Design and Analysis of Self Balancing Two Wheeler

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Abstract: *Lack of stability of a two-wheeler has been a major issue in accidents that happen across India. This paper discusses design and analysis of a self-balancing model two-wheeler using the concept of gyroscopic precession. When the vehicle tilts, it tilts the direction of angular momentum of flywheel and because of the flywheel rotating at high rpm that makes the flywheel precess about a gimbal axis and this precession helps in bringing the vehicle upright in accordance to the law of conservation of angular momentum.. Proceeding with the design, first a 2d model was sketched in FUSION360 and finally a 3d model was made and assembled. Various analysis were done in ANSYS software to optimise our design and get what we actually wanted. The base was made with plywood because that is economical and it helps in absorbing shocks. The point of center of gravity of the two-wheeler was taken into consideration(it should be close to the center of gravity of the flywheel).*

Introduction

According to data published in statistica.com two-wheelers made up a share of about 75 percent of the total vehicle fleet in operation across India in financial year 2019. The majority of accidents that happen in India include a two wheeler and in most of the cases it's because of losing balance by the rider. Needless to say, a lot of investment goes into manufacturing and development of state-of-the-art high technology motorbikes but none can guarantee road safety and it solely depends upon the rider. So it is important to design a bike that could balance itself and ensure the rider's safety.

Self balancing bikes are one of the most awaited technologies in the world right now. Some companies like Honda, Harley Davidson have already shown their success in this concept.In 1903, an Irish-Australian inventor Louis Grennan was first to patent a gyroscopic balancing vehicle. In 1912, Russian inventor Dr.Pyotr Shilovsky in collaboration with Louis Grennan developed and designed a two wheel car with gyroscope sitting in the middle of the body of the car to maintain stabilizing force.

Here in this project too, we will be using the concept of gyroscopic precision to balance the two wheeler. If we see a two wheeler closely, it's nothing but just an inverted pendulum and if we somehow manage to avoid it from tilting and falling to the ground, our task is completed. The flywheel is allowed to move forward and backward about a gimbal axis that generates reactive gyroscopic torque that helps in the balancing of the two wheeler.

What are gyroscopes and how do they work?

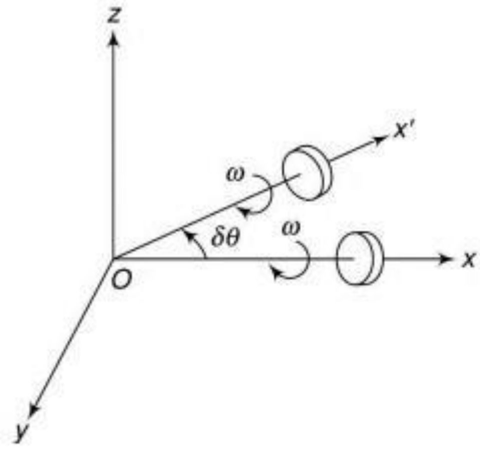
A gyroscope is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself. Suppose we have a spinning body about an axis and if we give an acceleration perpendicular to the axis of spin, an angular acceleration acceleration acts on the body about a third perpendicular axis. This is called gyroscopic motion. And the torque required to produce this acceleration is called gyroscopic torque. Gyroscopes find its application in airplanes, ships, automobiles, spacecrafts etc.

Fig: a toy gyroscope(source:Real world physics problems)

Gyroscopes work on the principle of conservation of angular momentum. Gyroscopes are also based on other operating principles, such as the electronic, microchip-packaged MEMS gyroscopes found in consumer electronics devices, solid-state ring lasers, fiber optic gyroscopes, and the extremely sensitive quantum gyroscope.

A gyroscope consists of a disc spinning about an axis and a gimbal axis that could orient the axis of rotation of the disc in order to produce a reactive gyroscopic torque. The gimbal axis is also called the precessional axis.

Here is the sign convention that could help us to determine the direction of the gyroscopic torque.



Suppose we have a disc that is spinning about the OX axis in an anticlockwise direction as shown in the figure. If we rotate the axis of the rotation by (θ) in OX' direction , it simply means we are applying a torque about the OZ axis(precessional axis) , then a reactive gyroscopic torque will be induced about the OY axis. Had the direction of the spinning disc been clockwise, the reactive gyroscopic torque would have been about the negative OY axis. We can apply the simple rule of multiplication of signs in determining the direction of reactive gyroscopic torque.

