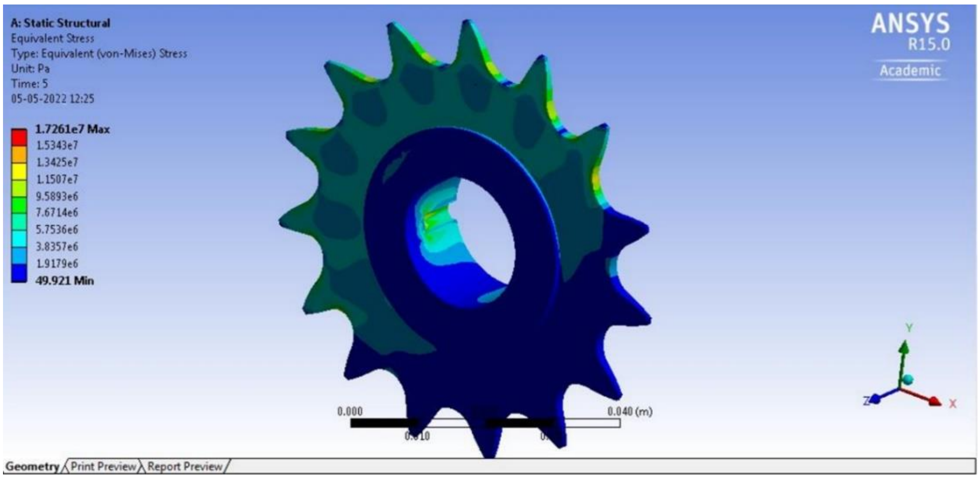


Figure 37: Equivalent Stress on Front sprocket

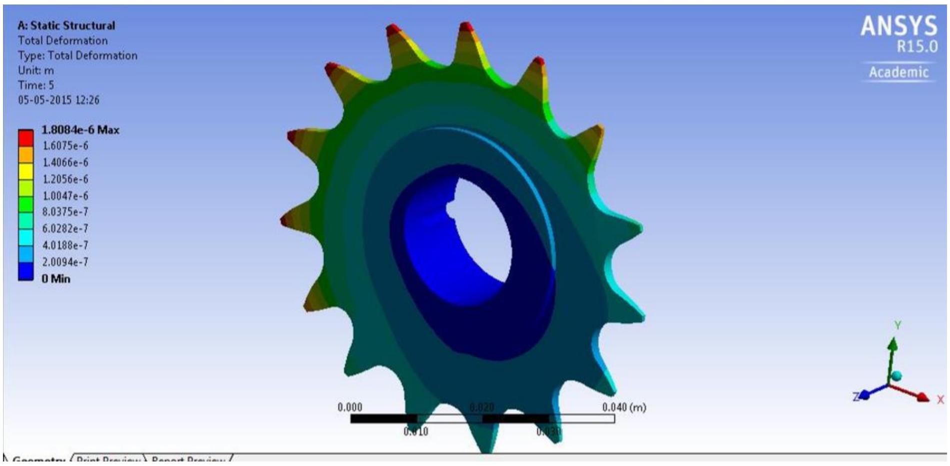


Figure 38: Total Deformation of Front Sprocket

Description:

The above figures are discussed as follows,

5.3.1 Equivalent Stress on Front sprocket

The front sprocket shows an equivalent stress of a very small factor. Mainly this stress occurs at the teeth of the gear and so the teeth are subjected to failure. But in our case, even at a very large rpm the teeth are strong enough to withstand all forces and work in accordance with all components.

5.3.2 Total Deformation of Front Sprocket

Some of the deformation of very small order of mm is shown after various cycles. But we have used Aluminum for our case. If we subject this all to steel, then the failure of various gears can also be prevented and so the life cycles are also increased.

5.4 Central Shaft

This part is made of stainless steel SS304. As all the components rests on this particular part this part needs to be strong. To increase the life of this part, it has been made of Stainless Steel SS304.

Forces acting on the shaft are given as,

- Flywheel weight = 65.04N
- Weight of other components =20N

Structural supports are given as,

- Two end point fixed supports

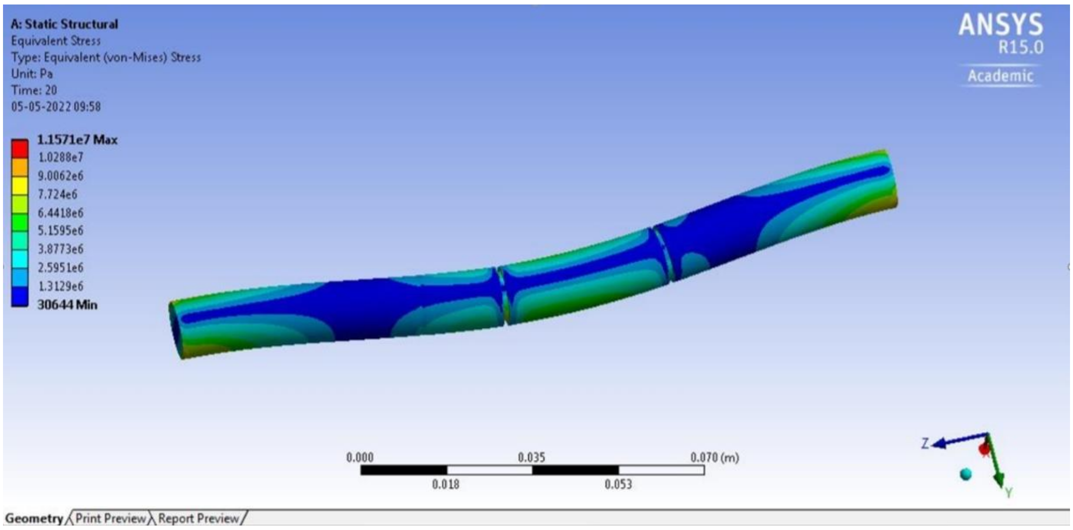


Figure 39: Equivalent Stress on Central Shaft

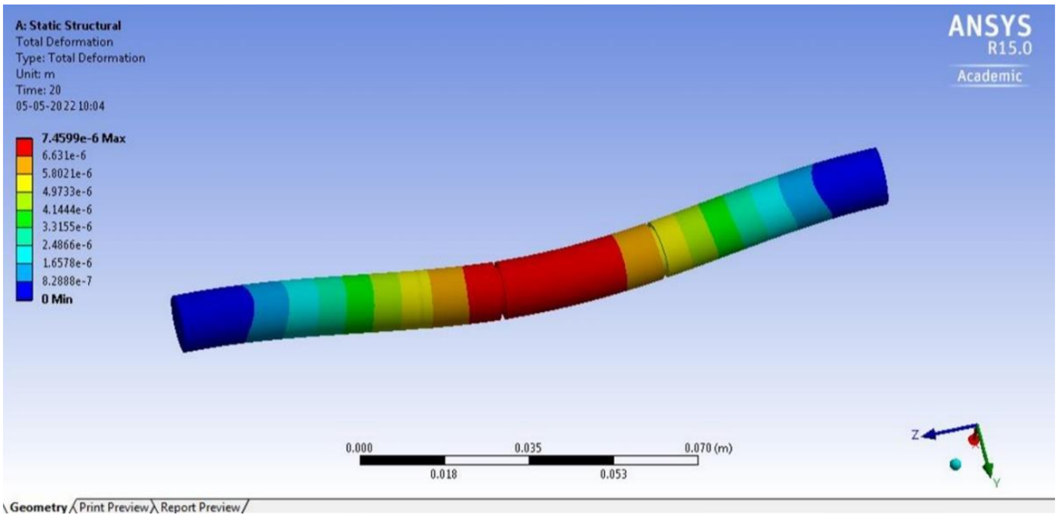


Figure 40: Total Deformation of Central shaft

Description:

The above figures are discussed as follows,

5.4.1 Equivalent Stress on Central Shaft

As the central shaft is experiencing the load of almost all the working apparatus of the bicycle so it must be designed in such a way that it prevents failure during the working. The shaft of steel can support various loads and so no such failure is expected before a million-to-million cycles.

5.4.2 Total Deformation of Central shaft

The load on the shaft or axle is applied in the negative z axis and so the deformations are usually produced downwards and so the smooth working of the shaft and the gears attached to it is affected.

5.5 Clutch Drive

This is one of the safe and robust components of the KERS. Still FEA is done to check whether the design is safe or not.

Forces acting on the Clutch Drive are given as,

- Clutch actuation force = 373.4N
- Spring force (torque) = 21.33N

Structural supports are given as,

- Compression only supports on the shaft
- Displacement support by the counterpart

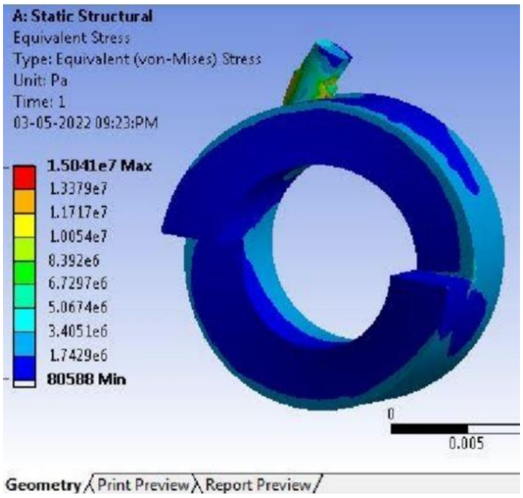


Figure 41: Equivalent Stress on Clutch

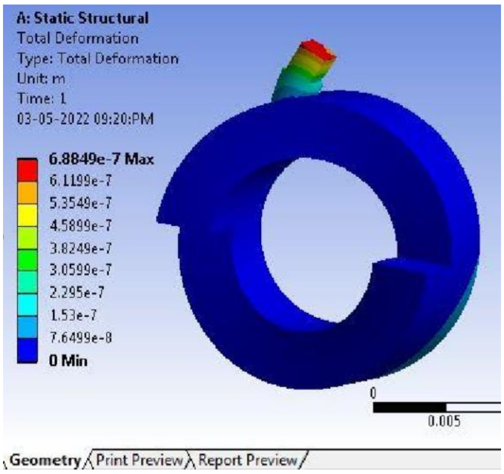


Figure 42: Total Deformation of Clutch

Description:

The above figures are discussed as follows,

5.5.1 Equivalent Stress on Clutch

This mechanism is not supporting any load but is only moving the clutch plate in the x direction for the actuation with the flywheel. It is also made from 3-d printing and the material cannot support so much load on it. It is one of the critical parts in the whole assembly. The stresses are somewhat large but mainly occur at the corners.

