DESIGN OF
KINETIC ENERGY RECOVERY SYSTEM
FOR BICYCLE

A PROJECT REPORT
SUBMITTED IN FULFILLMENT OF
B. Tech. In Mechanical Engineering

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Certificate

This is to certify that the work presented in the report entitled “Design of Kinetic Energy Recovery System for Bicycle” by Shreemoy Kumar Nayak represents an original work under the guidance of Prof. S. K. Behera, Department of Mechanical Engineering, National Institute of Technology Rourkela, 769008.

I hereby certify that this work is completely authentic and has never been published by any other student at any institute to get a degree or diploma.

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Shreemoy Kumar Nayak

ABSTRACT

Kinetic Energy Recovery System, commonly abbreviated KERS, is a system to recover the Kinetic energy of a moving vehicle under braking. This system stores the kinetic energy in the form of potential energy and converts it back to kinetic energy when needed. When riding a bicycle it becomes too tiresome to start the bicycle again after braking. If the bicycle is provided with a kinetic energy recovery system then the rider will have two power sources that he can use at his will. When brakes are applied kinetic energy is wasted because the kinetic energy converts into heat energy due to friction at the contact surface and the heat energy dissipates into the atmosphere due to thermal radiation. Vehicles equipped with KERS devices are able to take some of its kinetic energy out slowing down the vehicle. This is a form of braking in which energy is not wasted, instead gets stored in some device. Using a proper mechanism, this energy that is stored in terms of potential energy can be converted back into kinetic energy to give the vehicle an extra boost of power. In the literature review different types of available KERS systems are compared and a mechanical based KERS system is found to be the best suitable for a bicycle. Mechanical KERS system there are of two types, one is a clutch based and another is a CVT based K.E. recovery system. In this project a hybrid of the above two type of KERS systems is designed. Instead of CVT a variable sprocket ratio is used to make the power transmission smoother. Finally the complete manufacturing process of this KERS system is explained elaborately so that any researcher can follow those steps and design a KERS system for his/her bicycle.

NOMENCLATURE

v = Final velocity of the bicycle at the end of discharging cycle (m/sec)

u = Initial velocity of the bicycle at the starting of the discharging cycle (m/sec)

a = Acceleration of the bicycle (m/sec^2)

E = Total energy of the system (Joules)

D_R = Diameter of the bicycle wheel (m)

R_R = Radius of the bicycle wheel (m)

F_a = Inertia force (N), force required to accelerate the bicycle a rate of “a”

F_R = Rolling resistance (N)

F_A = Aerodynamic drag (N)

C_d = Coefficient of drag

ρ = Density (Kg/m^3)

A = Projected area of a bicycle

F_f = Frictional resistance (N)

F = Total force (N)

T = Torque (Nm)

E_{fl} = Energy of the flywheel (Joules)

s = Sprocket ratio = $\frac{rear}{front}$

m = Mass of the flywheel (Kg)

μ = coefficient of friction

ω_1 = Maximum angular velocity of the flywheel (rad/sec)

ω_2 = Maximum angular velocity of the flywheel (rad/sec)

I = Moment of inertia of the flywheel (Kg.m^2)

t = Thickness of flywheel (m)

r_1 = External radius of the clutch plate (m)

r_2 = Internal radius of the clutch plate (m)

P = Axial pressure intensity on the clutch plate (Pa)

p = Pitch of the chain (m)

T_1 = Number of teeth on the front sprocket

T_2 = Number of teeth on the rear sprocket

X = Center distance between front and rear sprocket (m)

L = Length of the chain used (m)

K = Number of chain links in the chain drive

T_w = Torque acting at the center of the wheel (Nm)

T_F = Torque required at the flywheel end (Nm)

F_T = Threshold force to move the bicycle (N)

F_C = Force required by the clutch drive (N)

F_S = spring force (N)

T_{TW} = Threshold torque required at the wheel end (Nm)

T_{TF} = Threshold torque required at the flywheel end (Nm)

F_{TC} = Threshold force required by the clutch drive (N)

F_{TS} = Threshold spring force (N)

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CHAPTER 1

INTRODUCTION:

A kinetic energy recovery system abbreviated as KERS is an automotive system which recovers the kinetic energy of a moving vehicle under braking. The energy recovered is stored in terms of potential energy a reservoir for later use for acceleration. Examples of reservoir are high voltage batteries, flywheels, hydraulic coupling, etc. The selection of reservoir largely depends on the purpose.

In recent days recovering Kinetic energy has become an interesting area of research for many. Let us first find out why? The total energy in this universe can be broadly divided into two parts Potential Energy and Kinetic Energy. The Potential Energy is the energy possessed by the body due to its position or state where as the Kinetic Energy is the energy the body gains due to its motion. As we know notion is a relative concept so as the Kinetic energy. For example a car possess some Kinetic energy with respect to road but with respect another car moving at same speed it has no Kinetic energy. So when we need to impart motion into a body we have to convert some amount potential energy into Kinetic energy. When that body has to come to rest, that amount of kinetic energy needs to get converted into Potential energy. But in nature the form of potential energy to which the Kinetic energy gets converted is of a lower grade, in most of the cases, and is very difficult to reuse. Taking the example of a car, when we run a car we burn petrol and convert the potential energy of the petrol into the Kinetic energy of the car and when we apply the brakes the kinetic energy converts into heat energy in the brake callipers and eventually gets diffused into the atmosphere. If this energy would have been saved it could have been used.

There are two type of Kinetic Energy Recovery Systems which have gained popularity in recent days. One is Electrical KERS and another is Mechanical KERS. Both have their respective pros and cons. The electrical system is less efficient but it can store power for a longer duration and gives us the agility to manipulate the torque and rpm output as per our requirement. In the other hand the mechanical system has a better efficiency (nearly twice as that of the prior one) but it is prone to decay due to its inherent property of friction, though it is very small in value, hence cannot be stored for loner period and need to be used within a short period of time. In the real world we can find many situations where we need to use the recovered Kinetic energy with in very short span of time of its recovery and we don’t even need a wide range of torque and rpm output as a particular range of torque & rpm combinations satisfy our requirements completely. A bicycle is a perfect example of this kind.

This is why KERS for bicycle has been chosen as the final year project. There has been a lot of work related to this topic but this topic still needs more research. During the project the goal will be to design an optimised mechanical KERS which will improve the storing time of the kinetic energy as well as improve the compatibility and manufacturability of the system.

MOTIVATION:

The motivation for this project started long back in my second year when I joined SAE NITR chapter. There I came to know about various recent day technologies those are used in today’s automobiles. KERS is one of those systems. KERS impressed me more than any other gadget used in automobiles because it regenerate the energy that could have lost in braking. No one but a cyclist can feel the pain of losing kinetic energy more than a cyclist. While riding down a slant surface, which is the most enjoyable moment for a cyclist, at some point of time the cyclist realises that his bicycle is reaching the speed that is beyond his control and he has to apply the brakes. Unfortunately all the kinetic energy that he has gained is lost. What if he was able to store that energy and would be able to use that whenever he wants. There is no me blessing than this for a cyclist. This thing motivated me to take this project as my final year research work.

CHAPTER 2

LITERATURE SURVEY

2.1. History of KERS:

The first of these systems to be revealed was the Flybrid. This system weighs 24 kg (53 lbs) and has an energy capacity of 400 kJ after allowing for internal losses. A maximum power boost of 60 kW (81.6 PS, 80.4 HP) for 6.67 seconds is available. The 240 mm (9.4") diameter flywheel weighs 5.0 kg (11 lbs) and revolves at up to 64,500 rpm. The maximum torque generated at the flywheel is 18 Nm (13.3 ft-lbs), and the torque at the gearbox connection is correspondingly higher for the change in speed. The system occupies 13 litres of volume.

Two small accidents were reported during testing of various KERS systems in the year 2008. The first incident happened with Red Bull Racing when the team tested their KERS battery for the first time in July, the battery malfunctioned and accidentally caused a fire, to avoid any causality evacuated the building. The second incident happened within a week. A BMW Sauber mechanic got an electric shock when he touched Christian Klien's KERS-equipped car during a test at the Jerez circuit.

Formula one has stated that they support environment friendly technology and thy have allowed use of KERS in 2009 F1 championship. Due to the previous accidents with KERS system many teams did not use it in their cars. Only four teams opted for KERS in 2009 session that to in few races only. Ferrari, BMW, Renault and McLaren were the fore teams using the KERS in their cars. Due to some malfunctioning BMW and Renault stopped using this system during the season. Vodafone McLaren Mercedes was the first team to win a F1 GP using a KERS equipped car on July 26, 2009 at the Hungarian Grand Prix. Lewis Hamilton was driving that car to become the first driver to win a pole position with a car equipped with KERS. In that race only their car which was also equipped with KERS finished fifth. Kimi Räikkönen won Belgian Grand Prix with KERS equipped Ferrari on 30th August 2009. This time the KERS contributed directly to race victory. Giancarlo Fisichella who came out second in that race claimed that he was faster than Kimi Räikkönen and Kimi only beat him because of KERS equipped car. KERS helped Kimi win the race substantially and get the lead.

In 2011, though KERS was legal no team used it on a united assertion. In 2011 F1 changed the rules and increased the minimum driver and car weight limit by 20Kg and the total weight to

640kg. This time the FOTA teams agreed to use the KERS devices and KERS is back in race. This time also the KERS system was options but all the teams except three used KERS devices on their cars.

Fig.2.1. Ferrari F1 car [31]

WilliamsF1 was the first to develop their own flywheel-based KERS system. Unfortunately they could not use it in their F1 cars because of packaging issues. Thus they developed an electrical KERS system of their own. They even set up Williams Hybrid Power to sell their developments in the field of KERS. In the year 2012 Audi announced to use Williams Hybrid Power in its Le Mans R18 hybrid car. By the year 2014, the power accumulation capacity of KERS systems has increased from 80bhp to 160bhp. F1 started using 1.6 litre V6 engines with an integration with KERS devices instead of 2.4 litre V8 engines.

In the field of motor racing Bosch Motorsport Service is a pioneer and it is developing a KERS that can be used in motorbikes. In the year 2009 KTM racing boss Harald Bartol announced that during the 2008 season-ending the factory raced with a KERS secretly fitted to Tommy Koyama's motorcycle in 125cc Valencian Grand Prix. This use of KERS was illegal, hence the team was banned from using that equipment in future.

KERS system can also be used on a bicycle. Students of the University of Michigan working with EPA has developed a system called RBLA (hydraulic Regenerative Brake Launch Assist). Recovery of Kinetic energy has also been done by mounting a flywheel on a bike frame and connecting it with a CVT to the back wheel. By shifting the gear, 20% of the kinetic energy can be stored in the flywheel, ready to give an acceleration boost by re-shifting the gear.

2.2. Comparative study of different type of KERS:

As we can see there are various ways of regenerating and reusing the kinetic energy of the a system, a comparative study of different Kinetic energy recovery systems is required to realise their respective pros and cons.

a) Mechanical KERS:

The mechanical KERS utilises a flywheel as a flywheel as the energy storage device and a variable drive transmission to control and transfer the energy to and from the driveline [4]. The transfer of vehicle kinetic energy to flywheel kinetic energy can be seen as a momentum exchange [4]. Energy is transferred from the vehicle to the flywheel. In doing this the speed of the vehicle decreases and that of the flywheel increases which we can effectively call as a braking [5]. At the start of braking process the vehicle has a higher speed than the flywheel, giving a certain speed ratio between them whereas at the end of braking the vehicle has a lower speed than the flywheel so the ratio of speeds has changed [6]. Examination of the energy transfer shows that the ratio between vehicle speed and flywheel speed necessarily changes continuously during the energy transfer event [5] [6].

b) Electrical KERS:

Electrical kinetic energy recovery system converts the kinetic energy into chemical energy for storage and an electric motor generator system is used as the energy transfer and control media [7]. The common components used in battery storage type kinetic energy recovery system are Electric Propulsion Motor /Generator, Power Electronics –Inverter, and the Quad Flywheel Storage [7] [8] [9]. Capacitors are fundamental electrical circuit elements that store electrical energy in the order of microfarads and helps in filtering [10] [11] [12] [13]. The main function of a capacitor is to get charged and discharged electricity [13] [14] [15]. A super-capacitor is an upgraded version of a capacitor having special features such as long life, rapid charging, low internal resistance, high power density, and simple charging method as compared to capacitors and batteries [16][17].

c) Hydraulic KERS:

Regenerative braking in vehicles using a variable displacement hydraulic pump/motor together with a hydro pneumatic accumulator has attracted considerable interest during the last 20–25 years. Such a system is particularly suitable for application in city [18] [19] [20] [21] [22] [23]. Despite the significant gains in the efficient use of energy that the use of this system has not attained great popularity [22] [23]. The added cost, which may represent 10–15% of the total for the vehicle, is one of the major drawbacks of this system [25] [26] [27].

d) Hydro-electric KERS:

A hydraulic electric synergy system (HESS) is a hydraulic accumulator and battery hybrid energy system [28]. This system follows hybrid energy structure to integrate a high specific energy battery with a high power hydraulic accumulator to get required output [22]. Hence it overcomes the drawbacks of a single energy storage source type KERS.

A thorough study by Radhika Kapoor and C. Mallika Parveen In their paper “Comparative Study on Various KERS” [3] have shown the following points:

I. A flywheel is capable of offering maximum steady voltage and power levels as compared to other types of storage systems. Even flywheels are independent of load, state of charging and temperature. Next to the flywheel storage system, comes the Li-ion battery system. It has also been mentioned that super capacitors have the lowest ever stability, i.e. around 30%.

II. Flywheels are the most robust power storage systems having a wide range of temperature withstanding capability, going from -40°C to 150°C. In the other hand Lead-Acid batteries have the shortest range starting from -15°C to 50°C. In case of temperature range super-capacitors come next to flywheels.

III. In case of efficiency super capacitors are the best in the list followed by the hydraulic system, then the flywheel system and lastly the battery system which has the least efficiency.

IV. If the KERS systems are listed in terms of reduction in fuel uses the list will be something like this:

    a. Super capacitors (best)
    b. Flywheel system
    c. Hydraulic system
    d. Battery system serially (worst).

V. Finally if the cost of these devices are taken into account it can be seen that the battery system is the cheapest among all the KERS devices. Next to battery system comes flywheel system. The super capacitor system is twice the cost of flywheel system and the hydraulic system costs even more than thrice the cost of a flywheel system.

2.3. KERS Related Research work:

From the history of KERS we can see that there has been sufficient amount of work in the field of kinetic energy recovery system for high end vehicles. Though some amount of the work is done in the field of two wheelers, which is not sufficient to get an optimum kinetic energy recovery system. In India a huge percentage of its population depends on two-wheelers for transport. So KERS for two wheelers needs a lot more research and improvement.

Following are some of the papers who have worked on Kinetic energy recovery system for bicycles. They have focused on energy storage improvement.

The following are the observations by Sreevalsan Et. All in their paper "Design and analysis of kinetic energy recovery system in bicycles". They have mentioned some of the most basic requirements of a KERS for bicycle [1].