Direction of spinning disc	Direction of precessional axis	Direction of reactive gyroscopic torque
positive	positive	positive
positive	negative	negative
negative	positive	negative
negative	negative	positive

Right hand rule can be used to find the sign of the axes. Here we have assumed OX,OY and OZ to be positive x,y and z axes respectively.

Numerically the gyroscopic torque is given by the product of moment of inertia(I) of the disc, its angular velocity(ω) and the precessional angular velocity(ω_p).

Gyroscopic torque( ) = $I^* \omega^* \omega_p$

The application of gyroscopic principles in our project is also similar.

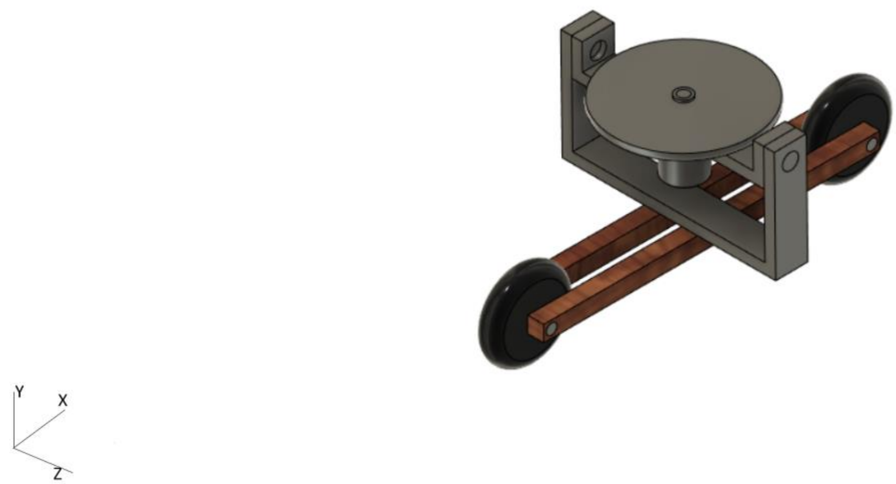


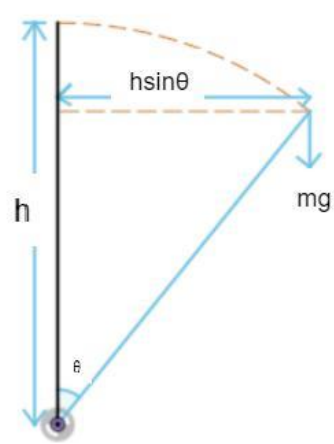
Fig: a 3d model of self balancing bike

Here our flywheel is spinning in an anticlockwise direction i.e. the direction of angular momentum is in the positive y axis. Let's say our bike tilts in the left direction, this tilts the direction of angular momentum of the flywheel as well. Because of the law of conservation of angular momentum, the flywheel wants to regain its original configuration i.e. the direction of angular momentum pointing in the positive y-axis. The tilting of vehicle to the left means a torque applied about positive x-axis. It means in order to balance the bike, a reactive gyroscopic torque should be induced about negative x-axis. According to the sign convention mentioned above, the gimbal should spin about the negative z-axis in order to balance the two-wheeler. Hence the self balancing is obtained.

Designing the model

The model was designed in FUSION360 software. First, a 2d model was sketched which helped in designing the 3d model for the project. Various tests were carried out on ANSYS software to optimise the design and proper selection of materials for the parts. The main part of the bike i.e. Flywheel was made up of mild steel. A flywheel needs to have a large moment of inertia and needs to spin with high rpm to give the self balancing result for the bike. The wheels were made up of rubber and the frames joining the wheels were made up of plywood because it would help a lot in absorbing shocks. The gimbal frame was also made up of mild steel as has the responsibility of supporting the heavy flywheel.

Mathematical modelling of bike



Here h is the point of center of gravity of the bike and its mass is m. When it is tilted by an angle θ a torque is induced

$$= mghsin\theta \quad \text{-------------------------} \quad (1)$$

In order to balance this torque, a torque should be produced which is equal in magnitude and opposite in direction to the induced torque and this task is accomplished by the reactive gyroscopic torque which is given by

$$\text{Gyroscopic torque} = I*\omega*\omega_p \text{----------------------} \quad (2)$$

Where I = moment of inertia of the disc

ω = angular velocity of the disc

ω_p = precessional angular velocity(angular velocity of the gimbal)

Both of these torques should be equal

$$mghsin\theta = I*\omega*\omega_p \text{---------------------------} \quad (3)$$