- To prevent this failure on the corners we have given some clearance on the edges so that the failure is prevented.

5.5.2 Total Deformation of Clutch

As discussed earlier the failure is caused at the edges and the deformation is also maximum at the edges.

Results and Conclusion

The following results are obtained after testing.

- The system is safe to run for many revolutions and fatigue failure comes after several million cycles.
- Some of the shocks with high intensity may cause damage the parts
- The maximum speed boost of 40 km/hr is obtained during testing when the flywheel was engaged.
- This system is not for implementation on bicycles but is a model and a depictive state of KERS in different vehicles.

CHAPTER 6 # Alterations Depending on Market, Availability and Design

All the components were designed earlier but when we visited the market, many changes were made in all the components involved in KERS. The components alongside the changes done are discussed as follows.

6.1 Flywheel

- Selecting a suitable material for flywheel was of great importance Firstly we stood with cheap material like mild steel but the machining cost for that was of greater value than that of aluminum, moreover with several advantages of aluminum flywheel including reduced clutch wear and improved clutch efficiency, better heat dissipation compared to steel.

- Flywheel was designed with a thickness of 3.6cm and 23cm of diameter weighing about 5.9 Kg however due to availability of material with maximum thickness of 3.15 cm the design was altered and weighed 5 Kg.

- Flywheel was supposed to be made from a circular rod but due to unavailability of Rod of 23cm diameter it was cut out from a square shaped aluminum plate with dimensions as 24x24x3.15 cm.

6.2 Clutch Plate

- The mechanism is of a dog clutch, so it was designed with a gear on its one side and brake pads on the other side. However due to limited functionality of CNC in market and high associated costs we had to go with a clutch without gear and the gear later made by using laser cutting operation. The gear was then mounted on the clutch.

- Clutch plate had to also move in axial direction over the axle while rotating so for this purpose the bearing used initially was of 28mmx12mmx8mm but due to cutting ability of laser cutter gear of clutch plate was merely of 7mm. So, we went with bearing of dimensions 24mmx12mmx6.5mm. The reason for choosing a large bearing was because the small bearing used to get stuck.

6.3 <u>Clutch Drive Mechanism</u>

- Clutch drive mechanism consisted of two similar drives. Rotating one fixed drive will translate the other drive along the axle. Firstly, we like to machine these drives out of 20mm Teflon rod however due to difficult geometry of the drive mechanism it could not be machined on manual machines. So, we went with 3D printing the drives out of PLA material.

- The quality of 3D printing was not very fine, so we had to file and finish the clutch drives for easy slippage and rotation.

6.4 <u>Axle</u>

- Axle design which was made initially was altered due to changes in other parts. These changes included position of threading, turning.

6.5 <u>Teflon Mountings</u>

- To mount KERS on the bicycle frame mountings were designed according to the frame parameters and KERS assembly. Teflon was machined according to the specifications however due to unavailability of Teflon sheet of required thickness in the market we had to add additional layer of material to fill up the space.

6.6 <u>Aluminum Mountings</u>

- Mountings were designed with several iterations to come up with the best design that was stable and efficient. It was designed by keeping efficiency and safety in mind. The changes in other parts resulted in changes in mountings

6.7 <u>12 teeth Gear on Clutch</u>

- A spur gear of 12 teeth was first designed with a face width of 8mm and bearing size of 28mm however due to changes in manufacturing process i.e. going on laser cutting from machining resulted in new specifications of gear with 12 teeth and a face width of 6.5mm and bearing size of 24mm.

- Initially clutch gear was thought to be premade on the clutch plate however that resulted in high machining cost so we had to mount the separately manufactured gear on the clutch plate.

6.8 36 teeth step-down gear

- A spur gear with 44 teeth was initially selected but later to during our research we came to know that we must have a sprocket ratio of 1:3 between the bicycle and flywheel. This would solve the problem for jerk experience.
- Due to high machining cost face width of this gear was reduced to 6.5mm to be cut on laser cutter.
- Due to poor finishing of laser cutter the gear was then undergone finishing process for smoother meshing
- Cutouts were made in gear to aid in better heat dissipation.

6.9 Front chain gear

- A standard bicycle single gear locked in each direction was selected however due to its larger inner diameter another part was made on which this gear was mounted via threads and then the gear was mounted on the shaft.

6.10 Gear driven shaft

- To transfer the 36 teeth gear transmission into the chained gear the shaft was mounted in the 36 teeth gear going through two flanges connected to aluminum mounting having bearings of 24mmx12mmx6.5mm inside.
- The shaft was screwed into both gears.

6.11 Rear Sprocket

- Initially in the design phase rear sprocket was designed with 36 teeth to keep the same sprocket ratio throughout but we decided to use bicycle sprocket which consisted of 44 teeth and a different size. This was done because we had to use bicycle chain so we can easily get the sprockets with same pitch as the bicycle chain pitch.

- There is no place in bicycle to mount another sprocket in rear wheel so for that purpose we bought a dual axle on which we made use of disk brake and mounted the sprocket using screws to the disk brake.

6.12 Chain drive

- We bought a standard bicycle chain of length, and the length of chain was reduced according to our position of gears and sprockets.
- The chain was given a negative drive to remove slag.

6.13 Clutch actuating mechanism

- We made use of front brake lever.
- The brake wire was replaced with rear brake wire due to long length requirement which was then cut to reach the clutch drive mechanism
- As this needed a lot of force so for that problem, we made use of mechanical advantage physics.

Chapter # 7 Manufacturing and Machining Processes

7.1 Flywheel

A flywheel is a mechanical device which uses the conservation of angular momentum to store rotational energy. It is the form of kinetic energy proportional to the product of its moment of inertia and the square of its rotational speed. Flywheels are often used to provide continuous power output in systems where the energy source is not continuous

Mainly we will discuss about the manufacturing process of flywheel in this section. We selected Aluminum as a material for flywheel. Material for flywheel was available to us in two forms. The forms are:

1. Cylindrical shape
2. In the form of sheets

Now for selection based on cylindrical form, we had constrained two constraints which we took in consideration to avoid using cylindrical shape. The constraint was:

1. The desired diameter that is our concerned diameter, flywheel was not available in the market in that form.
2. Secondly, price for the cylindrical shape was much more than in sheet form.

So, these were the two constraints that made us use flywheel material (Aluminum) in form of sheets. We took Aluminum in sheet form, and we converted it into cylindrical form using lathe and machine tooling. First that sheet was hold in chuck in the lathe and then cutting was done and then machining was done in machine workshop in the college.

Coming towards the wear and tear of the flywheel during manufacturing process, we had already set clearance In sheets as we knew conversion of sheet into cylindrical form would definitely need clearance for accuracy and safety factor.

Also, density for Aluminum theoretically is 2900 kg/m^3 but in market we got 2700 kg/m^3 so we did our calculation according to the density available in the market.

We did finish and polishing of material in electroplating shop in the college for example making buffing for smooth surfaces and shinning. We made a hole in the canter of flywheel and used bearing there for supporting the other assembly that will be attached to it for KERS.

And for mounting purpose, we did 6 equal spaced small holes by drilling and threading to attach the assembly according.

Hence, the above complete manufacturing process were involved in the manufacturing of the flywheel that is our energy storing medium.

7.2 Clutch Plate

A Single Plate Clutch is defined as a type of friction clutch, which is made of a single clutch plate. The amount of frictional force that generates within the clutch plate due to the contact that takes place between the friction lining which is mounted on the clutch plate

Coming towards the manufacturing of clutch plate. We selected Aluminum as a material for clutch plate. Material for clutch plate was available to us in two forms. The forms are:

1. Cylindrical shape
2. Sheets form.

Now for selection based on cylindrical form, we had constrained two constraints which we took in consideration to avoid using cylindrical shape. The constraint was:

3. The desired shape was not available in the market in that form.
4. Secondly, price for the cylindrical shape was much more than in sheet form.

We purchased plate in square sheet and then we had two ways to cut in our desired shape. The process available to us for this was:

5. Using CNC Machining on it for cutting.
6. Using Laser Cutting on it for cutting

As any other cutting cannot be done for making clutch. Laser cutting was not done in this regard because Laser cutting is a process which cannot cut in depth, or we can say it cut simply at full length cutting. So just the option to cut this sheet for clutch plate into desired shape was CNC Machining though being expensive. We tried to do it from DMTS and RM Lab but due to busy schedule there, we had to make it done from outside. We contacted our Supervisor and HOD as well in this regard.