Energy should be stored during braking. This is the most fundamental requirement of this device. Its name suggests that. The energy recovery should be rider friendly and should meet all his needs. Energy should be returned to the bicycle to start up. There must be simple way release the energy that is stored during braking in a positive way. The system must get fit to the bicycle otherwise it is irrelevant to design a model that cannot be used. The designer must keep in mind the space available while designing the system. The KERS system should be of light weight. Otherwise the weight of the system will increase unnecessarily and there won't be any advantage in installing an over weighted KERS system. The KERS should be able to slow down the system considerably when the rider applies it. The stopping range should be less. In case of requirement of sudden brakes there should be provisions for application of sudden brakes. The stopping force should be large. Larger the stopping force higher is the rate of charging of the flywheel. The system should be inexpensive and must be affordable. Otherwise the product won't make any profit. The KERS system should be safe to use and must be environment friendly. Safety is the most vital concern of a consumer product. The product must be economical and cheaply available in the market. It should be reliable and have a long life of operation. The product should be easy to manufacture. In order to make a product economical in production, its manufacturability should be of greatest concern. The aesthetics of the product should be good otherwise it won’t get its share in the market. It should be adaptive to the existing models of bicycles. It should not obstruct normal riding. If the device interferes with the riding experience in a bad way it won’t be a desirable product. And last but not the least the driver should have a controlled over the release of power from the KERS system.

2.4. Importance of flywheel:

Rotating wheels have long been used to store energy and to deliver it hen required since ancient times. Potter’s wheel is one of the first inventions that resembles a flywheel. This has existed for nearly 4,000 years. In 1784 the first appearance of the word flywheel occurred during the time of industrial revolution. In those times flywheels were used on steam engine trains, boats and even used as energy accumulators in industries. With drop in price of iron and steel flywheels became more and more popular during the time of industrial revolution flywheels used to be huge to store high amount of potential energy at low speed. During 1950’s Gyrobuses used flywheel for the first time on road vehicles in Switzerland. That flywheel was 1500kg in weight and 1.626m in diameter. It was capable of storing 3.3e7 joules of energy when fully charged. Flywheels are now found in almost all road, sea, air and space vehicles. In power plants flywheels are used tis tor energy and to control voltage. Flywheel has gained even more attention now days due to raised concerns regarding environment. Invention of carbon fibre has made flywheel technology useful. Now flywheels can spin faster, safer and release more energy than ever before with smaller size. Flywheels can always remembered 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.

High power density is the most distinctive feature of a flywheel. With the development in the field of carbon fibre it is now possible to make small and light weight flywheels that can store very high amounts of energy safely. They can be charged very quickly and can discharge high amounts of power. These kind of application can be seen from their uses in nuclear fission plants [2]. These are olso the most pollution free energy storage systems. In short run flywheels are got efficiency near one hundred percent. The efficiency drops with increase in storage time. The rate of decay of energy greatly depends on the housing and establishment of the flywheel. Transmission has been one of the greatest concerns in flywheel energy storage system. Inefficient transmission can cut the output energy by even half or more. The design of transmission systems often decides the upper limit of speed at which the flywheel can operate.

Flywheels are replacing electrochemical batteries in road vehicles and other applications due to their pollution free nature. Flywheels have a longer life time than batteries, can get charged faster, have high energy density and are lighter in weight. Flywheels don’t have an economic advantage over batteries yet, since flywheel technology for road vehicles is not completely developed, but there is a promising future for flywheel hybrid cars.

2.5. Types of mechanical KERS:

There are two types of mechanical KERS

1. Clutch type
2. CVT type

A comparative study between these two is needed.

2.6. Inference from literature survey:

Concluding this literature review we can say that Mechanical KERS is the most suitable type of Kinetic energy recovery system that we can use for a bicycle. The constraints for the design and development of the KERS for the bicycle are recognised. As there has not been much work related to bicycle KERS this field needs extensive research and development. No one has done any work on the mass production procedure of this product and its marketing. This field needs serious attention. A tie between the clutch type mechanical KERS and CVT type mechanical KERS can be broken by further study.

Flywheel technology is rising across many kinds of technology. It is a pollution free method of storing energy having many current applications as well as future uses. In the case of road vehicles it necessary to be concerned about energy efficiency, especially when considering pollution per unit of energy output. Any system that can regenerate energy from braking can help that, but flywheels have the potential to increase the efficiency of road vehicles without any direct or indirect negative effects on the environment. The use of batteries can cause serious environmental effects at the time of its manufacturing and disposal whereas flywheels have a very small environmental effect only at its time of their production. Flywheels have the potential to heavily outweigh those costs through their uses. Bicycles don’t have the pollution problems like cars and other modes of transportation, but use of a flywheel as KERS in a bicycle can tremendously increase its efficiency.

CHAPTER 3

OBJECTIVE AND IDEAS:

Any project at its starting comprises of setting the objective. Then comes ideas and their comparison to get to the best method to achieve the objective. Similarly for this project a lot of brain storming resulted in a good and efficient model of KERS system for a bicycle. Form the literature survey we found that a clutch based flywheel is very much efficient and cheaper as compared to CVT type. But there are always limitations and advantages for every mechanical system. In advantage. Let us take the CVT based KERS system can give us a smoother starting after braking it has the limitation that it keeps the KERS system always engaged even the rider doesn't want to use KERS in some circumstances. In the other hand for the clutch based KERS system we have the liberty to engage and disengage the KERS system any time we want but this system also has its limitations. In a clutch based KERS system the initial jerk when the KERS system is actuated is very high. So in this this project it has been tried to develop a hybrid between a clutch type and a CVT type KERS system.

Criteria to find out different gear ratios for Charging and discharging of the flywheel**:**

Charging criteria:

1. High energy consumption in less time
2. To reach very high RPM (flywheel)
3. Only on pressing the right brake charging will start
4. The rear sprocket is one directional and the front sprocket is fixed.

Discharging criteria:

1. System always tries to discharge energy back to the bicycle.
2. Discharge gear ratio should be less than the charging gear ratio.
3. The rear sprocket is one directional and the front sprocket is fixed.
4. If the cycle is moving faster than the flywheel and we don't want to charge the flywheel, the system should not charge it in any means.

IDEA 1:

First when the project was undertaken the idea was to develop a completely clutch based KERS system and to reduce the initial jerk to make it more handy. The thought behind this was when the brakes are to be applied the rider first actuates the KERS and the flywheel charges. After some time the speed of the cycle will reduced and then the rider will disengage the KERS system and will apply the brakes. For this function the brake wires are connected the right brake handle; both the front an rear brakes. And the KERS system is connected to the left brake handle.

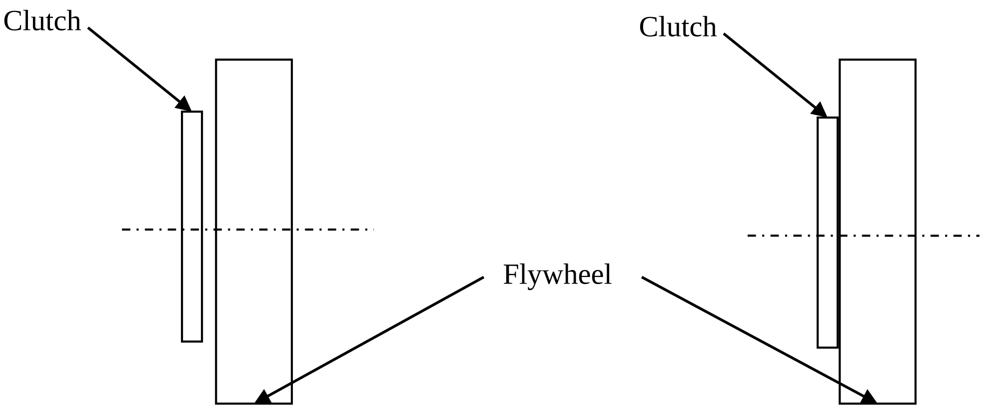


Fig.3.1 (a) clutch disengaged

Fig.3.1 (b) clutch engaged

Fig.1a and Fig.2b represents the KERS system in the disengaged and engaged state respectively.

This system has its limitations. They are

- This KERS system is not user friendly.
- Braking is a very important thing when it comes to mobile vehicles. Here the rider has to plan many thing before braking. Like when to apply the Kers when to disengage it and then to apply the brakes. During all this work he may lose concentration and there is a chance of accident.
- Both front and rear brakes are connected to only one rider handle. So the mild braking is not possible. Every time the rider applies the brakes it is a hard brake.
- Again to get acquainted to this new type of braking system is tedious task.
- Customers will not prefer this product.

Due to all these disadvantages is idea is ruled out.

IDEA 2:

The second idea was to go for a completely CVT based KERS system for the bicycle. The plan here was that there will be no clutch instead the rear wheel will be connected to the flywheel directly through a chain drive. This means the flywheel is always connected to the system. During starting the rider has to keep a high gear ration to charge the flywheel fast and during discharging he has to keep a low gear ratio to increase the time of discharge and to get the maximum benefit. In this case the brake system is free and the chance of accident is completely avoid. So the safety part is done. Now coming to the actuation part of the KES system, for that the driver has been provided a controller (mechanical controller) to change the gear ratio as per his requirement.

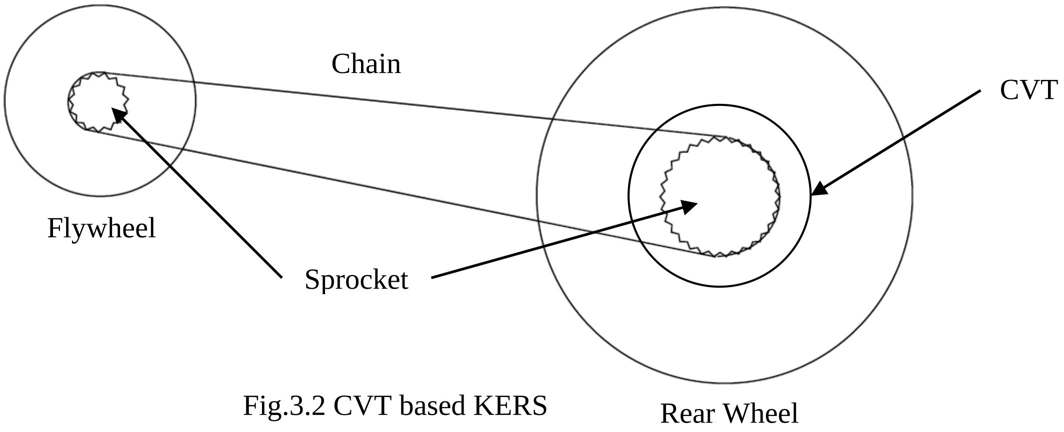


Fig.3.2 CVT based KERS

Fig.2 shows a schematic diagram of a CVT based KERS system.

The main limitations of this system are:

- The starting effort required is very high.
- As the road is always unpredicted, sometimes this may happen that the rider has completely discharged his KERS system and he comes across an upward slant. The effort required will increase many fold.
- Due to all time engagement the system may undergo sever wear and tear.
- Also this high engagement time causes losses due to friction at the flywheel.
- The cost of the CVT is very high for a bicycle. Hens the product will not find popularity.

IDEA 3:

The next idea is a hybrid of the above two Ideas. In this case the clutch system is optimised and variable transmission (instead of CVT) system is used to get the optimum output of the KERS mechanism. This system has advantages over the above two methods and eliminated their respective limitations. In this paper the working principle, design and manufacturing process if this model is elaborately discussed.

The advantages of this system are

- This is user-friendly.
- The braking system is completely independent avoiding any chance of misshape.
- This is less costly.
- Avoids completely the initial jerk.
- Avoids the application jerk upto a large extent.
- Easy to fit.
- Marketable.
- Easy to manufacture.

CHAPTER 4

COMPONENTS OF KERS:

The components required for the making of the KERS for a bicycle are mentioned below:

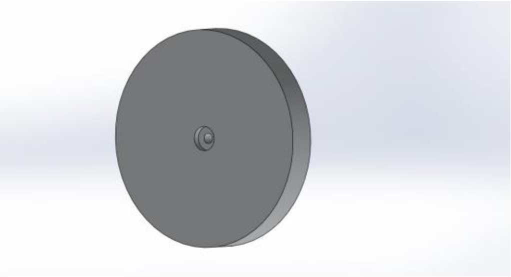


Fig.4.1. Flywheel

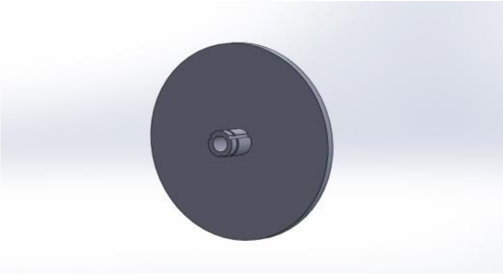


Fig.4.2. Clutch

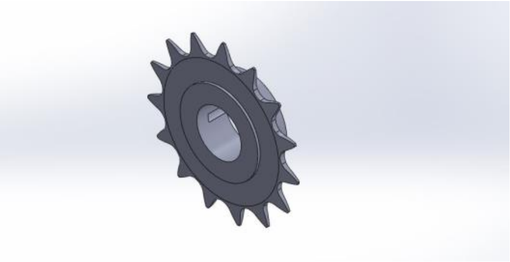


Fig.4.3. Front Sprocket

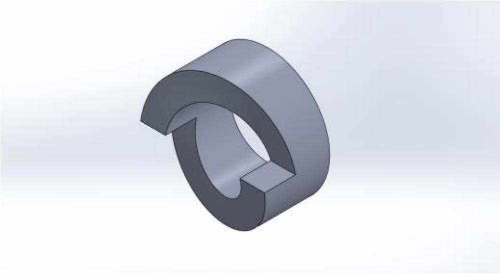


Fig.4.4. Clutch drive

Fig.4.5. Rear Sprocket

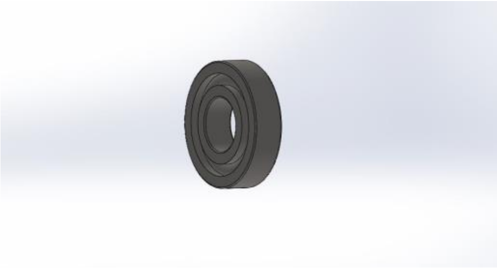


Fig.4.6. Ball bearing

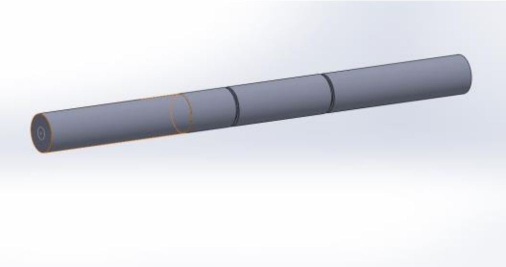


Fig.4.7. Central Shaft

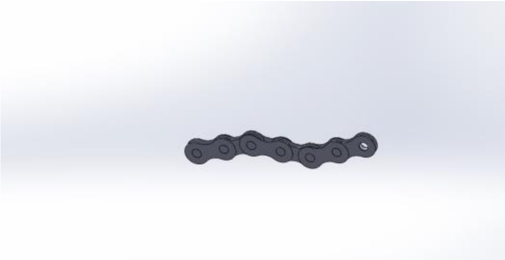


Fig.4.8. Chain

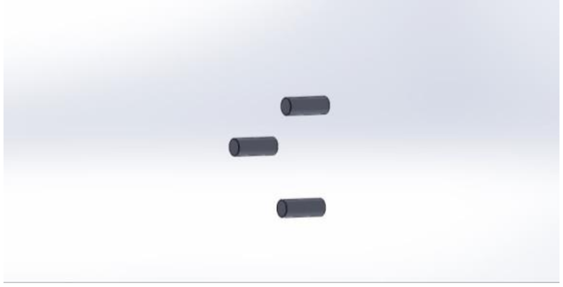


Fig.4.9. Key

Fig.4.10. C_clamp

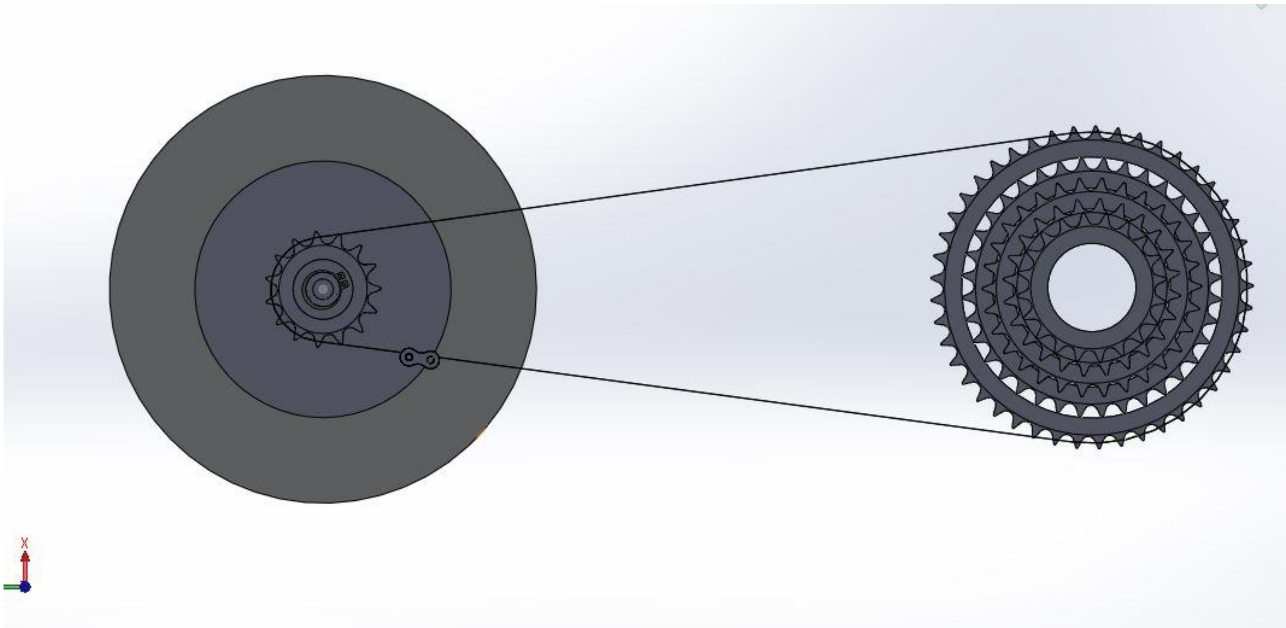


Fig.4.11. Front View of the KERS

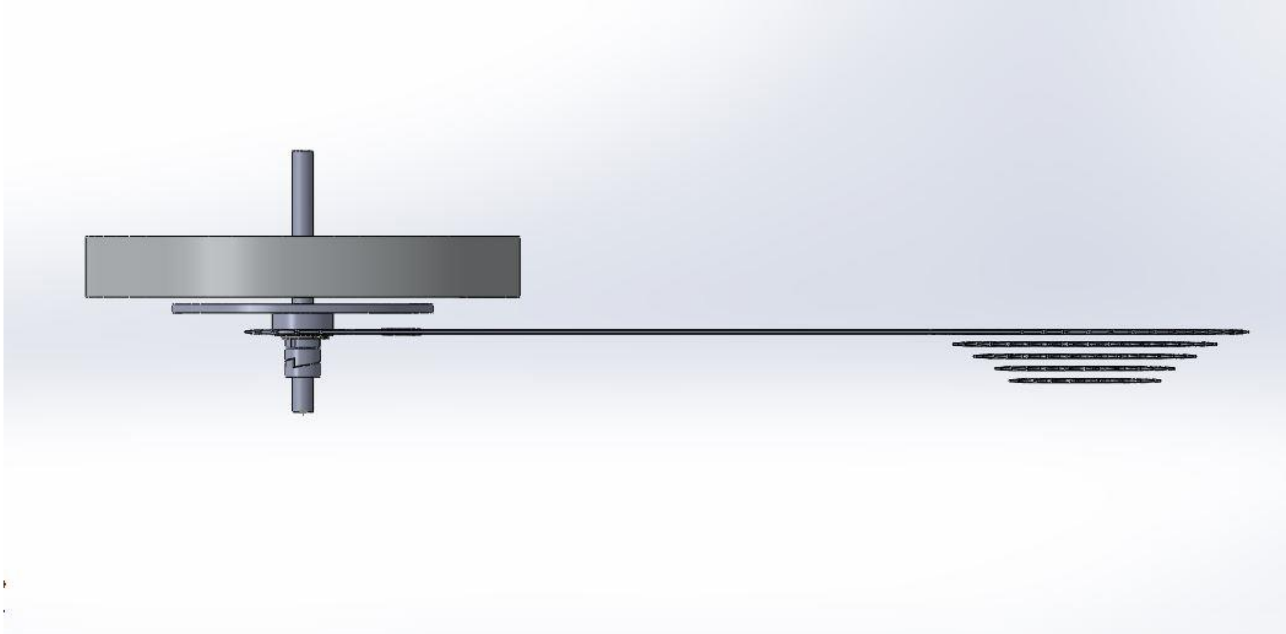


Fig.4.12. Top view of the KERS

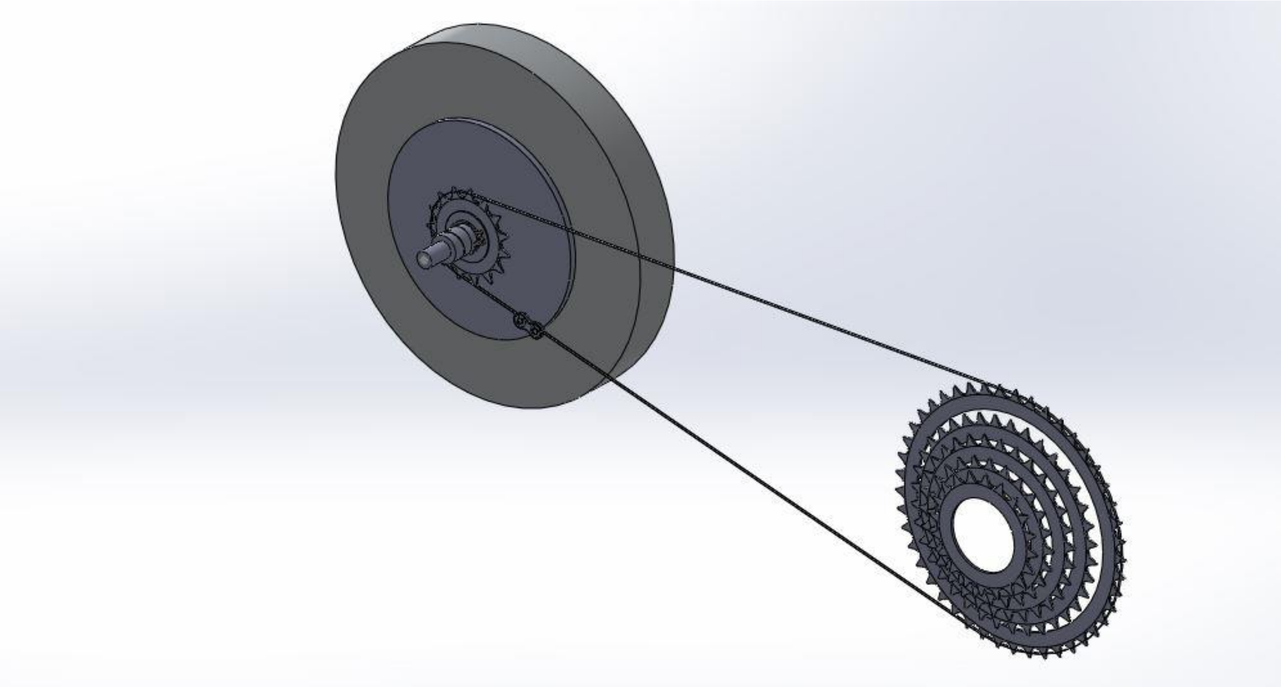


Fig.4.13. Isometric view of the KERS

CHAPTER 5

WORKING PRINCIPLE:

The working principle of the KERS system is described below in details.

1. To actuate the KERS the lever near the left brake is to be actuated. This pulls the wire connected to the clutch drive and rotates it by some angle less than 180°.
2. Due to the rotational motion of the clutch drive it undergoes translational motion, because its counterpart is fixed.
3. The translational motion of the clutch drive pushes the clutch plate to bring it in contact with the flywheel.
4. In this design we have connected the KERS actuator on the opposite side of the left brake lever so when clutch is actuate brake is not actuated (which is the default position) and when the brake will be actuated the clutch will automatically disengage.
5. The clutch drive is always in the actuated state with the help of a sprig that always keeps it rotated by nearly 150°.The rest 30° is for wear and tear compensation.
6. The clutch plate is a continuously moving part as it is connected with the front sprocket using three keys.
7. The front sprocket is driven by the rear sprockets through a chain drive.
8. The rear sprockets are a set of sprockets on which the chain can change position to get different gear ratios. These are interconnected and rotate at same RPM as the rear wheel.
9. During charging of the flywheel, power flows as follows
   Rear Wheel ➔ Rear Sprocket ➔ Chain Drive ➔ Front Sprocket ➔ Clutch ➔ Flywheel
10. During the discharging cycle, power flows exactly in the reverse direction.
    Flywheel ➔ Clutch ➔ Front Sprocket ➔ Chain Drive ➔ Rear Sprocket ➔ Rear Wheel.
11. As there are 5 sprockets on the rear sprocket system we can have 5 different gear ratios and can manipulate them to get the required charging and discharging conditions.
12. During charging it is preferred to use a higher gear ratio (Rear: Front) so that the flywheel can get charged within less time. But this will cause higher initial jerk while engaging.
13. So it is preferred to engage the clutch at the lowest gear ratio and then increase the gear ratio to the maximum.
14. This has an additional advantage. With every increasing gear ratio the relative velocity of the flywheel as compared to the rear wheel decreases. Thus additional torque acts on the

flywheel and accelerates it to even higher speed. This way the flywheel can attain its maximum desired RPM smoothly.

15. Now the flywheel has its maximum potential energy. So if the driver wants to brake, he simply applies the brake and the flywheel automatically disengages as the string that actuate the flywheel is connected to the opposite end of the left handle brake as mentioned earlier.
16. Now coming to the discharging of the flywheel. Discharging can be done for a long time if we keep the sprocket ratio (rear: front) low. But if the gear ratio is more the torque will be more.
17. We need higher torque when discharging starts and low but continuous discharge when the cycle attains some speed.
18. From the previous discussion we can see that at the end of the charging cycle the gear ratio is at maximum. So when the discharging starts we simply need to reduce the gear ratio in successive intervals.
19. This has another advantage. When the gear ratio is lowered the relative velocity of the flywheel becomes more as compared to the rear wheel. So the power flows from the flywheel to the rear wheel and the cycle accelerates.
20. The gear changer for the KERS system will also be on the left hand side. So the driver has to concentrate only on hand to operate this system. And when he needs to brake (sudden brake) he simply can apply brakes. The cycle will stop.
21. The starting effort will be a little more but not that more because while starting the gear ratio is at minimum. Or if the driver is a bit smart he can apply the brake lever slightly and accelerate the bicycle easily. At that condition the KERS will be disengaged and the brakes are not also applied.
22. In normal riding the sprocket ration stays at minimum. When the rider wants to slow down (mild braking) he can simply increase the sprocket ratio with the help of gear shifter available at his left hand. And when he wants to boost his speed he can simply gear down or reduce the sprocket ratio to accelerate the bicycle.
23. The most important thing the amount of power released from the KERS system is completely controllable. The rider can release the exact amount of power he needs to release and get the required acceleration.

CHAPTER 6

DESIGN PROCEDURE:

First of all a cycle is chosen on which the KERS is to be mounted. In this case an AVON BOOM cycle is being chosen. There is no special reasons for this selection neither any mechanical or aesthetic advantage. It is a completely random selection.

Fig.6.1 position of flywheel in a bicycle [30]

So now coming to the space available in this cycle to fit the KERS system. For that all the dimensions have been shown in the picture and from that we can infer the KERS flywheel that we can use is 25cm at maximum.

Next task in hand, the flywheel. To design the system we need to find out of what material and of what structure we shall make the flywheel.

6.1. Flywheel:

Calculation for the energy stored in the flywheel:

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

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

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

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

$$a = (V - U)/\ \text{Time}$$

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

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

So let us calculate the rpm or speed of the wheel and the flywheel

D_R = Diameter of the bicycle wheel

$$= 29\text{inch} \cong 750\text{mm}$$

Number of revolution made by the wheel at 10kmph per sec

$$= \frac{v}{2\pi R_R} = 1.179\text{rps}$$

$$= 70.74\text{rpm}$$

Force required to take the bicycle from rest to 10kmph in 5 sec

$$F_a = ma = 55.56\text{N}$$

Now considering the rolling resistance of the bicycle

$$F_R = 20 \text{ watt at } 10\text{kmph} = 7.2\text{N}$$

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

Aerodynamic drag = F_A

$$F_A = C_d \rho A v^2$$

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

ρ = density of air = 1.25 kg/m^3 at 25°C

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

v = velocity of bicycle = 2.78m/sec

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**

$$(F_A)_{avg} = \frac{C_d \rho A \int_0^{2.78} v^2 dv}{\int_0^{2.78} dv} = 2.313\text{N}$$

Other frictional resistances

F_f = 2N

Total requirement of force = F

$F = F_a + F_r + F_A + F_f$

= 71.69N (Taking upper limit)

Torque required at the center of the wheel to get this required force = T_w

$$Tw = F \times r = 71.69 \times 0.75 \div 2 = 26.884 \text{ Nm}$$

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

Let the Sprocket ratio = s

So Flywheel rpm = 70.74s rpm = 1.18rps

Energy released by the flywheel = E_{fl}

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

$\omega_2 = 2\pi \times \text{RPS} = 7.41s$

ω_1 is constrained by the top speed of the bicycle

$\omega_1 = 22.22s$

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 × displacement

$= F \times (v^2 - u^2)/2a$

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

=> $219.63 \times I \times s^2 = 497.85$

=> $I \times s^2 = 2.267$………………………………………........Eq.6.1

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

$m = \rho \times \pi \times d^2 \times t = \rho \times 2.4544 \times 10^{-3}$ Kg……….. Eq.6.2

$I = ½\, mr^2 = \rho \times 1.9175 \times 10^{-5}$ Kgm^2

Putting the value of 'I' in Eq.6.1 we get

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

$\rho \times s^2 = 118228.34$ ……………………….. Eq.6.3

Choosing flywheel material as structural steel ($\rho = 8000$ Kg/m^3) Eq.6.3 implies

$$s^2 = 14.77$$

$$s = 3.84$$

Now putting the value of ρ in Eq.6.2 we get

$$m = 8000 \text{ x } 2.4544 \text{ x } 10^{-3}$$

$$= 19.64 \text{ kg}$$

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

Let us try some other material say Aluminium ($\rho_{\text{aluminium}} = 2700$Kg/m^3) in Eq.6.3

$$s^2 = 43.79$$

$$s = 6.62$$

Now Eq.6.2 will give

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

$$= 6.63 \text{ Kg}$$

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.