Therefore,

$$\omega_p = mghsin\theta/(I*\omega) \text{----------------------------}(4)$$

Calculation processes

Let us assume the following parameters

Mass of wheels = m_w

Mass of frame(wooden part) = m_{fw}

Mass of frame(steel mart) = m_{fs}

Mass of flywheel = m_f

Mass of gimbal = m_g

Mass of motor = m_m

Let 'h' be the variable that represents the height of center of gravity of these components with the same subscripts as have been used to represent masses

Height of COG of wheels = h_w

Height of COG of frame(wooden part) = h_{fw}

Height of COG of frame(steel part) = h_{fs}

Height of COG of flywheel = h_f

Height of COG of gimbal = h_g

Height of COG of of motor = h_m

Now

Height of COG of the two-wheeler(H) = $(m_w * h_w + m_{fw} * h_{fw} + m_{fs} * h_{fs} + m_f * h_f + m_g * h_g + m_m h_m)/M$

Where, M = mass of the whole body = $m_w + m_{fw} + m_{fs} + m_f + m_g + m_m$

Using our relation,

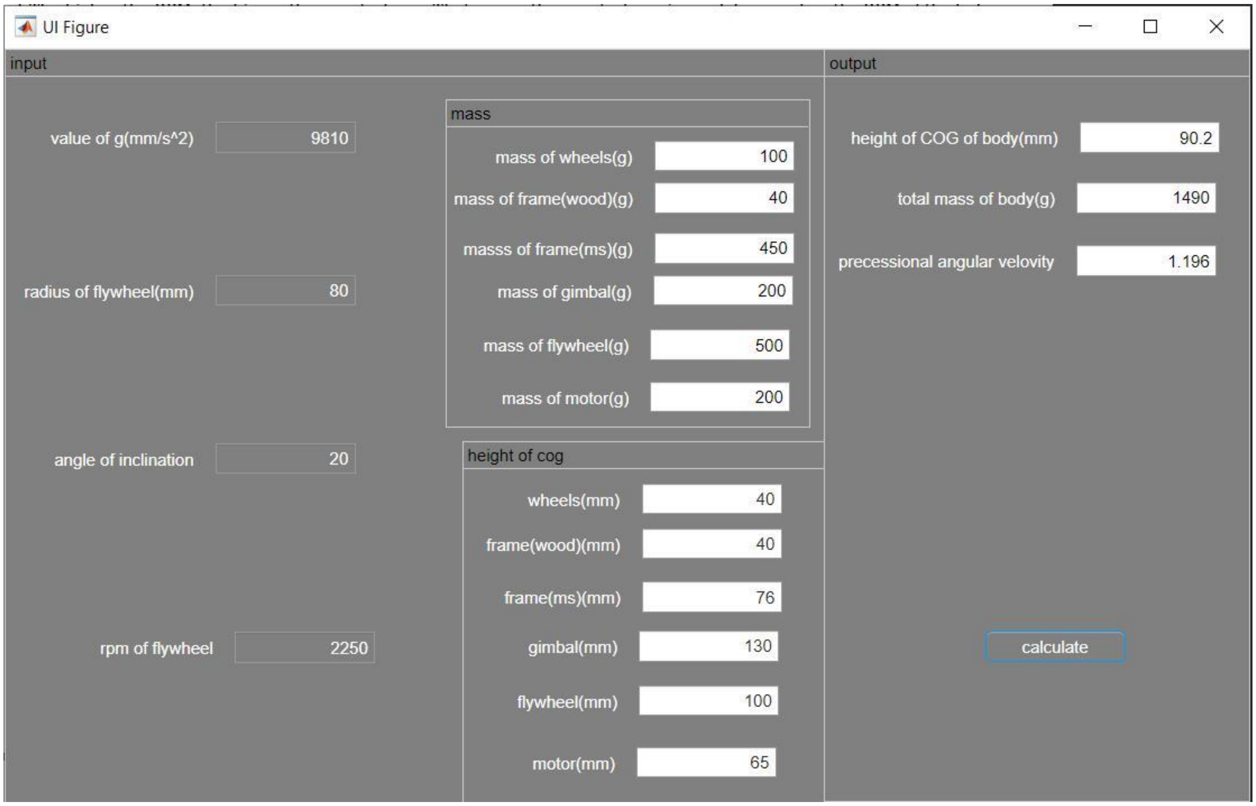
$$MgHsin\theta = I*\omega*\omega_p$$

Here ω is the angular velocity of the flywheel which can be calculated by $\omega = 2\pi N/60$ Where, N = rpm of the flywheel,

Θ is the angle of tilt for which we will design the two wheeler, 'G' is the value of acceleration due to gravity

And I is the moment of inertia of flywheel which can be calculated by $I = (m_f{*}r^2)/2$

To optimise the design of the two-wheeler a GUI was made in MATLAB so that we could select the appropriate mass of the flywheel and rpm of motor by performing many iterations.