Also, there was a small gear, we had to use with out clutch plate but that gear we made with laser cutting as it was easy to do so. Hence like this, some thickness of material with sheet was wasted as we first thought that we can do it complete clutch with gear included with CNC machine, but pricing changed that.

So, from CNC, our clutch plate is made only and from 3D laser cutting we made small gear. That gear would be press fitted with that clutch plate. A hole was drilled in the canter from where central rod will pass and it will work through clutch drive mechanism.

So, this was the way we made out clutch plate. The CNC individual took almost one week to complete this manufacturing process.

7.3 Brake Shoe

Brake pads are a component of disc brakes used in automotive and other applications. Brake pads are composed of steel backing plates with friction material bound to the surface that faces the disc brake rotors.

Generally, brakes pad is placed on clutch plate. On the corners of clutch plate, we have created depths, and, in those depths, our brake pads will be paced. We have created four depths. These were purchased online from Daraz and after we received it we placed those brake pads on the clutch plate. It can be placed either by kneels or press fitting into clutch plate. We ordered 4 x brake pad which are almost 2cm each. No manufacturing part is involved in this regard.

7.4 Aluminum Mountings

Mounting simply means supporting or backing something. We have used two mountings for our KERS.

1. Aluminum Mounting
2. Teflon Mounting

Discussing the Aluminum mounting manufacturing process first, aluminum mounting runs from the rod to the flywheel and then comes back from the flywheel to the cycle rod. These are an integral part of the system and cycle.

Talking about the internal mounting, material used for making the internal mountings is selected Aluminum. The reason is as under:

1. To maintain minimum weight as desired by KERS.
2. Keeping in mind the clutch assembly in our case.

The total weight for the system using the mountings was around 7.2 kilograms. We made the mountings on the SolidWorks and after that placed our parts together onto a sheet of Aluminum. Once maximum possible parts that can be placed on the sheet was done, the sheet was taken to market.

We had two option available to us:

1. CNC Machining
2. 3D Laser Cutting

Considering price and other options especially the pricing, we decided to go on to the laser cutting. All parts were done with laser cutting. Disadvantages of laser cutting are that it doesn't give a very good finish to the part and the efficiency is not good efficiency but as compared to the price of CNC it was better for us to go to towards laser cutting so we use laser cutting for making mount and after that we got out Aluminum mountings into shape.

7.5 Teflon Mounts

Mounting simply means supporting or backing something. We have used two mountings for our KERS.

1. Aluminum Mounting
2. Teflon Mounting

Aluminum mounting is already discussed above. This portion includes the manufacturing of Teflon mountings.

So, taking Teflon into the material used is Teflon. We have taken a block in square form. We have cut it into four equal parts and those four equal parts are supposed to be placed on cycle rod, two blocks on each side through which central rod will pass by.

In the canter there will be half spherical cut and there will be holes in the Teflon material. After two parts of the Teflon are joined together and there is spherical hole in it which will pass through them. After, this both are mounted with the aluminum mounts.

The reason for choosing Teflon is:

1. Price
2. Strength
3. Less weight

For cutting the Teflon, any cutting tool can be used, and it can be cut by hand as well. For the holes, drilling was done. This is the complete description of Teflon mountings.

7.6 Smaller Gear attached with Clutch Plate

This gear is of very small diameter so that it was not machined. The possible options available were as follows,

- Lathe machine
- CNC
- Laser cutting

After careful scrutinization, it was decided that the material bought for the laser cutting of the aluminum mountings was left to some extent. The material from that part was taken and the model of the gear was given to the laser cutting shop. We has so much material left that 3 such gears can be created from that part. The finishing of the gear wasn't good enough and the gear was not meshing properly. The gear was buffed properly and then was finally available for the use.

7.7 Larger Gear meshed with the smaller on

This gear is of large diameter. The possible options available were as follows,

- Lathe machine
- CNC
- Laser cutting
- Machining

After careful scrutinization, it was decided that the material bought for the laser cutting of the aluminum mountings was left to some extent. The material from that part was taken and the model of the gear was given to the laser cutting shop. By using that material, the gear is created from laser. To obtain good finishing, the laser was run on the part twice. The finishing of the gear wasn't good enough and the gear was not meshing properly. The gear was buffed properly and then was finally available for the use.

7.8 Central Rod

Adhering to our KERS, to join our assembly obviously we used a central rod. Coming to manufacturing of the rod, material used for this axle is stainless steel.

As per the availability in the market, medium grade of stainless steel was used for this purpose. The consideration taken include:

1. The diameter of centre hole.
2. Bearing consideration which were press fitted.
3. Desired length.

Taking all notice, we took certain desired length stainless steel rod and then cut it using machining and after wards, press fitted it into the flywheel for our KERS.

7.9 Clutch Drive Mechanism

In the mechanism of a clutch, the driving shaft is directly connected to an engine whereas the other one or the driven shaft provides the power output that is utilized by the user for working. Often clutches are used to limit the motion or amount of power transmission between two components.

This is a very small mechanism. Option available to us for choosing the material are as under:

1. Aluminum
2. Teflon
3. Nylon
4. PLA

Two considerations considered for selection of material are:

1. Weight reduction
2. Stiffness

We had two methods for manufacturing of clutch drive mechanism. Those are:

1. First method was that we use Teflon from scrap, and we cut it and at proper angles we designed and made proper clutch drive mechanism
2. Second method was to use 3d printing and as per gram rate is RS.18 Pkr/- so 7 to 8 grams will cost us around RS.150 Pkr/-.

Keeping the factor of efficiency in mind. It was good using 3d printing, so we used 3d printing for this purpose. It was done in RM lab. What we did was to make the CAD model of the mechanism and give product file as .stl file in the lab and give it to manufacturer and he made it for us using 3D printing.

CHAPTER 8 # Final Components After fabrication

8.1 Flywheel

The flywheel was cut from the square sheet of 25*25 cm. Then after machining and making it circular disc of weight 5.2 kg and diameter 23 cm. The final fabricated component is shown below.

Figure 43: Flywheel

The disc plate is also applied at one side of the flywheel and is shown in the figure below.

Figure 44: Flywheel along with Disc Brake

8.2 Clutch Plate along with Brake shoes

After CNC, the final look of the clutch plate is shown in the Figure 44. Brake Pads are also connected to it. They are usually mounted by the means of screw or press fitted.

Figure 45: Clutch Plate with Brake Pads

8.4 Aluminum Mounting

Three different types of mountings were created from the Aluminum sheet. These mountings are to be attached with the frame of the bicycle. The final look of the mounting is shown as,

Figure 46: Aluminum Mounting

The other two parts having the central part of the Al mounting and the rear part of the mounting is shown in the figure 46.

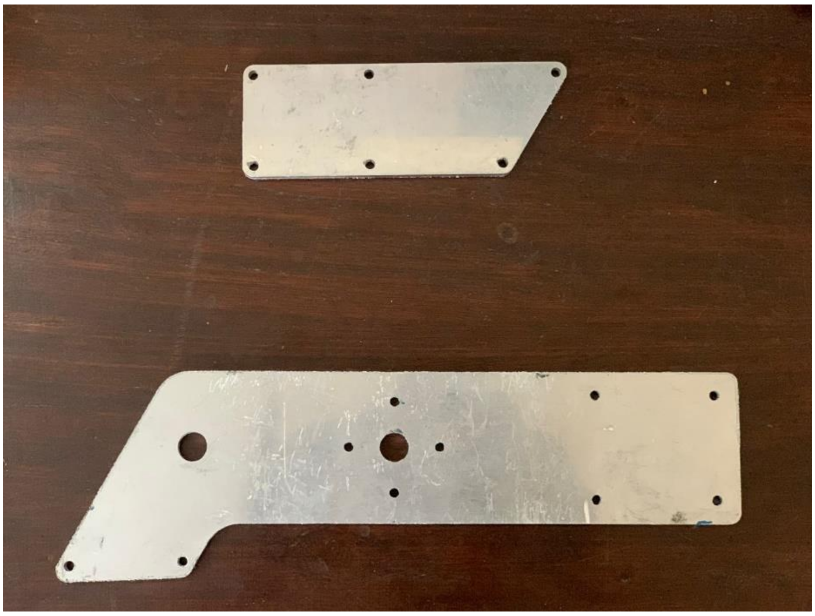


Figure 47: Aluminum Mounting

8.6 Teflon Mounts

These mounts are created by proper machining and finishing on Teflon. The central hole is created by drilling and lathe machine was used for the whole purpose. The final look is shown in the figure 47.

Figure 48: Teflon Mounts

8.7 Smaller Gear attached with Clutch Plate

The smaller gear was made by the remaining sheet of Al after laser cutting. This gear is buffed, and the gear teeth are cleansed. Finally, the gear is attached with the centre of the clutch plate and the final look is shown in the figure 48.

Figure 49: Smaller Gear attached with Clutch Plate

8.8 Larger Gear meshed with the smaller one

Larger gear was made by the remaining sheet of Al after laser cutting. This gear is buffed, and the gear teeth are cleansed. Finally, the gear is attached and meshed with the smaller gear and the final look is shown in the figure 49.

Figure 50: Larger Gear which is to be meshed with the smaller one

8.9 Central Rod

This is a simple steel rod and is attached with the gears. It was long enough and after cutting and buffing the final part is shown in the figure 50. The diameter of the rod that was bought from the market was a bit larger, so it was machined for the application.