6.2. 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 = T_F

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

$= \text{pressure} \times \text{area}$

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

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

$= F_r$

$= \mu \times dw$

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

Frictional torque actin on the ring

$= T_r$

$= F_r \times r$

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

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

We shall now consider two cases

1. When there is uniform pressure
2. When there is uniform wear

Considering uniform pressure:

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

$$P = \frac{W}{\pi[r_1^2 - r_2^2]}$$

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

$$= T_r$$

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

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

= > Total frictional torque acting on clutch

$$= T$$

$$= \int_{r_2}^{r_1} 2\pi\mu P r^2 dr$$

$$= 2\pi\mu P[\frac{r^3}{3}]$$

$$= 2\pi\mu P[\frac{r_1^3 - r_2^3}{3}]$$

$$= 2\pi\mu \frac{W}{\pi[r_1^2 - r_2^2]} [\frac{r_1^3 - r_2^3}{3}]$$

$$= \frac{2}{3}\mu W \frac{[r_1^3 - r_2^3]}{[r_1^2 - r_2^2]}$$

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).

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

$$P.V = \text{Const.}$$

$$P = \text{Const.}/V$$

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

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

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

$$= 2\pi.\,C.\,dr$$

Total force acting on the friction surface

$$W = \int_{r_2}^{r_1} 2\pi.\,C.\,dr$$

$$= 2\pi.\,C.\,[r]_{r_2}^{r_1}$$

$$= 2\pi.\,C.\,(\,r_1 - r_2)$$

$$C = \frac{W}{2\pi.(\,r_1 - r_2)}$$

We know the friction torque acting on the ring

$$T_r = 2\pi\mu P r^2 dr$$

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

$$= 2\pi\mu C r dr$$

Total friction working on the friction surface

$$T = \int_{r_2}^{r_1} 2\pi.\,\mu.\,C.\,r.\,dr$$

$$= 2\pi.\,\mu.\,C.\,[\frac{r^2}{2}]_{r_2}^{r_1}$$

$$= 2\pi.\,\mu.\,C.(\frac{r_1^2 - r_2^2}{2})$$

$$= \pi.\,\mu.\,C.(\,r_1^2 - r_2^2)$$

$$= \pi.\,\mu.\,\frac{W}{2\pi.(\,r_1 - r_2)}.(\,r_1^2 - r_2^2)$$

$$= \mu.\,W.(\frac{r_1 + r_2}{2})$$

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 center of the rear wheel is

$T_w = 26.884$

And the Maximum gear ratio for the Al flywheel = s

Torque transmitted by the clutch

$T = \frac{26.884}{s}$

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

6.3. Calculation of the Chain Length:

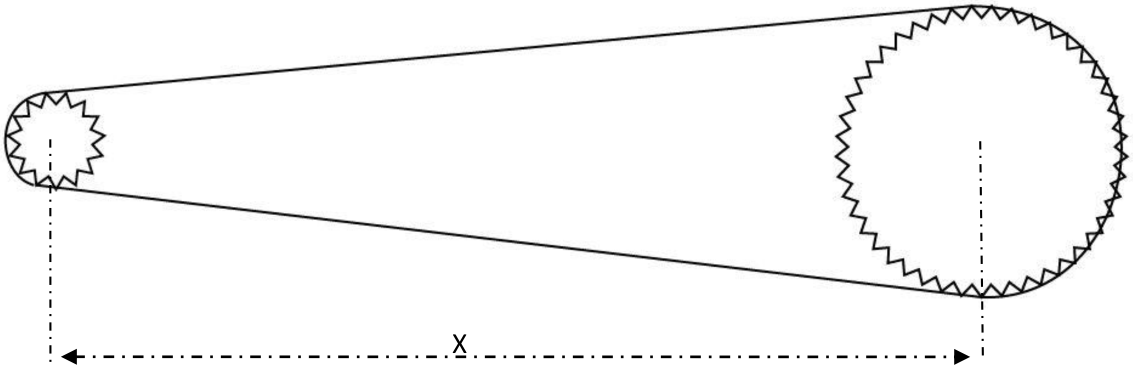


Fig.6.2. Chain link between front and rear sprocket

T_1 = number of teeth on the smaller sprocket

P = pitch of the chain

T_2 = number of teeth on the larger sprocket.

X = center 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.

$$L = K \times p$$

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

$$K = \frac{T_1+T_2}{2} + \frac{2X}{p} + \left(\frac{T_2-T_1}{2\pi}\right)^2 \times \frac{p}{X}$$

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

$T_1 = 15$
$T_2 = 60$
X = Distance between centres
= 1m (approximately, because this distance varies from cycle to cycle.)
p = 12.7mm

$$K = \frac{15+60}{2} + \frac{2*1000}{12.7} + \left(\frac{60-15}{2\pi}\right)^2 \times \frac{12.7}{1000}$$

$$= 195.63$$

$$\cong 196$$

$$L = 196 \times 12.7$$

$$= 2489.2\text{mm}$$

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

$T_1 = 15$

$T_2 = 20$

$$K = \frac{15+20}{2} + \frac{2*1000}{12.7} + \left(\frac{20-15}{2\pi}\right)^2 \times \frac{12.7}{1000}$$

$= 174.98$

$\cong 176$

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 solving the below triangle.

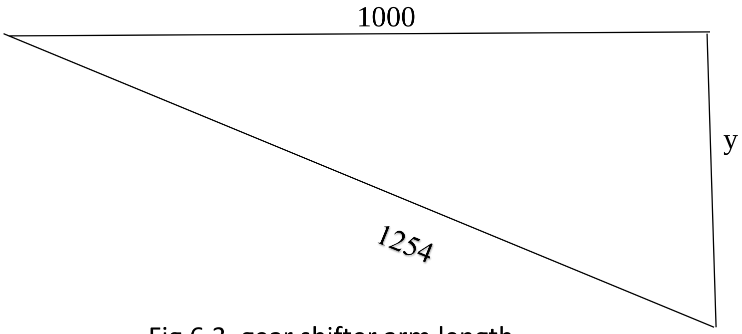


Fig.6.3. gear shifter arm length

$Y = \sqrt{(1254^2 - 1000^2)}$ = 756mm this length is very difficult to achieve.

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

T1=15

T2 = 45

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

Pitch= p = 12.7mm

$$K = \frac{15+45}{2} + \frac{2*1000}{12.7} + \left(\frac{45-15}{2\pi}\right)^2 \times \frac{12.7}{1000} = 187.63 \cong 188$$

L = 188 × 12.7 = 2387.6mm

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

T1 = 15

T2 = 20

K = $\frac{15+20}{2} + \frac{2*1000}{12.7} + \left(\frac{20-15}{2\pi}\right)^2 \times \frac{12.7}{1000}$ = 174.98 ≅ 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 solving the below triangle.

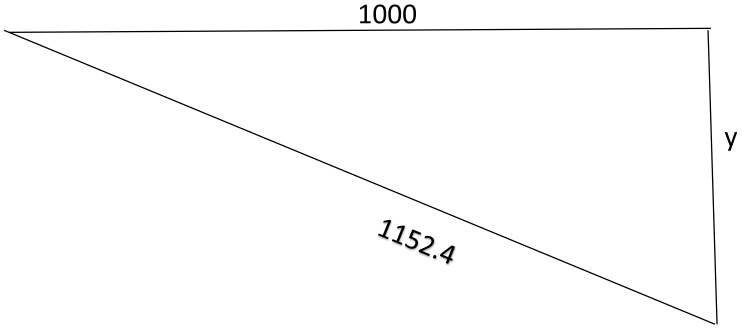


Fig.6.4. gear shifter arm length

Y = $\sqrt{(1152.4^2 - 1000^2)}$ = 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.

For example a picture is given:

Fig.6.5. Gear Shifter arm [32]

6.4. Design of the clutch drive system:

From previous calculation we know

$$T = \frac{26.884}{s} \text{Nm.}$$

As we have found out s=3

$$T = 8.96\text{Nm.}$$

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

$$F_T = F_R + F_A + F_f$$

F_a is neglected here .Even F_A won't come into picture if there is no relative flow of wind.

$$F_T = 7.2 + 2.313 + 2$$

$$= 11.513\text{N}$$

Now considering F_T = 12N so that it will just accelerate the system with minimal acceleration.

Threshold Torque required at the rear wheel center.

$$T_{TW} = 12 \times (\text{readius of the rear wheel}) = 12 \times (\frac{0.75}{2}) = 4.5\text{Nm}$$

We generally engage the flywheel at high sprocket ratio **s.**

$$T_{TF} = \frac{4.5}{s}$$

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

$$T_{TF} = \frac{4.5}{1.25} = 3.6\text{Nm}$$

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

Mean radius of the clutch surface = $\frac{10+2}{2}$ = 6cm =0.06m

Minimum force applied by the clutch drive = F_{TC}

$$F_{TC} = \frac{3.6}{\mu \times 0.06} = \frac{3.6}{0.4 \times 0.06} = 150\text{N}$$

The mechanical advantage at the clutch drive = n

$$n = \left(\frac{\text{rotational travel by the outer5 periphery point in the clutchdrive that is connected to the spring}}{\text{linear travel of the clutch drive}}\right)$$

Linear travel of the clutch drive = 3mm

Rotational travel of the outer periphery point $= \frac{150}{180} \times 2\pi R = \frac{150}{180} \times 2\pi \times 10 = 52.36\text{mm}$

The mechanical advantage = n $= \frac{52.36}{3} = 17.454 \cong 17.5$

Threshold force applied by the spring = F_{TS} $= \frac{150}{17.5} = 8.6\text{N}$

The spring force should be greater than 8.6N.

With requirement of higher acceleration, required spring force will also increase.

For maximum acceleration:

$$T_F = \frac{26.884}{s}\text{Nm.} = \frac{26.884}{3}\text{Nm.} = 8.96\text{Nm.}$$

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

Force applied by the clutch drive = F_C

$$F_C = \frac{8.96}{\mu \times 0.06} = \frac{8.96}{0.4 \times 0.06} = 373.39\text{N}$$

Spring force

$$F_S = \frac{373.4}{17.5} = 21.33\text{N}$$

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

Mechanical advantage at the left brake handle = $\frac{x_1}{x_2}$

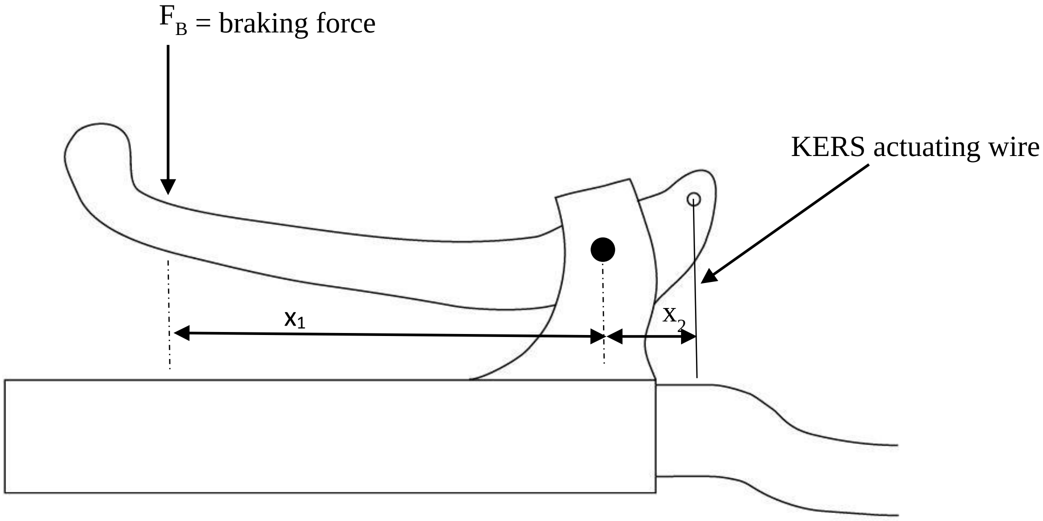


Fig.6.6.left brake handle.

Comfortable force that the rider can apply = 0.5Kg = 4.905N

Mechanical advantage at the left brake handle $= \frac{21.33}{4.905} = 4.35$

The left handle is to be designed with a mechanical advantage of 4.35.