Here the total mass of our self balancing bike came to be 1490 grams and the center of gravity was 90 mm from the base. A precessional angular velocity of 1.196 rad/s^2 can balance the bike. This bike is designed for a maximum tilt of 20 degrees.

Static analysis were performed to determine whether our(wooden) frame can stand the heavy load of gimbal,flywheel and the motor.

To test the strength of the materials under static load, the finite element method analysis of all the chassis components was done. It helped to understand the limitations of the design and further advancements were made to optimise the design.

Gimbal

The gimbal is responsible to hold the weight of the motor and the flywheel. So it should be strong enough to withstand the stress without getting deformed to a dangerous degree. Here the equivalent stress and the total deformation has been shown scaled to 2e03 factor of actual deformation.

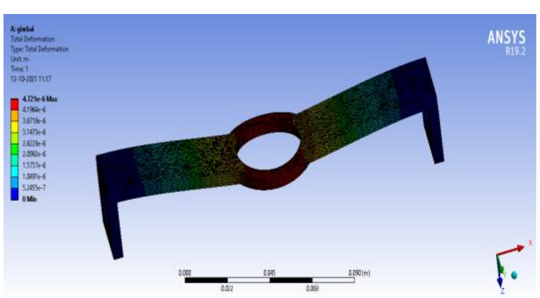


Fig: total deformation

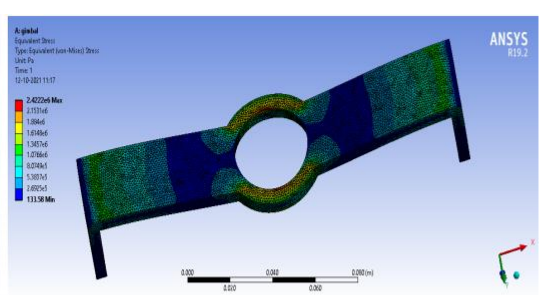


Fig: equivalent stress distribution

Wooden frame:

The base of the frame is made up of wood as it is good at absorbing shocks. The wood is responsible for withstanding the load of flywheel,motor, and steel part of the frame. So it should be strong enough to do its job and not break in between. Below is the simulation which shows how the frame would behave when applied to the given load. The deformation is scaled to 6.3e02 factor of the actual deformation.

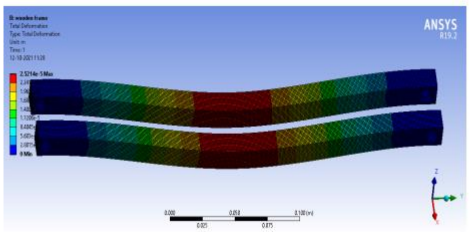


Fig: total deformation

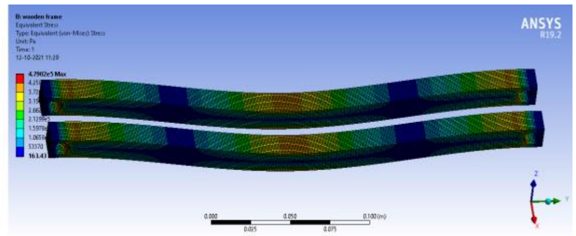


Fig: total stress distribution

Analysis result:

From the analysis that we performed, the maximum deformation, the equivalent stress distribution of both of the components were tabulated and analysed weather they satisfied our design criteria i.e. not deforming to a harmful degree.

Part name	Deformation(m)	Equivalent Stress(Pa)
Gimbal	4.721e-6	2.422e6
Wooden frame	2.52e-5	4.79e5

Conclusion:

A self-balancing two-wheeler was thus designed which requires the flywheel to spin at 2250 rpm for balancing. If we have a need to go from one place to another, we choose either a car or a bike. There is no need to self balance in cars but for bikes this concept of balancing by a gyroscope becomes very vital. Gyroscopes are used for balancing purposes in airplanes. The entire idea of the project was to validate the same point. The same idea was used in the design of gyro-x cars that were made in the 1960s. The vehicle we designed is able to balance itself for a tilt of 20 degrees.

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