Figure 51: Central Rod

8.10 Clutch Drive Mechanism

After 3-d printing, the final part is shown in the figure 51.

Figure 52: Clutch Drive Mechanism

CHAPTER 9 # Assembly of Components

The following steps were taken for the assembly of the components after fabrication.

- Rear tire axle was removed and replaced of dual mount axle.
- Rear sprocket was mounted by screws with disk brake which was mounted on the dual mount axle.
- Backplate made of aluminum was mounted to the bicycle frame with Teflon mountings in between holding on the bicycle rods. The plate was mounted using nuts and bolts
- Axle was mounted on center of black plate using thread and screw connection.
- Bearings were press fitted into the flywheel.
- Flywheel was mounted on the axle and was held in appropriate position using washers and nuts.
- Disk brake was mounted on the flywheel using 6 screws.
- Brake pads were attached to the clutchplate using screws.
- Clutch gear was mounted on the clutchplate.
- A spring was added on the axle to retract the clutch.
- Clutchplate was then mounted on the axle which was free to translate as well as rotate on the axle.
- Clutch drive mechanism was installed on the axle.
- One part of clutch drive mechanism was connected to the brake lever at bicycle handle using brake wire.
- The front side aluminum mounting was attached to the Teflon mounting which held the bicycle frame.
- Similarly other part of front mounting was attached.
- Both front mountings were connected to each other using screws.
- Two flanges were connected on the aluminum mounting plate one on front and one on its back.
- Bearings were fitted into the flanges.
- Front sprocket was mounted using flange and shaft.
- Shaft was passed through the flange’s bearings and aluminum mounting plate.

- Front sprocket was then positioned and held in place for proper meshing with clutch gear.
- A bicycle single gear was mounted on the shaft.
- The front bicycle single gear was then connected to Rear Sprocket using a chain drive.

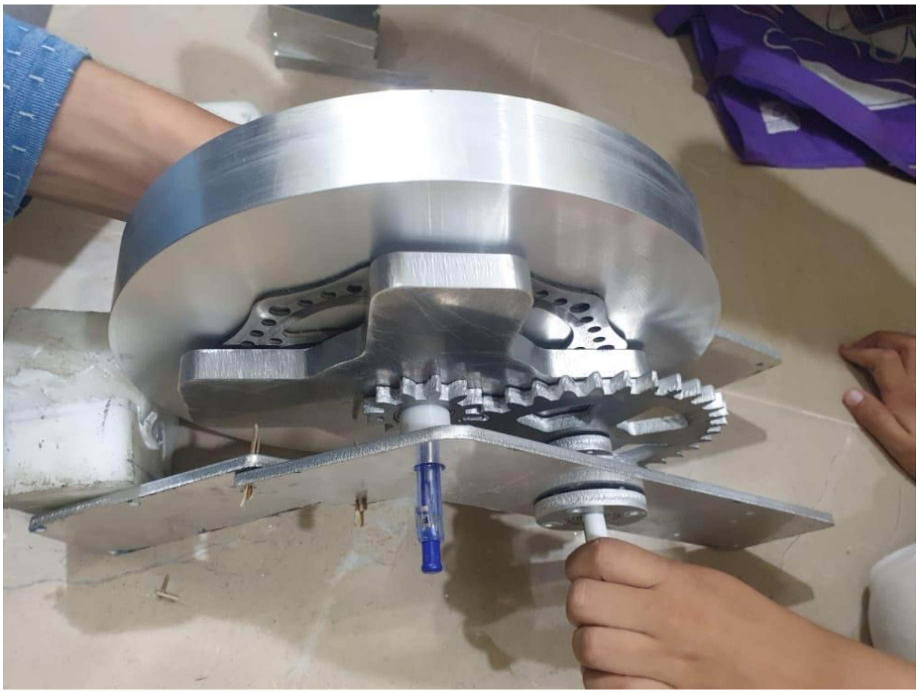


Figure 53: Final Assembly of KERS by Hand

CHAPTER 10 # Project Scope Management

Project Scope Management comprises of processes required to ensure that the project includes all and only the work required, for successful completion of the project. Managing of a project is importantly concerned with defining and controlling what is and is not part of or included in the project.

10.1 Plan Scope Management

- Role and position designation
- Planning and design of Kinetic Energy Recovery System for the implementation on bicycles.
- Planning of fabrication of KERS.
- Planning of strategies to implement Ansys and MATLAB on KERS.
- Timesheet concurrence of project deliverables

10.2 Collecting Requirements

- Gathering of research papers
- Thorough reading of literature review
- Preferred design sizes
- Material requirements and choices with possible change overs
- Financial data regarding materials

10.3 Product Scope Description

The simplicity of energy transfer in this mechanical KERS system makes it superior to the electrical KERS system. Mechanical hybrids are more powerful, more efficient, and cheaper than electrical hybrids. In the future, automobiles will be much more fuel efficient than the cars of today. Flywheel kinetic energy recovery system technology is practical because many car companies are looking into using the system in average everyday cars. Volvo in partnership with Flybrid, officially announced that they intend to develop and produce a vehicle that uses the flywheel based kinetic energy recovery system.

With improvement in technology, KERS will become even more efficient and affordable. The main driving force which will launch flywheel-based kinetic energy recovery systems into the automotive industry is the low cost in comparison with fully hybrid vehicles. Any vehicle could be designed and fitted with a flywheel-based kinetic energy recovery system, but the area most affected by this technology would be any vehicle with a start-stop cycle of driving. This technology has already been tested in FLYBUS (a flywheel hybrid system developed for buses).

The Flywheel KERS is a technology of great importance and potential. With more advancements and refinements, this system would increase the efficiency of hybrid vehicles. It can reduce fuel consumption and at the same time increase power. Its lower CO_2 emissions reduce air pollution. Probably the biggest advantage of this system is its ability to be retrofitted. The flywheel KERS does not come without flaws, however, developments still need to be made in reducing the forces that act upon the flywheel. With these forces minimized, the system would have much higher efficiency and would be able to store energy longer. It would rival hybrid electric vehicles in efficiency and range.

10.4 Project Deliverables

1. To study and develop a KERS and implement on a bicycle
2. To optimize the weight of flywheel
3. To calculate the maximum distance of travel with implemented KERS on bicycle

10.5 Project Acceptance Criteria

The project can only be accepted if the following requirements are met.

- Project is shown to the instructor in working condition
- The project objectives are met
- The final report of the project is accepted and is according to the requirements

10.6 Project Exclusions

- Testing with varied displacer lengths of different components of KERS
- Stability analysis of oscillations
- Weight calculations of the complete model
- Fatigue analysis and then discussion
- Multiple material choices for KERS

10.7 Project Constraints

- Project budget of Pakistani rupees 40000
- 10 months for completion
- Resource limitations

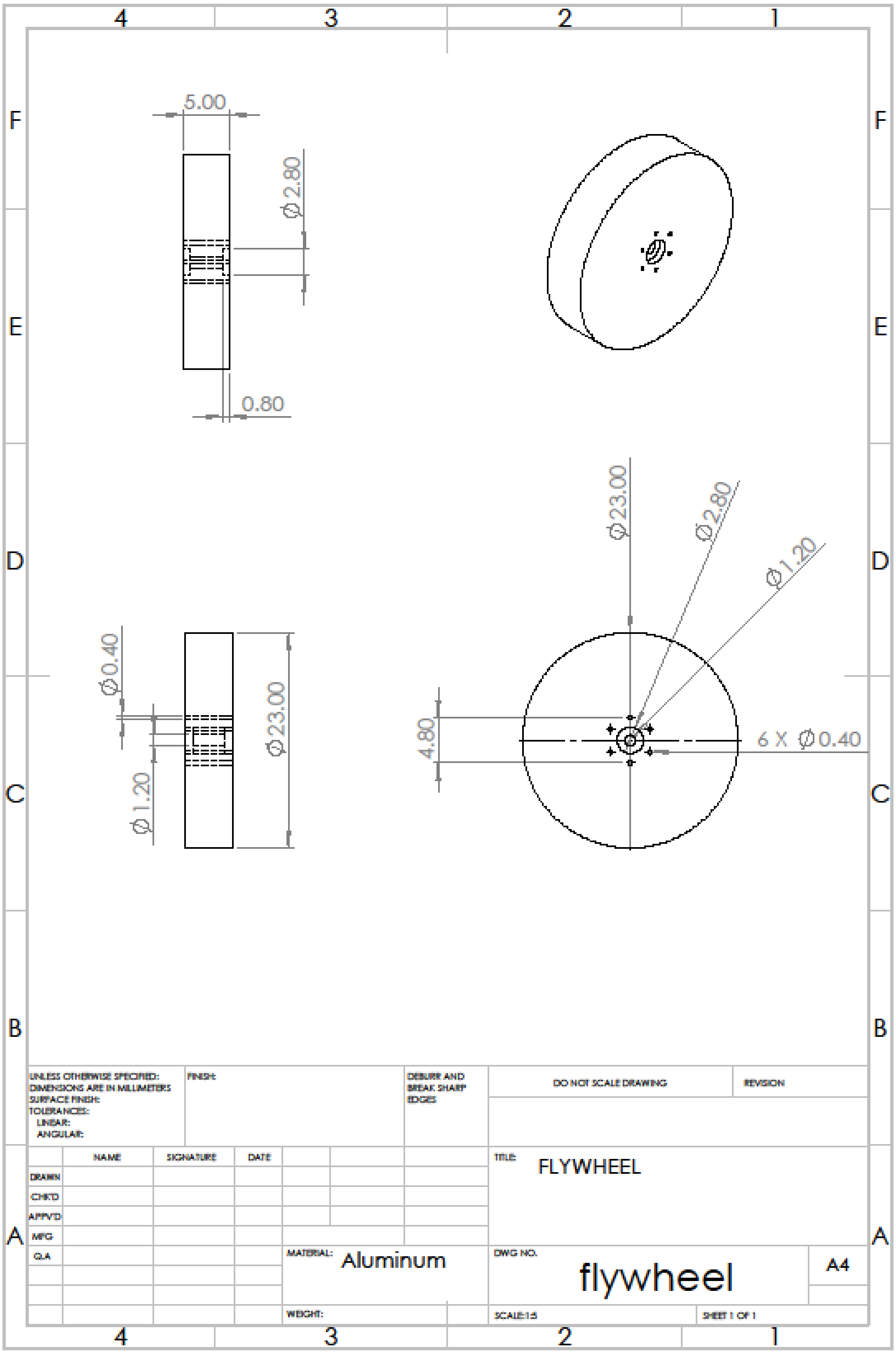
- University leadership will support project team and provide timely response to requests
- Supervisor to provide useful information
- Students will also be occupied with their semester studies

10.8 Validating the Scope

The scope of the project will be validated in the activities that will be carried out in the final year of the students. The judges of the activities will be faculty members and supervisors.