CHAPTER 7

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:

7.1. 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:

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

Supports of the flywheel:

- Bearing support.
- Displacement support

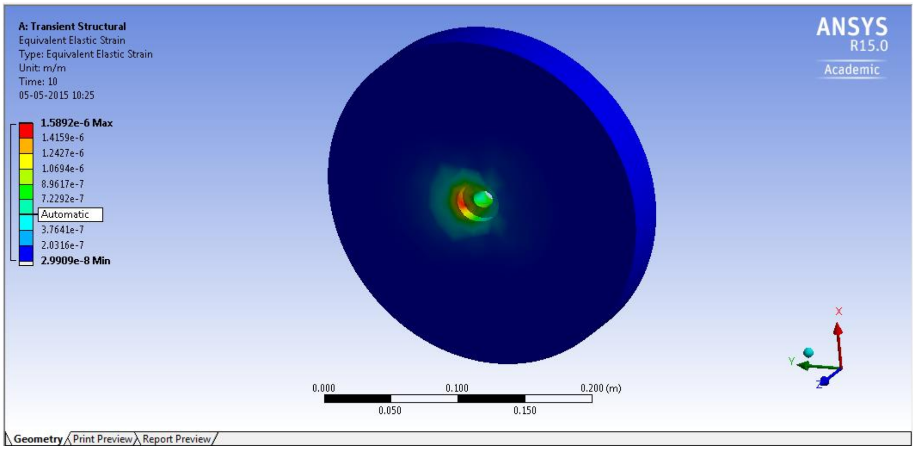
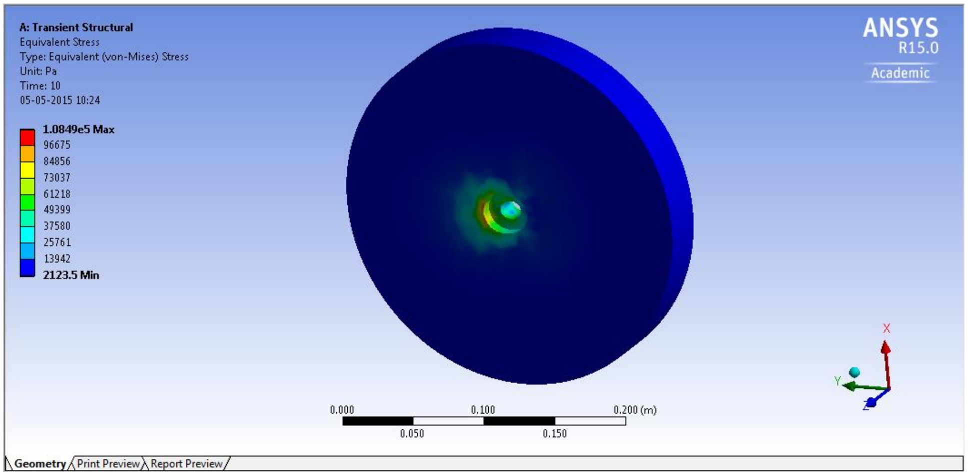
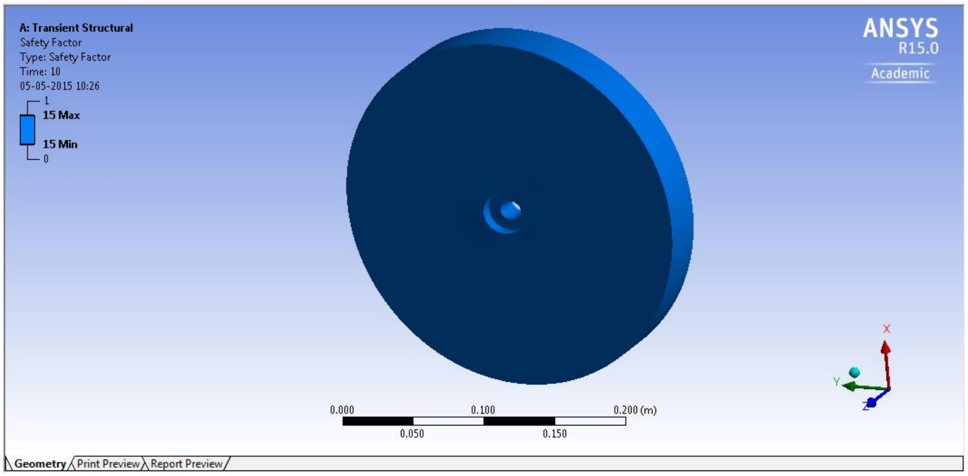


Fig.7.1. Equivalent Elastic Strain



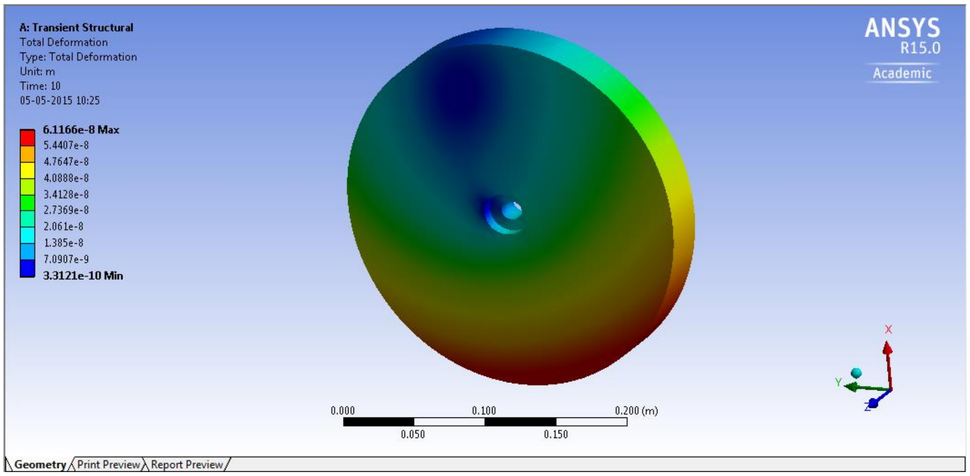
A: Transient Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 10
05-05-2015 10:24

Fig.7.2. Equivalent Stress



A: Transient Structural
Safety Factor
Type: Safety Factor
Time: 10
05-05-2015 10:26

Fig.7.3. Factor of Safety



A: Transient Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 10
05-05-2015 10:25

Fig.7.4. Total Deformation

From the FEA analysis photos we can see:

- Factor of safety of the flywheel = 15.

- Maximum equivalent stress = 108.5KPa
- Maximum equivalent strain = 1.5e-6
- Maximum deflection = 6.1e-8m

The above data show that the design of the flywheel is completely safe.

7.2. 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:

- Force due to actuation of the clutch

  F = 373.4N
- Gravitational force
- Rotational inertia force

  Speed of rotation when the cycle runs at 30Kmph amd the sprocket ratio is maximum (s=3)

  $=\omega_2 = 30 \times \frac{5}{18} \times \frac{2\pi}{\pi D} \times s$ = 66.66rad/sec
- Torque

  T = 8.96Nm

Supports:

- Compression only support
- Contact support, no displacement

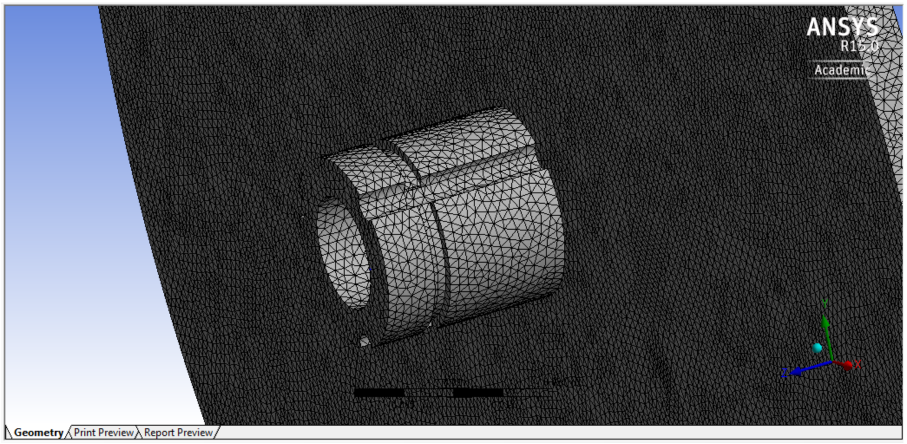
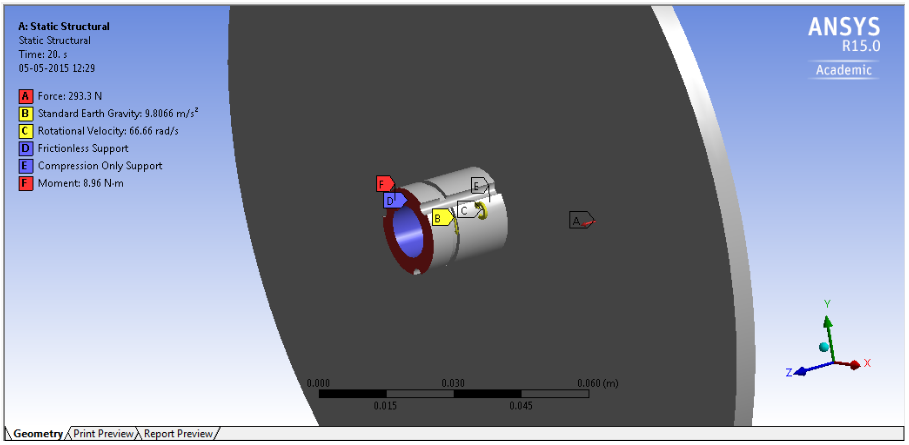


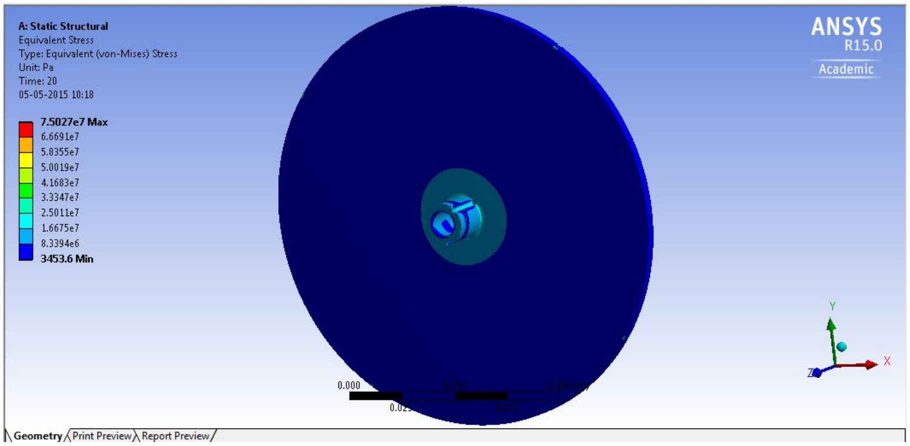
Fig.7.5. Meshing



A: Static Structural
Static Structural
Time: 20. s
05-05-2015 12:29

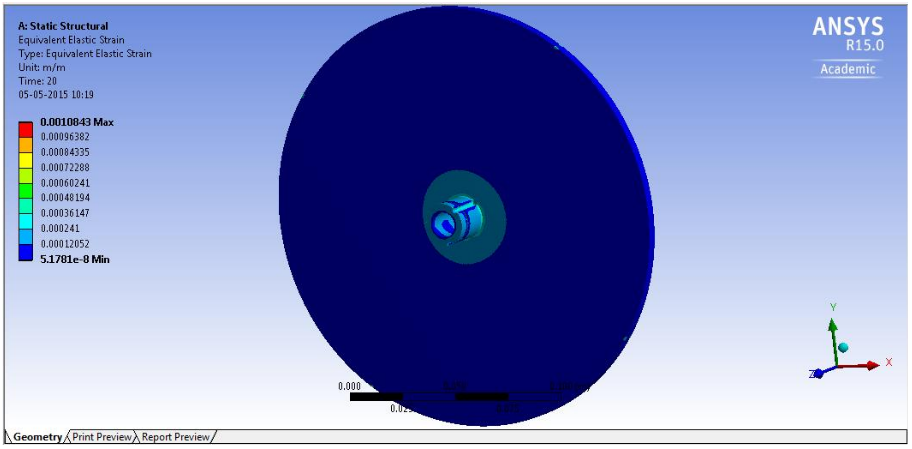
- A Force: 293.3 N
- B Standard Earth Gravity: 9.8066 m/s²
- C Rotational Velocity: 66.66 rad/s
- D Frictionless Support
- E Compression Only Support
- F Moment: 8.96 N·m

Fig.7.6. Forces Acting



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 20
05-05-2015 10:18

Fig.7.7. Equivalent Stress



A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 20
05-05-2015 10:19

Fig.7.8. Equivalent Elastic Strain

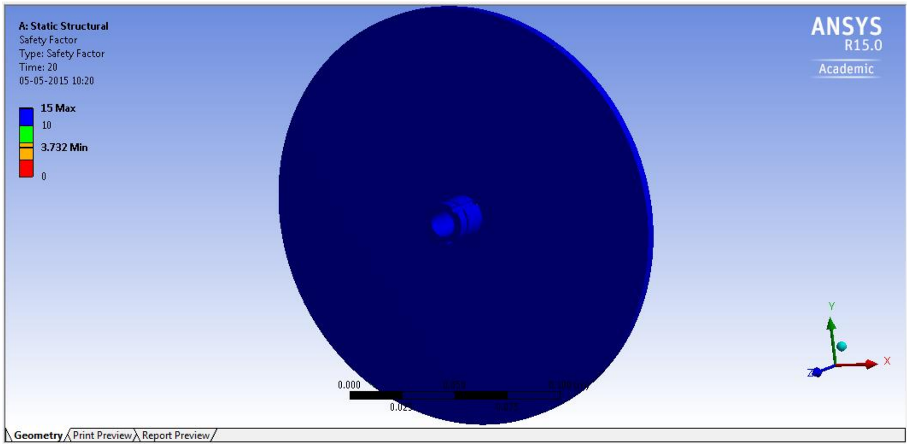


Fig.7.9. Factor of Safety

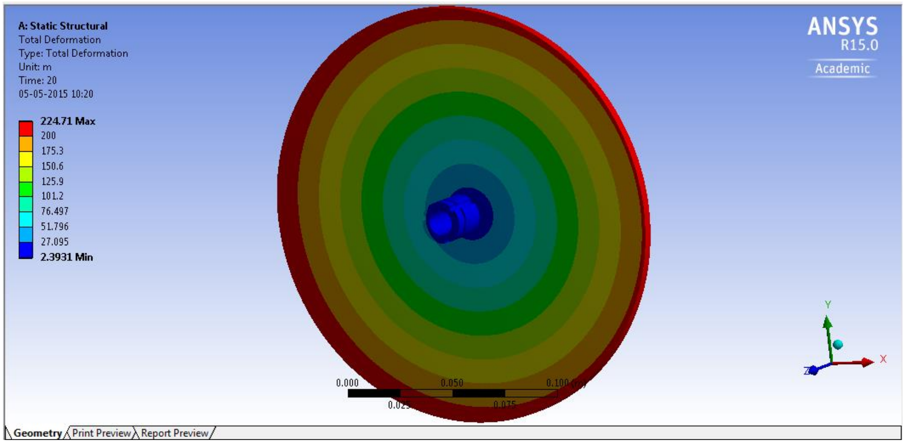


Fig.7.10. Total Deformation

From the FEA analysis photos it can be seen:

- Max. equivalent stress = 75.03MPa
- Max. equivalent strain = 0.00108
- Min. FOS = 3.732
- Overall FOS = 12
- Maximum deflection = 0.09mm

We can see on all the clutch the factor of safety is 10 to 15. Only on 4 peripheral points of the clutch the FOS falls below 10. For that if we are changing the material the component will be over engineered and we will increase the weight unnecessarily. To avoid failures at those point we can do heat treatment to increase the strength in the peripheral area. We can also use electromagnetic plating of stronger materials on those areas.