- Final Year Project Synopsis or Abstract
- Title Defense
- Mid Defense
- Final Year Project Actual Demo & Working
- Open-House (where we display our Projects) / Job Fair
- Final Presentation

Appendix



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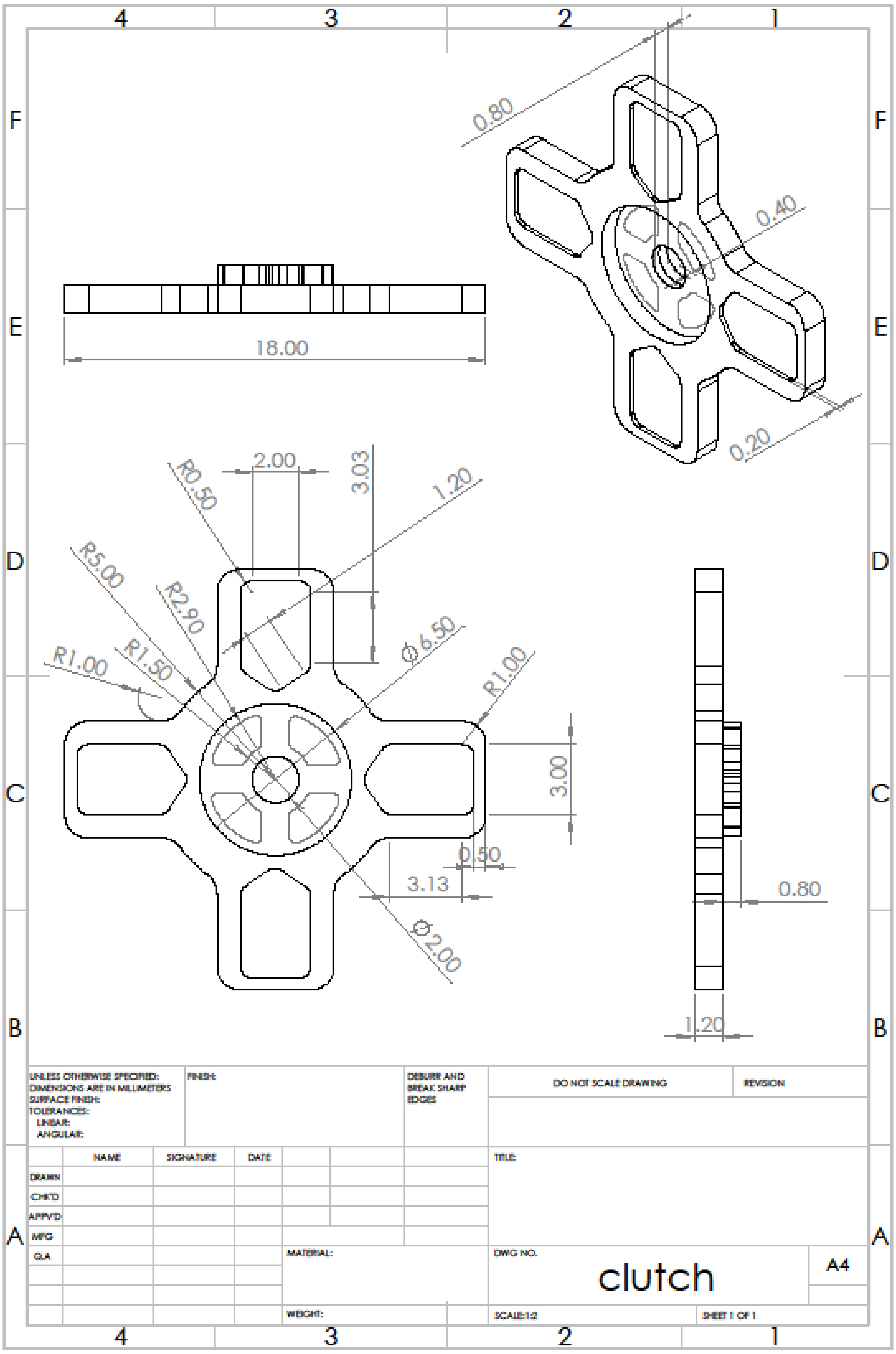
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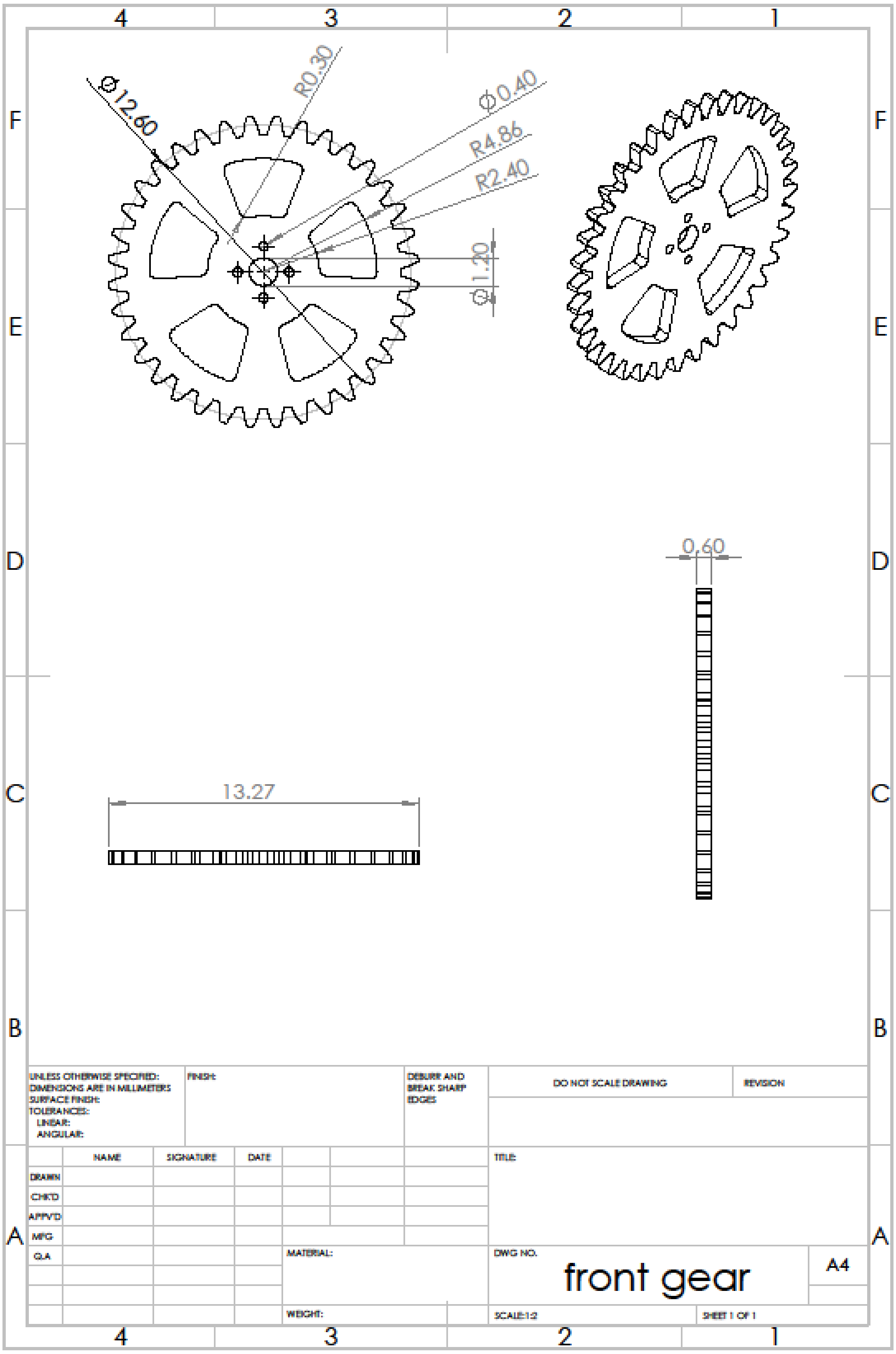
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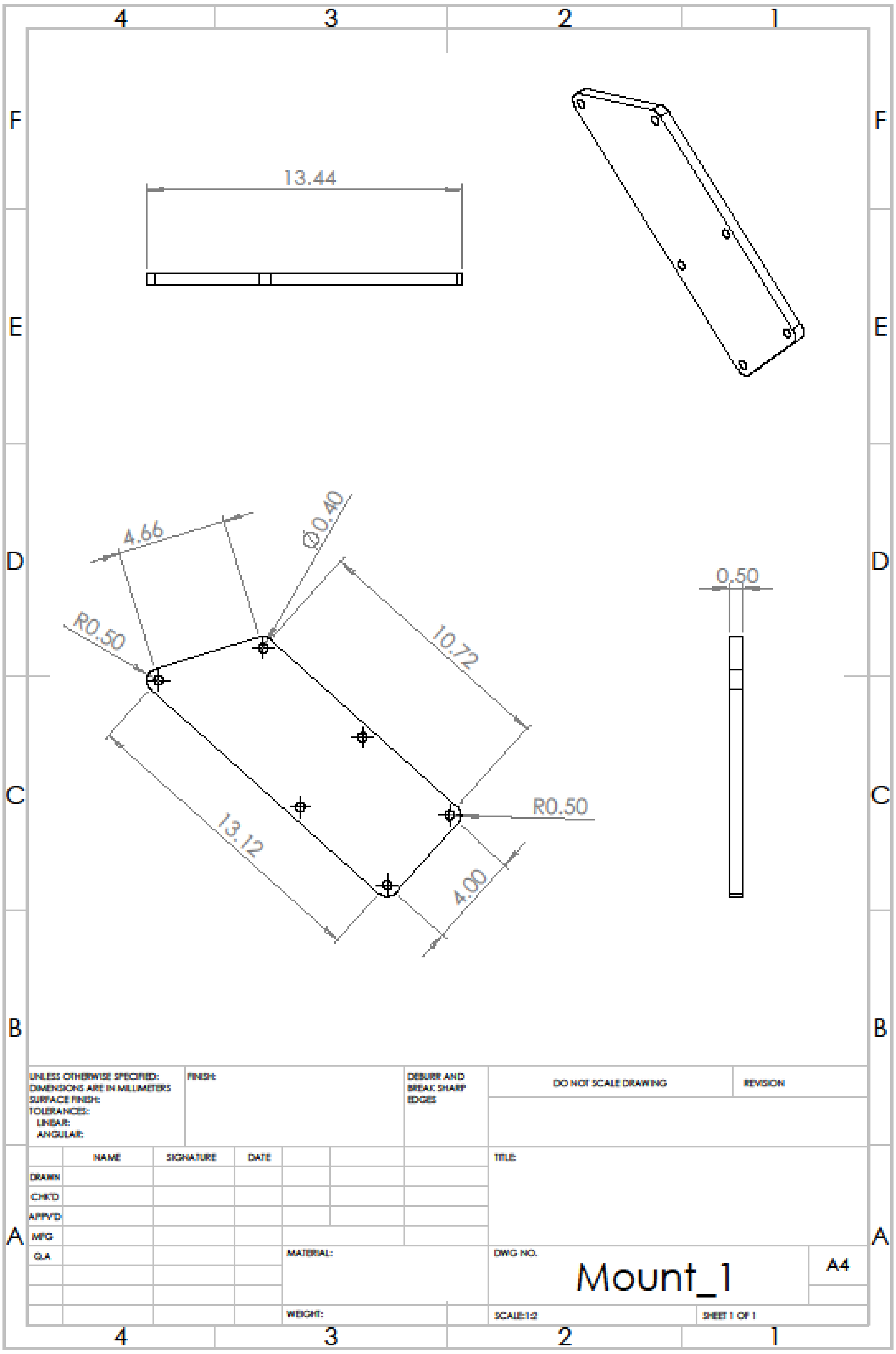
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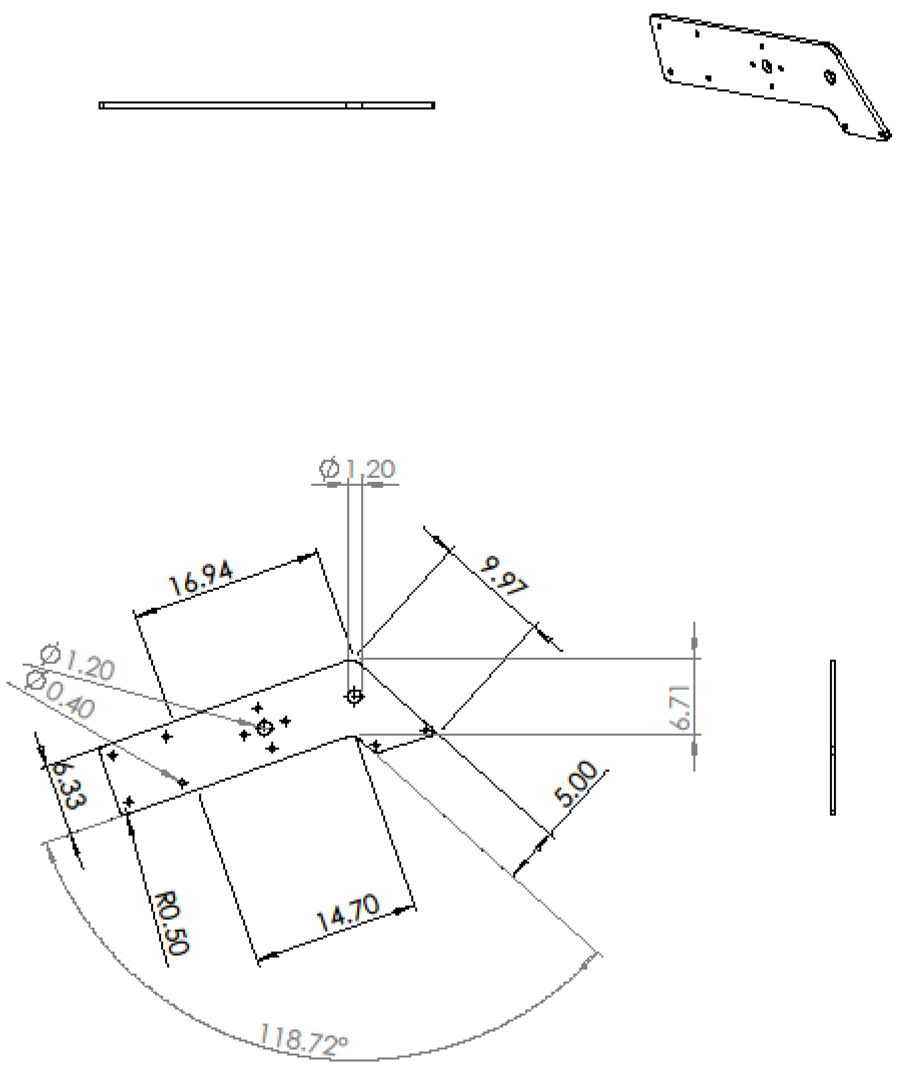