7.3. 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:

- Gravitational force
- Rotational inertia force
- Torque

  T = 8.96Nm

Supports:

- Compression only support
- Keyway support

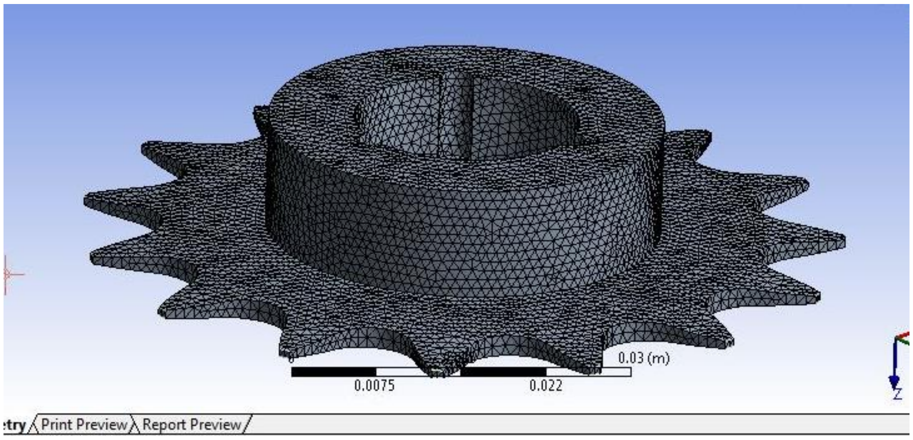
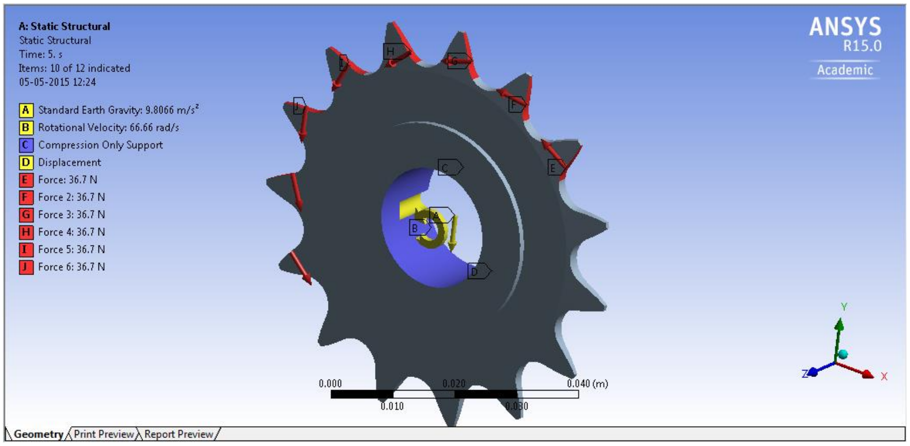


Fig.7.11. Meshing



A: Static Structural
Static Structural
Time: 5. s
Items: 10 of 12 indicated
05-05-2015 12:24

A Standard Earth Gravity: 9.8066 m/s²
B Rotational Velocity: 66.66 rad/s
C Compression Only Support
D Displacement
E Force: 36.7 N
F Force 2: 36.7 N
G Force 3: 36.7 N
H Force 4: 36.7 N
I Force 5: 36.7 N
J Force 6: 36.7 N

Fig.7.12. Forces Acting

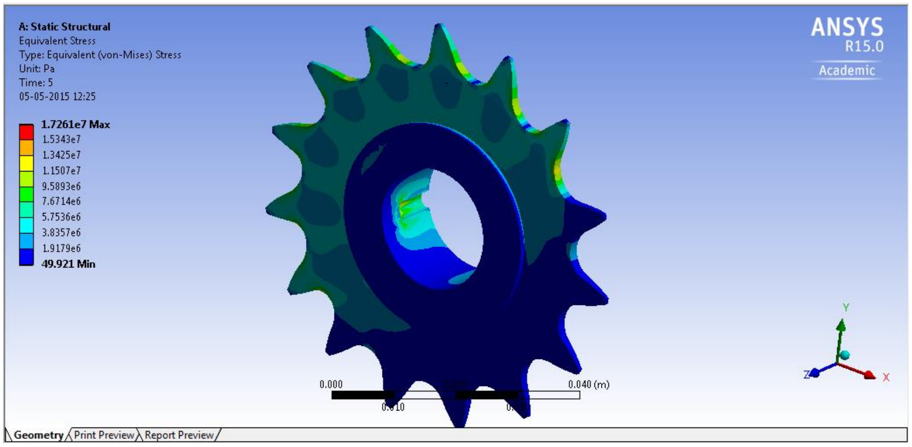

A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 5
05-05-2015 12:25

Fig.7.13. Equivalent Stress

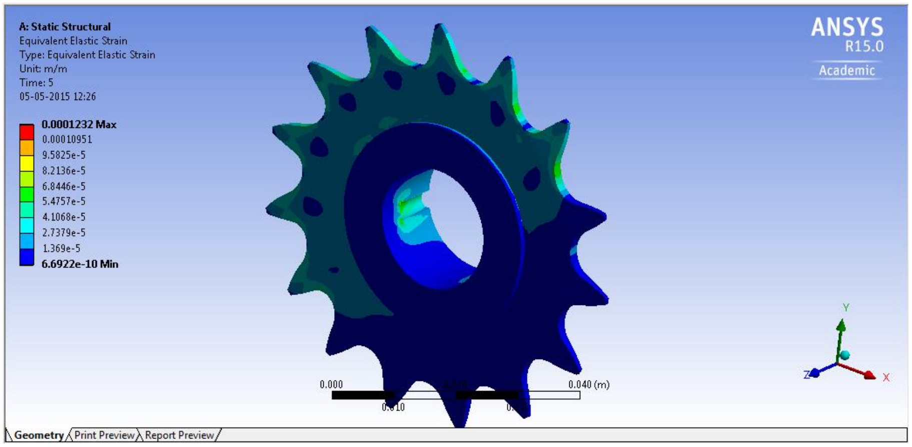

A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 5
05-05-2015 12:26

Fig.7.14. Equivalent Elastic Strain

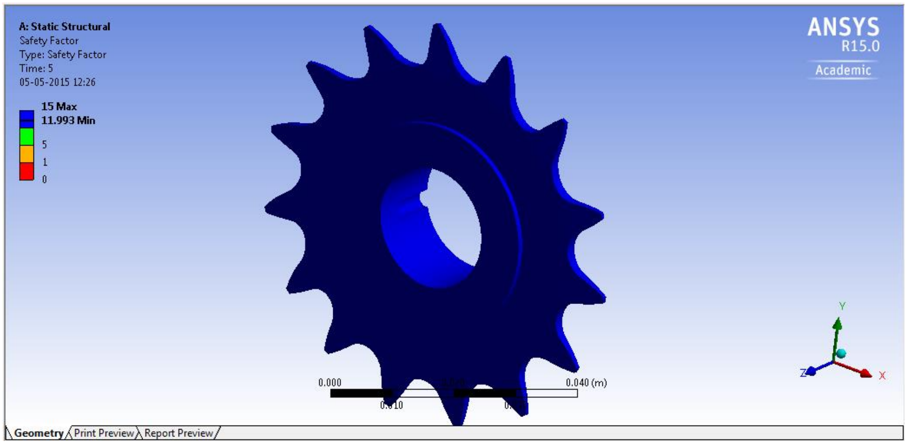

A: Static Structural
Safety Factor
Type: Safety Factor
Time: 5
05-05-2015 12:26

Fig.7.15. Factor of Safety

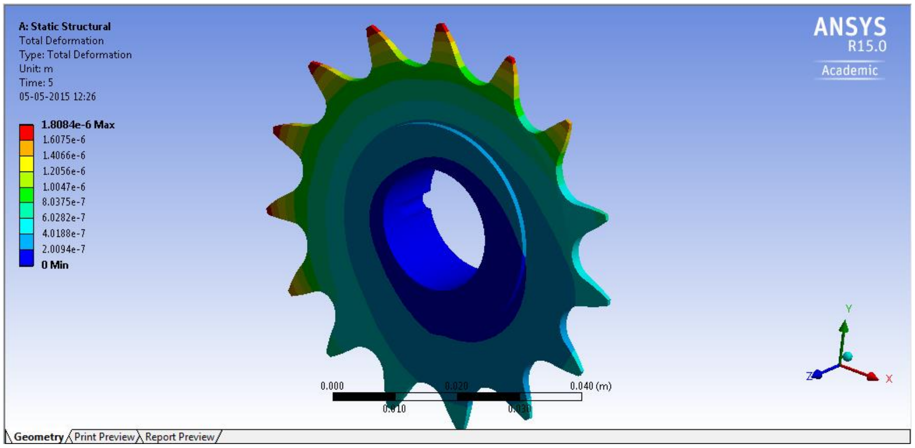


Fig.7.16. Total deformation

From the above pictures we can see:

- Maximum stress = 17.26MPa
- Maximum strain = 1.2e-4
- Minimum FOS = 11.993
- Maximum deflection = 1.81e-6m

The above data show that the design if the front sprocket is completely safe and there is no chance of any kind of failure.

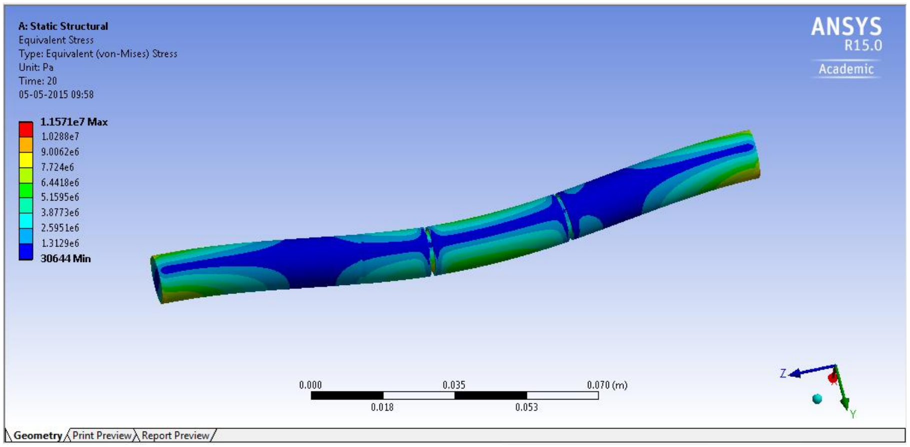
7.4. Central Shaft:

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 this parts life this part has been made of Stainless Steel SS304. Forces acting on the shaft:

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

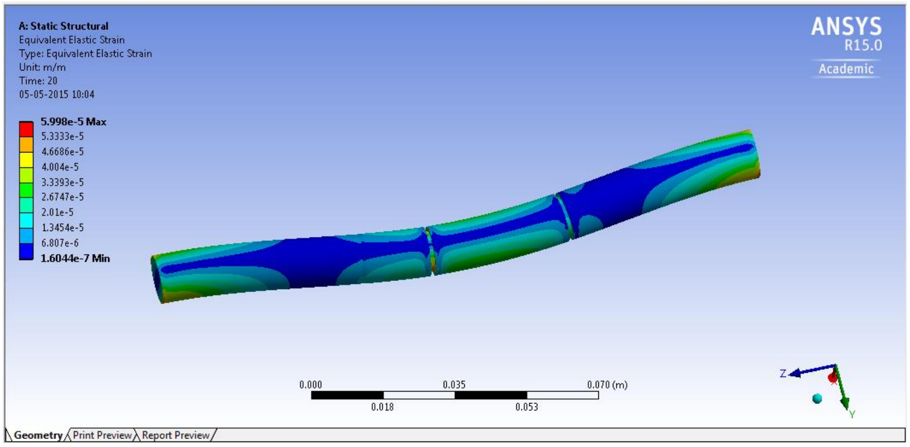
Structural supports:

- Two end point fixed supports



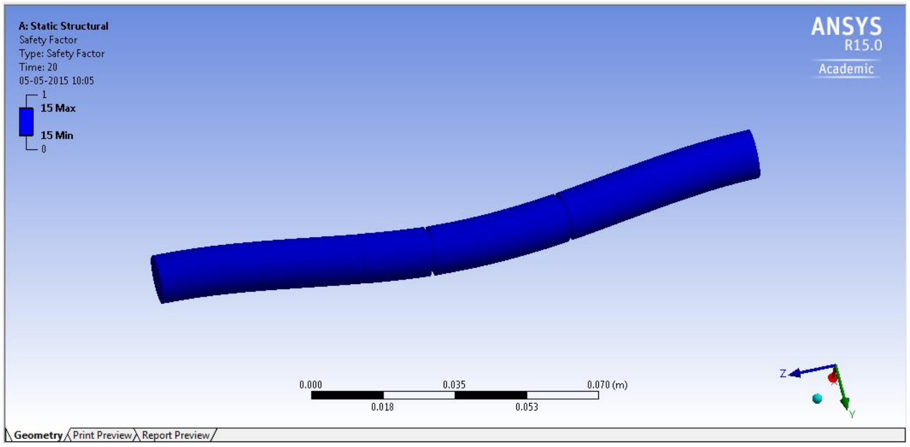
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 20
05-05-2015 09:58

Fig.7.17. Equivalent Stress



A: Static Structural
Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: m/m
Time: 20
05-05-2015 10:04

Fig.7.18. Equivalent Elastic Strain



A: Static Structural
Safety Factor
Type: Safety Factor
Time: 20
05-05-2015 10:05

Fig.7.19. Factor of Safety

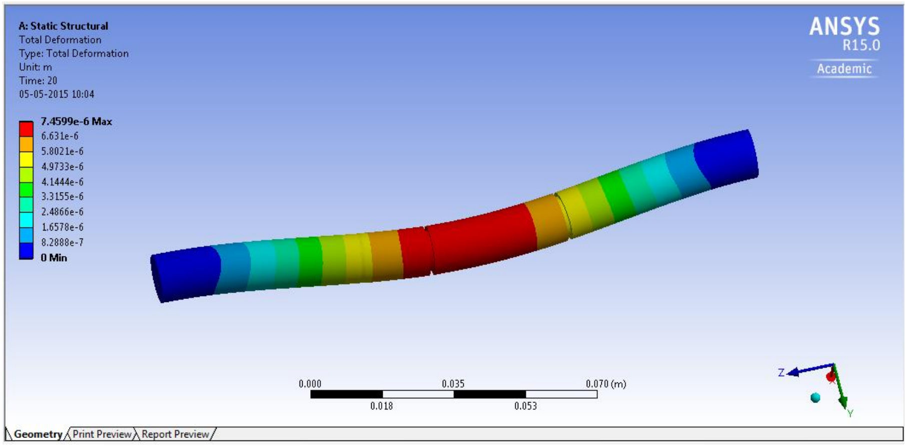


Fig.7.20. Total deformation

From the pictures above we can see:

- Maximum equivalent stress = 11.57MPa
- Maximum equivalent strain = 5.998e-5
- Minimum FOS = 15
- Maximum deformation = 7.46e-6m

From the above data it is clear that the design of the shaft is completely safe.