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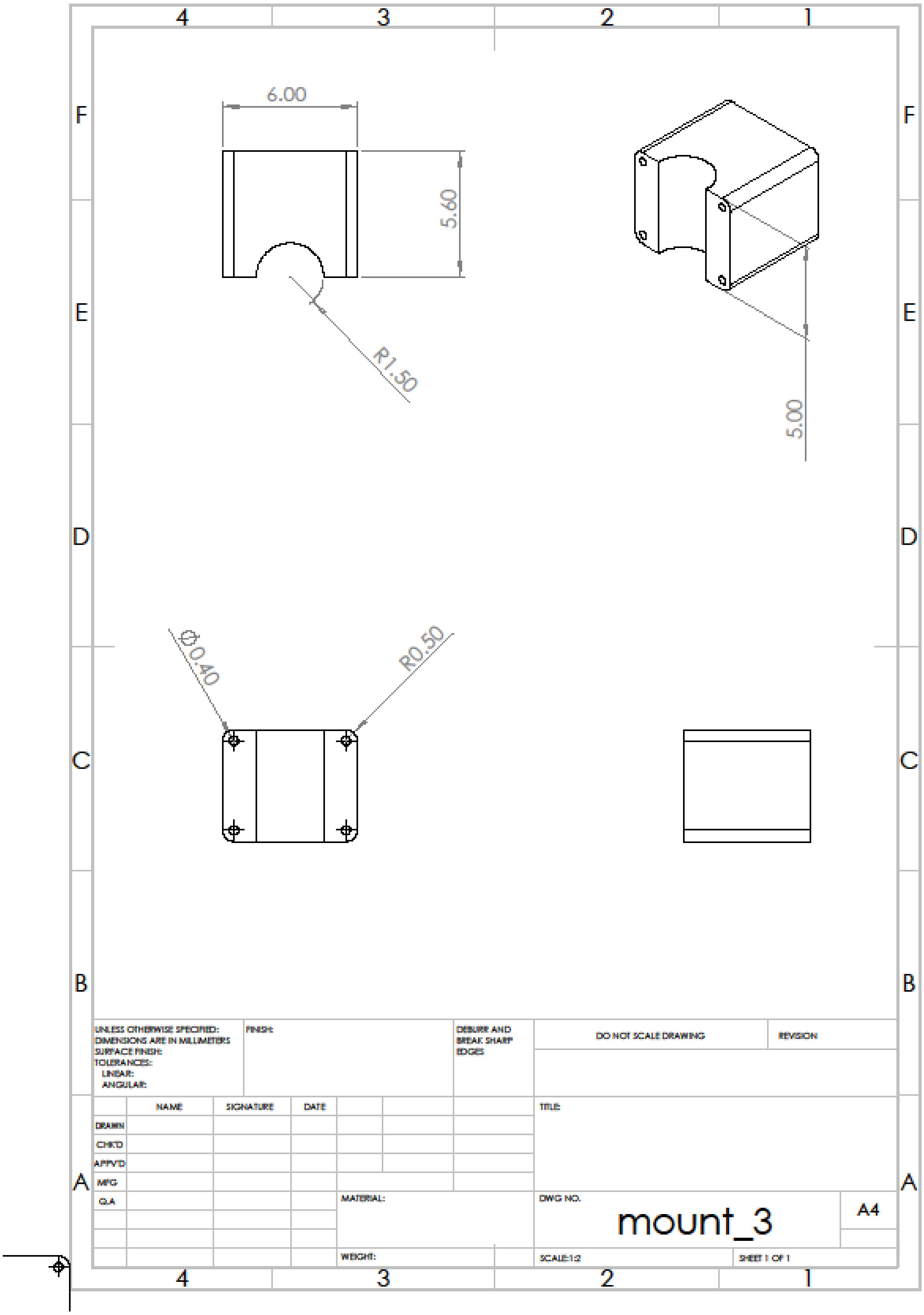
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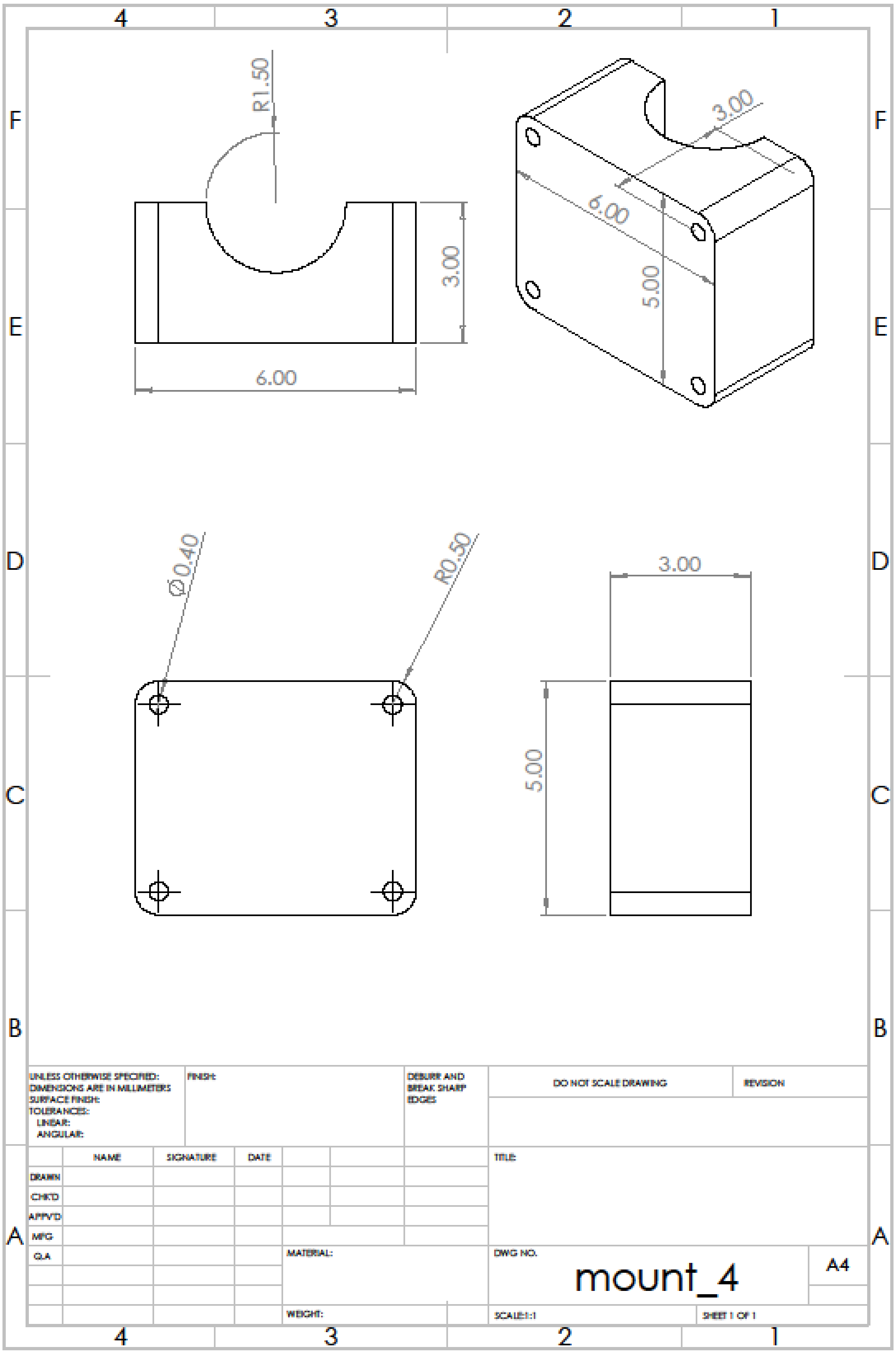
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6.00
3.00
6.00
5.00
Ø0.40
R0.50
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
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DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
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DRAWN
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TITLE:
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DWG NO.
mount_4
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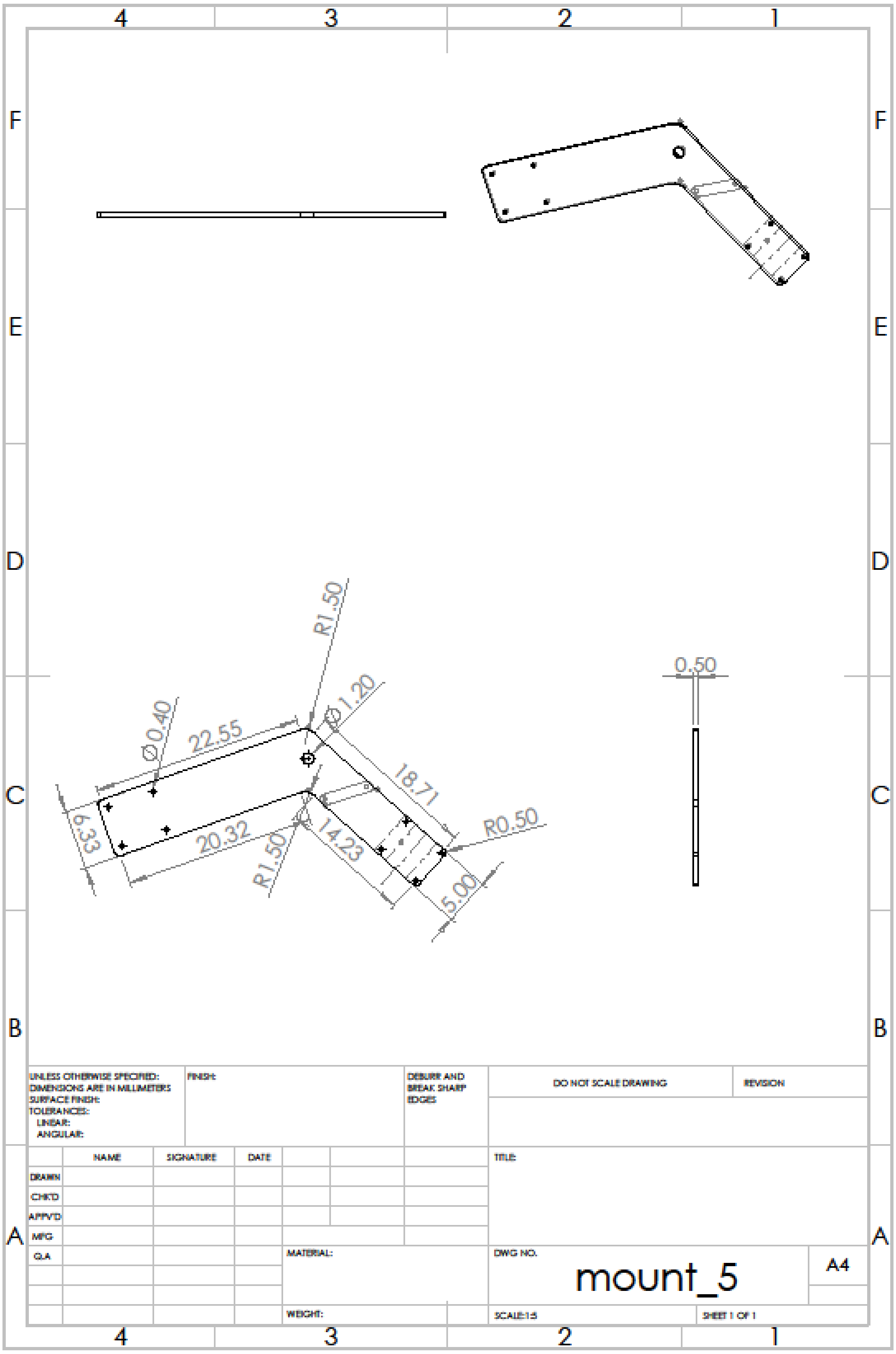
SHEET 1 OF 1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3
2
1
F
E
D
C
B
A
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6.33
20.32
R0.50
R1.50
14.23
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
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NAME
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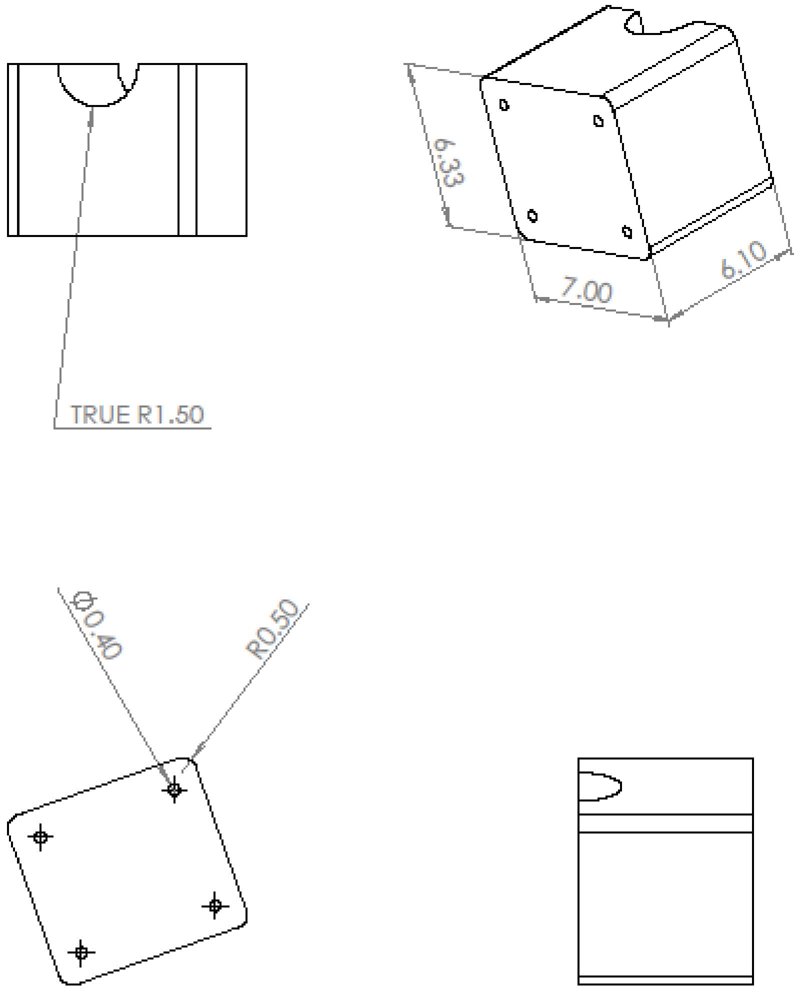
SHEET 1 OF 1