7.5. 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:

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

Structural supports:

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

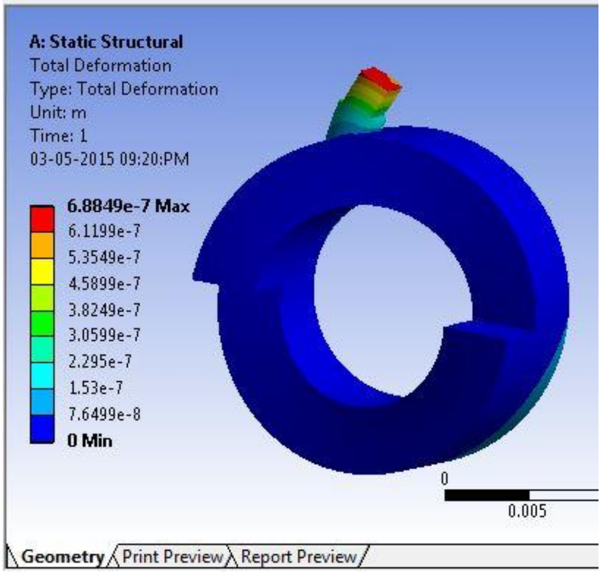


Fig.7.21. Total deformation

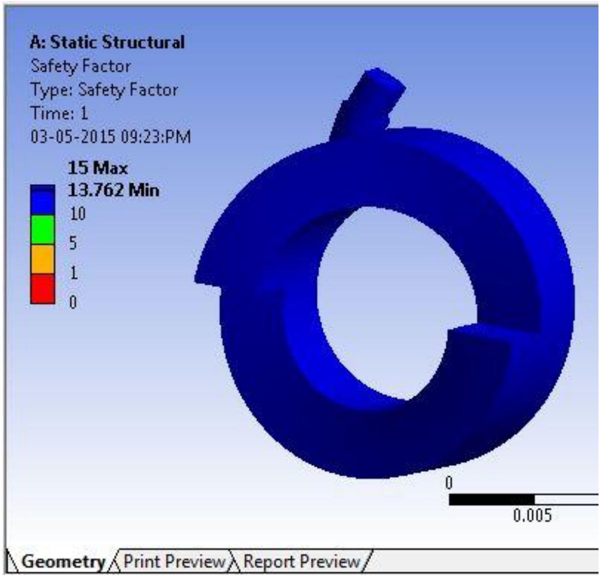


Fig.7.22. Factor of safety

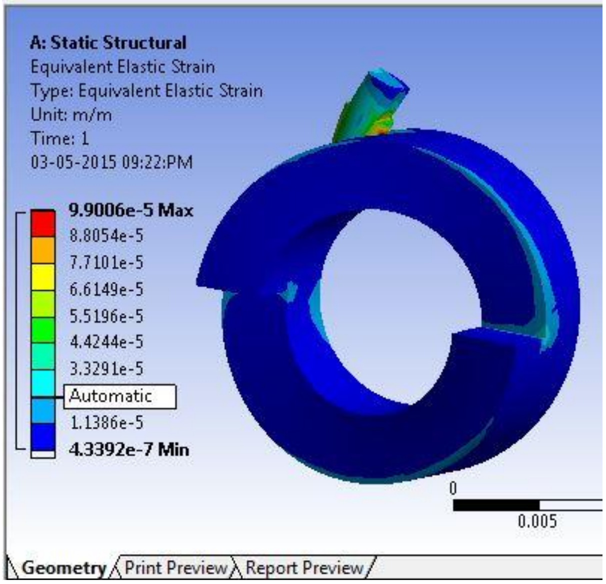


Fig.7.23.Equivalent elastic strain

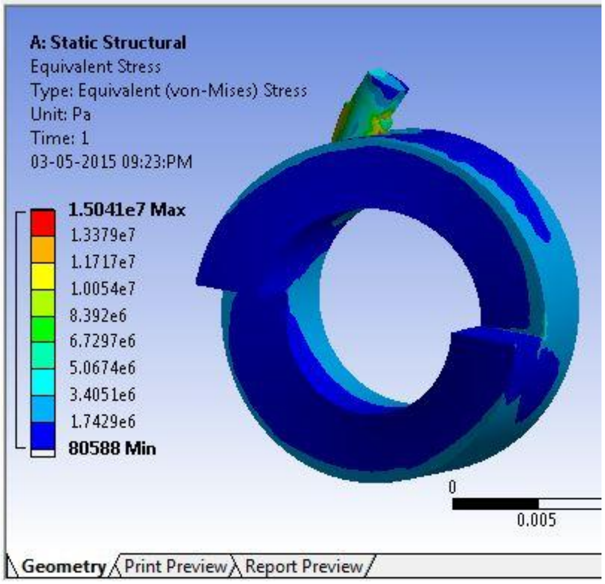


Fig.7.24. Equivalent Stress

From the above diagram we can see:

- Maximum equivalent stress = 68.85MPa
- Maximum equivalent strain = 9.9e-5
- Minimum FOS = 13.762
- Maximum deformation = 1.5e-7m

Above data clearly shows that the design is completely safe.

CHAPTER 8

MANUFACTURING PROCESS:

The manufacturing process of each and every model designed in this project has been mentioned below.

Manufacturing process of a single component involves the below mentioned steps.

1. Raw material required.
2. Primary machining
3. Testing and inspection
4. Insulation coating to prevent corrosion

8.1. Flywheel: (Refer to Fig.8.1)

The manufacturing process of the flywheel is easiest of all.

1. Raw material:
    a. Aluminium disk
       Outer Dia. : 26cm
       Thickness : 5.5cm
2. Primary Machining:
    a. Do Facing operation on both sides of the flywheel to bring the surface finish and reduce the thickness to 5cm. Face milling.
    b. Do Drilling with a 12mm drill bit (HSS) at the center of the flywheel.
    c. Then do turning to reduce its outer diameter to 25cm
    d. During turning hold the flywheel with the help of tailstock to avoid any eccentricity. Using mandrel.
    e. Do Boring operation to increase the diameter of the hole to 28mm with a tolerance of -0.05mm up to a depth of 8mm.
    f. Do the same operation on the other side.
3. Testing and inspection:
    a. Go gauge of 12mm
    b. No-Go gauge of 28mm
    c. Go gauge of 27.95mm.
    d. Check the eccentricity using the coordinate measurement machine (CMM).

4. Insulation coating to prevent corrosion
    a. As aluminium is corrosion free no protective coating is required.
    b. No antifriction coating is also require because we want COF to be high between flywheel and the clutch

8.2. Clutch: (Refer to Fig8.2.)

The manufacturing process of the clutch is mentioned below.

1. Raw Material:
    a. Aluminium
    Required amount
    Molten Aluminium
2. Primary machining:
    a. Do the centrifugal casting to get the initial shape
    b. Drilling the central hole with 12mm drill bit with 0.05mm tolerance.
    c. Machining: use cylindrical grinding to get the finishing on the peripheral surfaces.
    d. Do face milling to get the flat finished surfaces.
    e. Do the ball nose end milling to get the straight grooves of 3mm diameter.
    f. Do the grooving operation with the U-shape grooving tool to the circular groove of thickness 1.75mm and depth 1mm.
3. Testing and inspection.
    a. Go gauge of 12mm.
    b. No go gauge of 20mm.
4. Insulation coating to prevent corrosion.
    a. Put DLC (diamond like carbon) coating on the end surface of the cylinder and also in the 12mm groove. It increases the surface hardness to resist wear and at the same time reduces friction significantly.

8.3. Front Sprocket: (Refer to Fig.8.3)

The manufacturing process of the front sprocket is mentioned below.

1. Raw Material:
    a. Stainless Steel cylinder

SS304 stainless steel

Outer Diameter = internal diameter of the sprocket

   b. Stainless Steel Sprocket

      15 teeth

2. Primary machining:
   a. Central drilling with a 20mm drill bit.
   b. Drilling with 3mm diameter drill bit at 3 equidistant points on the inner periphery of the hollow cylinder
   c. TIG welding of the cylinder and the sprocket
3. Testing and inspection.
   a. Go gauge of 20mm.
   b. No go gauge of 20.1mm.
   c. Go gauge of 3mm
   d. No go gauge of 3.05mm.
4. Insulation coating to prevent corrosion.
   a. Put DLC (diamond like carbon) coating on all the surfaces of the front sprocket. It increases the surface hardness to resist wear and at the same time reduces friction significantly.

8.4. Clutch Drive: (Refer to Fig.8.4)

The manufacturing process of the clutch drive is mentioned below.

Its counterpart can be generated in exactly the same way.

1. Raw Material:
   a. Stainless Steel cylinder

      SS304 stainless steel

      Outer Diameter = 2cm
2. Primary machining:
   a. Central drilling with a 12mm drill bit with 0.05mm tolerance
   b. CNC end milling to get the contour.
   c. Helical interpolator can be used to generate the helical surface, for this G code has to be written

    d. If CAM is available with CNC the no need to worry, by simply putting the CAD model in the machine the product will be automatically machined.
3. Testing and inspection.
    a. Go gauge of 12mm.
    b. No go gauge of 12.05mm.
4. Insulation coating to prevent corrosion.
    a. Put DLC (diamond like carbon) coating on all the surfaces of the clutch drive. It increases the surface hardness to resist wear and at the same time reduces friction significantly.

8.5. Central Shaft: (Refer to Fig.8.5)

The manufacturing process of the central shaft is mentioned below.

1. Raw Material:
    a. Stainless Steel cylinder
       SS304 stainless steel
       Outer Diameter = 13mm
       Length = 30cm
2. Primary machining:
    a. Turning operation of the shaft to decrease its diameter to 12mm with a tolerance of -0.05mm.
    b. Grooving operation to make grooves of thickness 1mm and depth 1mm.
    c. The distance between the grooves should be 5cm.
3. Testing and inspection.
    a. Go gauge of 11.95mm.
    b. No go gauge of 12mm.
4. Insulation coating to prevent corrosion.
    a. Put DLC (diamond like carbon) coating on all the surfaces of the Central Shaft. Place markings 1 and 2 near the grooves to represent groove-1 and groove-2.
    b. Groove-1 is the groove on the open side of the flywheel.
    c. Groove-2 is the groove on the clutch side of the flywheel.