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APPV'D			
MFG			
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TITLE:

MATERIAL:

WEIGHT:

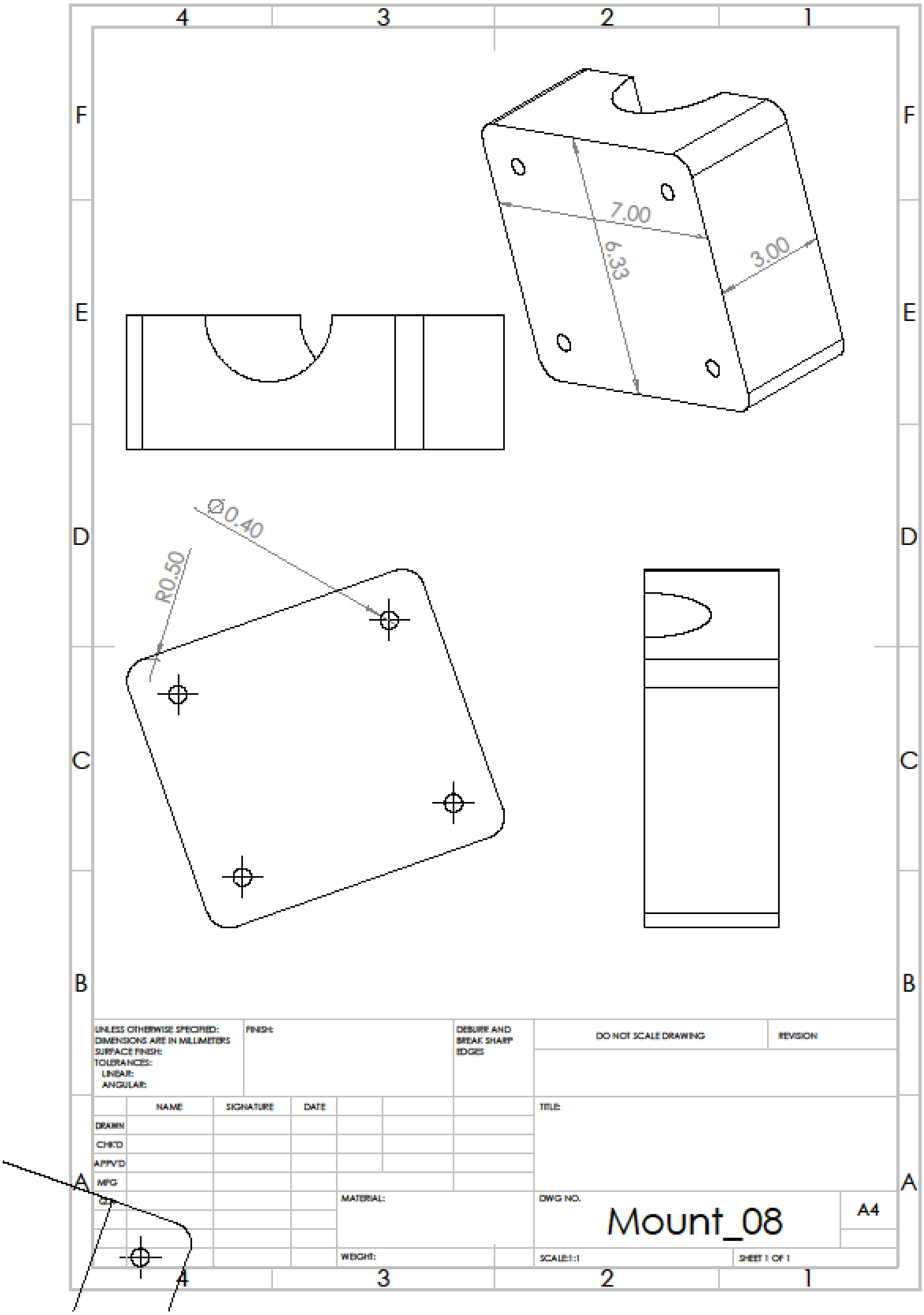
DWG NO.

mount_7

A4

SCALE:1:2

SHEET 1 OF 1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SHEET 1 OF 1

References

[1] D. K. Naresh Kumar, M. Sarath Kumar, S. Murugavel, M. Pradeep, P. Prasath (November 2014) "Design and Fabrication OF Flywheel Bicycle with Mobile Charger", International Journal of Scientific Research, Volume 3, Issue 11, ISSN No 2277-8179.

[2] Nishad Kumbhojkar, Kunal Mohite, Anand Kulkarni, Sanket Patil (April 2015) "Design and Implementation of Kinetic Energy Recovery System (KERS) Bicycle", International Journal of Mechanical Engineering and Technology (IJMET), Volume 6, Issue 4, pp. 101-108, ISSN 0976 – 6340 (Print), ISSN 0976 – 6359 (Online).

[3] U. Mugunthan, U. Nijanthan (May 2015) "Design and Fabrication of Mechanism of Recovery of Kinetic Energy Using Flywheel", International Journal of Emerging Technology and Advanced Engineering, Volume 5, Issue 5, ISSN 2250-2459.

[4] Sreevalsan S Menon, Sooraj, Sanjay Mohan, Rino Disney, Suneeth Sukumaran (August 2013) "Design and Analysis of Kinetic Energy Recovery System in Bicycles", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 8, ISSN: 2319-8753

[5] "Vacuum chambers for flywheels", John Micheal Pinneo, Jonathan Forrest Garber

[7] Ricardo Chicurel, "A Compromise Solution for Energy Recovery in Vehicle Braking," Energy, vol.24, pp. 1029-1034, 2009

[8] H. Shimoyama, S. Ikeo, E. Koyabu, K. Ichiryu, S. Lee, "Study on hybrid vehicle using constant pressure hydraulic system with flywheel for energy storage," SAE 2004-01-3064, 2004.

[9] Q. Xiao, Q. Wang, Y. Zhang, "Control strategies of power system in hybrid hydraulic excavator," Automation in Construction, vol. 17 (2008) 361–367.

[10] R. Kordak, "Hydrostatic Transmission Drives with Secondary Control," Bosh Rexroth AG, 2003.

[11] Kim YJ, "Integrated modeling and hardware-in-the-loop study for systematic evaluation of hydraulic hybrid propulsion options," Doctor of Philosophy in the University of Michigan, pp. 1-16, 2008.

[12]. Sreevalsan S Menon, Sooraj M S, Sanjay Mohan, Rino Disney, Suneeth Sukumaran "Design and Analysis of Kinetic Energy Recovery System in Bicycles" - International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 8, August 2013

[13]. Kevin Ludlum "Optimizing Flywheel Design for use as a Kinetic Energy Recovery System for a Bicycle", June 2013

[14]. Radhika Kapoor, C. Mallika Parveen, Member, IAENG "Comparative Study on Various KERS"- Proceedings of the World Congress on Engineering 2013 Vol III, WCE 2013, July 3 - 5, 2013.

[15]. Ricardo Chicurel, "A Compromise Solution for Energy Recovery in Vehicle Braking," Energy, vol.24, pp. 1029-1034, 2009.