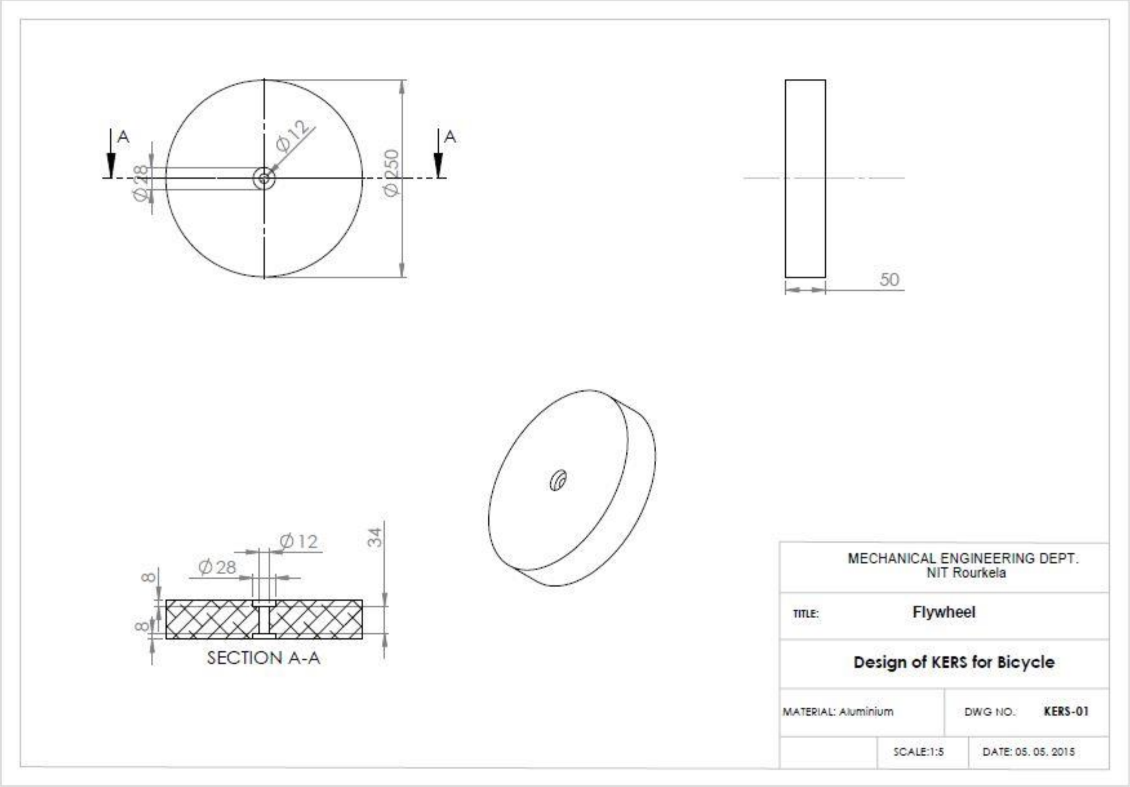


Fig.8.1. Drafting of Flywheel

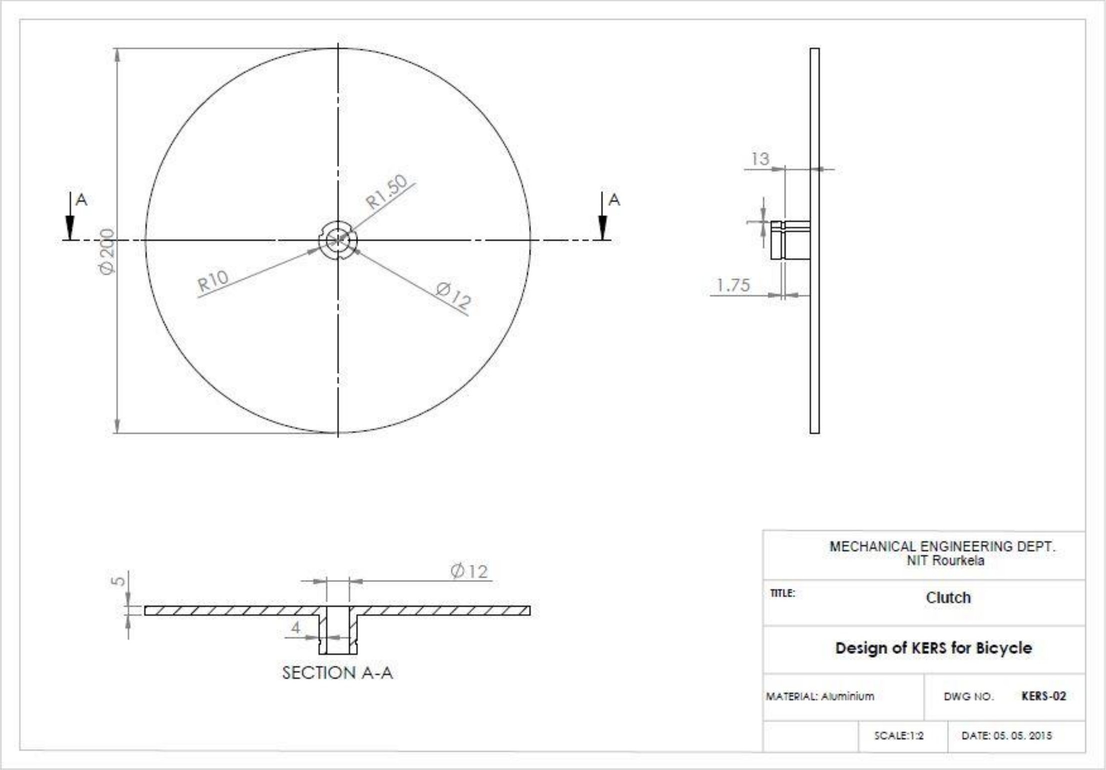


Fig.8.2. Drafting of Clutch

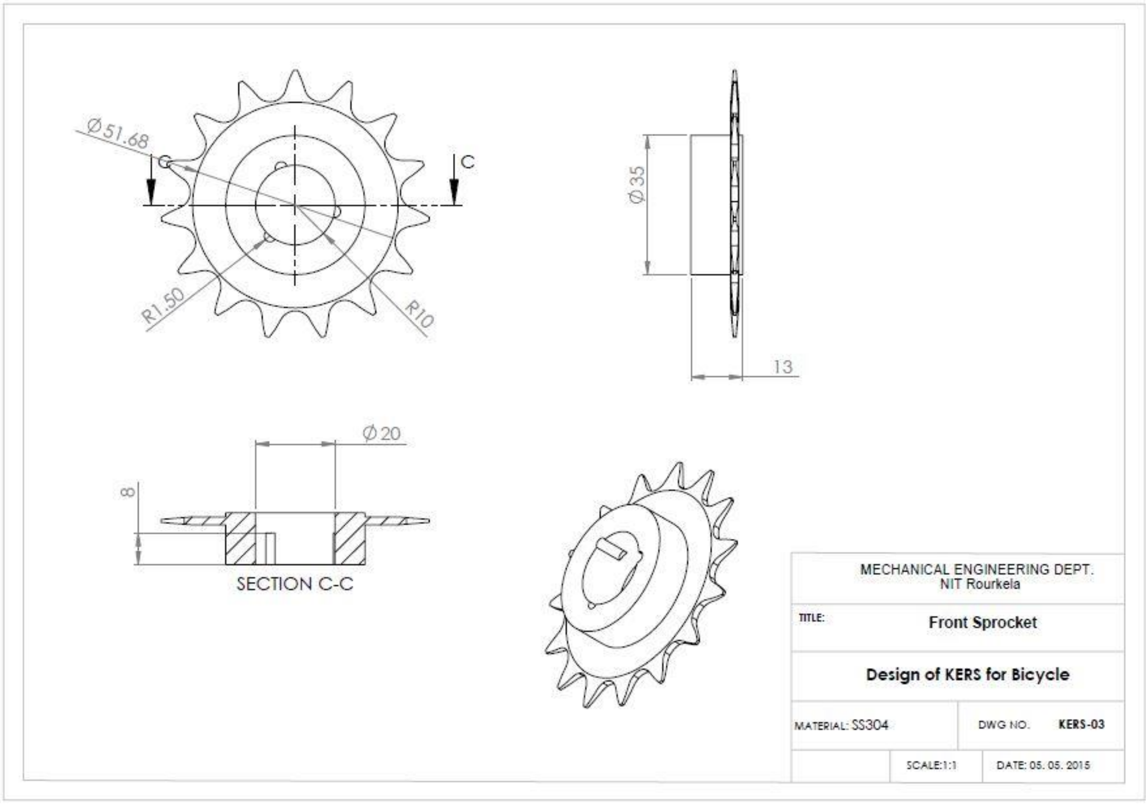


Fig8.3. Drafting of Front Sprocket

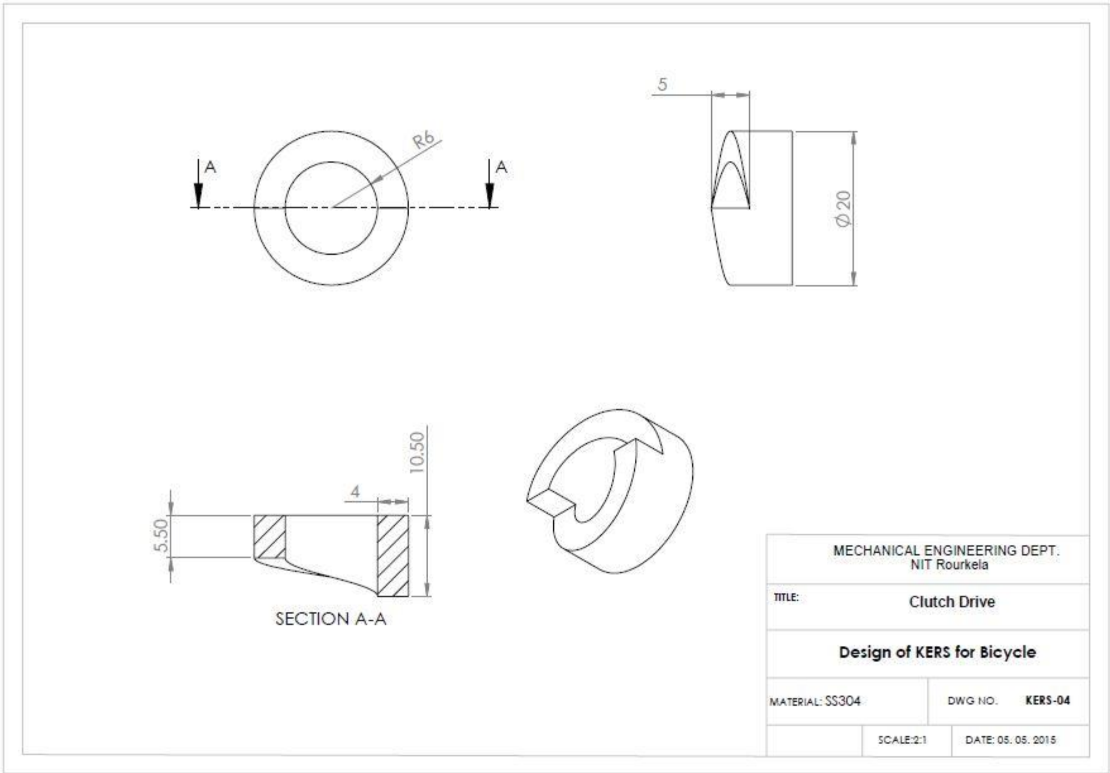


Fig.8.4. Drafting of Clutch actuator

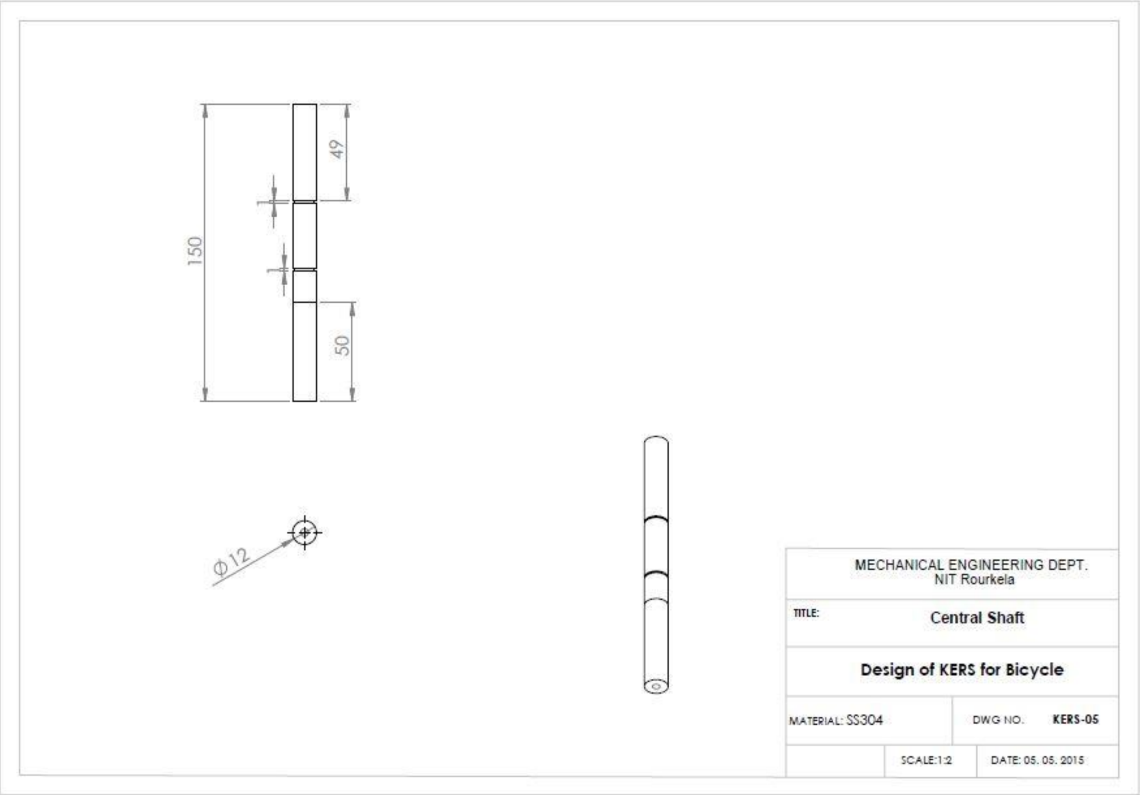


Fig.8.5. Drafting of Central Shaft

CHAPTER 9

ASSEMBLY PROCESS:

The design of this KERS system has been done keeping in mind the ease the assembly process. The design is focused on user friendliness. The assembly process of the KERS system is mentioned below:

1. Take the central shaft and place the C-clamp (IS 3075 NE-11) on the groove-1.
2. Press fit the Ball-bearings (IS 6455 SR-00-12-S) on both sides of the Flywheel.
3. Place the Flywheel bearing assembly after the C-clamp.
4. Place another C-clamp (IS 3075 NE-11) on groove-2.
5. Take the Clutch and place on the ground face down.
6. Place three Keys (Dia. 3mm and length 8mm) in their respective keyways and insert the Front-sprocket aligning its keyways with the Keys.
7. Place a C-clamp (IS 3075 HE-20) on the clutch groove to prevent the Front-sprocket from coming out.
8. Place the Clutch Front-sprocket assembly on the central shaft keeping the clutch plate towards the flywheel.
9. Place the Clutch-drive and its counterpart on the Central-shaft after the clutch assembly.
10. Mount the KERS assembly on the support structure by bolting with the corresponding bolts as the threads made on the shaft.
11. Fix the Clutch-driver counterpart with the mounting either by welding or any other suitable means.
12. Attach the spring and the actuator wire to the Clutch-drive.
13. Attach the multiple gear rear sprocket on the rear wheel.
14. Attach the gear shifter arm as required.
15. Connect the front, the rear sprocket and the gear shifter arm using the chain of required length.

In the figure below the exploded view of the assembly of KERS is shown.

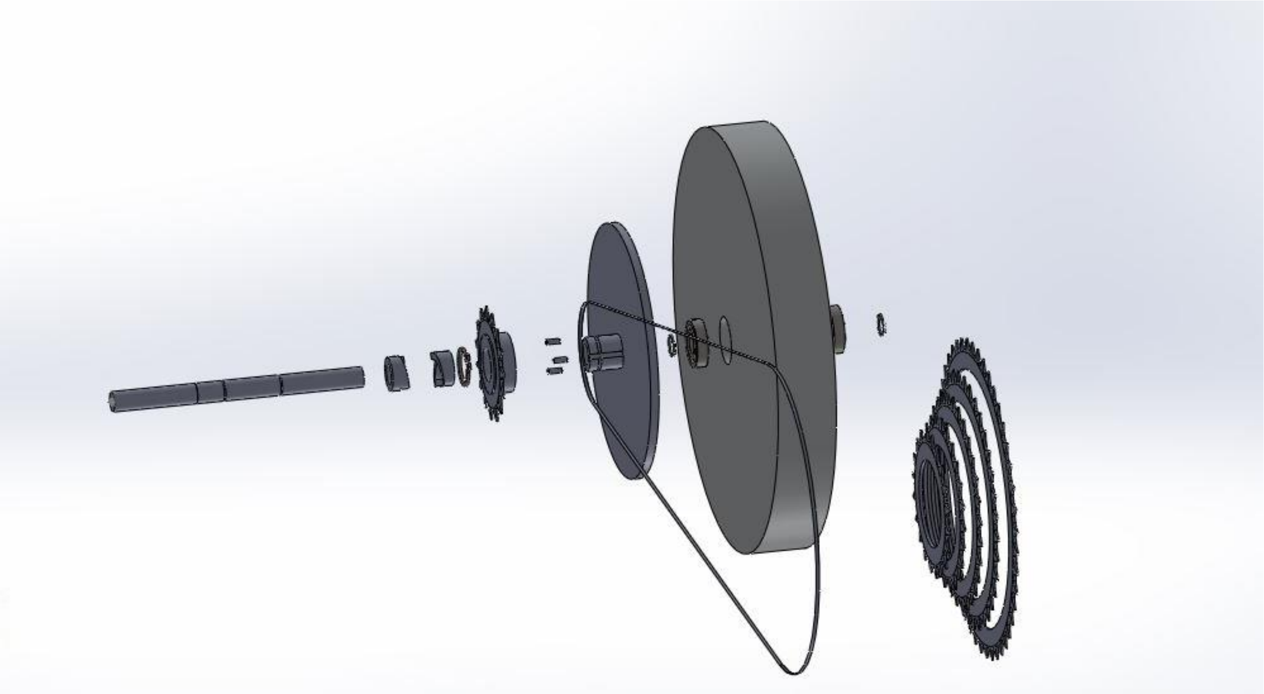


Fig.9.1.KERS assembly exploded view.

RESULTS AND DISCUSSION:

The 3D model of the KERS system is done with optimum precision. The model is simulated in SOLIDWORKS to check its working. Finite element analysis of the components is done to check the products robustness and product life. Initially all the components are designed using aluminium but some components like front sprocket, clutch drive and central shaft faced failure. Thus these are again redesigned with little modification and using SS304. The clutch also faced failure initially but its material is not changed because that will increase the weight, instead it is redesigned again and again to get the optimum design with maximum factor of safety.

CONCLUSION:

In this project a flywheel based KERS system was designed. The product designed in this project is a hybrid of clutch and CVT based KERS systems. This system is expected to be cheaper than CVT based KERS system. Effective and efficient manufacturing procedures for the components of the KERS were also found out. Using FEA analysis the components are tested and modified to avoid failure. This project can guide anyone to fabricate his own KERS system for his bicycle very easily. It was found that all the components were safe under the extreme operating condition. Different types of KERS systems and their uses were also studied. It was found that flywheel can be used instead of battery to store and deliver energy efficiently. As use of flywheel in bicycle is a new concept, this field has a huge scope and wide range of implementation ahead.

SCOPE AHEAD:

This project has a huge future scope. The design in this project can be fabricated. The KERS system can be automated using PID controllers. Instead of using lever arm servo motors can be used. The flywheel weight can be optimised. Multilayer flywheel can be designed using lighter material at the center and heavier material at the periphery. The design of the flywheel can be optimised. Instead of chain drive efficient belt drive CVT can be used to improve the power transmission. Design of a KERS with multi sprocket front sprocket system can be done. This allow the use of even broader range of sprocket ratios and will increase the efficiency. Research work can be done to shift the flywheel to the rear wheel center that will save lot of space and reduce the amount of complexity. Design of the left handle with required mechanical advantage and aesthetics can be done. Design of the KERS housing can be dome. As all the manufacturing procedures for the KERS components are described elaborately in this project can be used to develop a production line for large scale production this product can be brought to the market.

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