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Design and Fabrication of Self Balancing Two-Wheeler Model Using Gyroscope

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ABSTRACT

Self-balancing two wheeler using gyroscope finds its application in the field of road safety. The need for a system to balance a two wheeler irrespective of its motion is on the high. Gyroscopes findits application in other stabilizing systems such as stabilizers in ship and in flight control of aircrafts. We have incorporated the same principle to a two wheeler. In the current study we have designed a self-balancing two wheeler using gyroscope that consist of a flywheel, a floorboard, battery, 2 DC Motors, 2 sets of bearings, 2 sets of wheels and a voltage control unit. The 2D sketch of the model was prepared. Then the model was designed in 3D using Sketch Up and Solid Edge. Analysis and testing of the flywheel was done using ABAQUS software. To make it more economic and efficient, we had introduced a floorboard made of plywood instead of other metals as wood is a better absorber of vibrations and shocks. Then the gimbal frame is bolted to the floorboard and the flywheel is attached to it. Fabrication of the two-wheeler was completed and tested for stability. By incorporating the principle of gyroscope the two-wheeler was made to self-balancewhen it is subjected to a tilt.

Keywords

Self-balancing, Gyroscopes, floorboard, Fabrication

INTRODUCTION

In recent times there has been an explosion in the sales of motorcycles globally. In India alone the sales has been reported to be about 16.4 million units in the financial year 2015-16 which is a growth of over 3% from the same month in previous year 2014. The number of motorcycles sold from 1995 to 2005 is about 117.65 million units. Due to this huge demand, a lot of the investment goes into motor racing (High capacity engines) and in the development of state of the art high technologies such as ride by wire technology, multilevel traction control, slipper clutch etc. On the contrary even though motorcycles have been manufactured for so long, they tend to exhibit damped oscillatory behavior and go unstable under certain conditions namely high speed, rider error, faulty component etc. The increase in number of accidents due to this unstable nature is on the high. The development of a system is necessary to overcome this problem which can stabilize the motorcycle at any worst case scenario.The total number of two wheelers sold in the country in the fiscal year of 2016 is 7,016,971 units. However the safety features introduced in the two wheeler industry has remained the same for over the past two decades. A rider is very much vulnerable to mishaps and accidents of the road. Statistics show at least 200 accidents related to motorcycles happens everyday according to the Ministry of Road Transport and Highways. The loss of balance of the rider may be due to 1. varying road conditions 2. negligent and rash driving 3. drunk driving 4. speeding and 5. overloading are found to be the major reasons for these accidents. Our project enhances the two-wheeler with a safety feature where a rider can remain balanced at all times subjected to varying tilts and vibrations. This is achieved by utilizing the principle of a gyroscope in a two wheeler.

Designing and fabricating a motorcycle that is self-stabilizing was always challenging. In the present day market there are a few motorbike models that are self-stabilizing but are either not very efficient or is too costly. As our aim is to design and fabricate a self-stabilizing two wheeler that is both efficient and cheap, we always considered the most simple design and components.

The following are the major reasons to use a gyroscope for the stabilization of the two-wheeler –

• They make really smaller stabilized system

• They impart greater stabilization

• They are accurate and easy to understand

Gyroscopes are the real world manifestations of the law of conservation of angular momentum. They spin and tip and precess due to change in the torque applied with respect to the spin axis. Using the right hand rule, one can easily determine the direction of torque. Curling your fingers over your fist in the direction of the spin, the thumb will show the direction of the torque. Gyroscopes also exhibit smooth balancing and accurate analogue readings as they adhere completely to the conservation of angular momentum i.e. they conserve the magnitude as well as the direction in the absence of an external torque. The spin axis is always moves in the same direction as that of the applied torque. The gyroscope can be used to maintain physical stability when the input and output are perpendicular to the spin axis. It is to be noted that gyroscope is a inertial system. The gyroscopic sensor gives an output with reference to its original position and this information is then fed to the control system which is then used to keep a desired level. This is an effective method to self-balance the two-wheeler. The increased rate of accidents and need for safety features have led us to formulate the problem. The problem identified for our project is to design and fabricate a gyroscopic balancing two wheeler which is stable and self-balancing.

LITERATURE SURVEY

Motorcycles have existed for almost a 100 years and bicycles even longer yet we fail to fully understand the forces acting on it and how they work together to keep a bicycle upright once it is non-stationary. When the bike is in motion, disturbances can occur wherein which at high speeds the bike may experience low frequency weaving. On the other hand, at low speeds the bike undergoes high frequency wobbles[1]. The concept of gyroscope can be implemented in the optimizing the control parameters to obtain a smooth flight control even for a two degree freedom helicopter. The disturbances incurred to the system during flight may be because of the inertial forces of the chassis and inaccuracies in control parameters implemented in the electronic control systems [2].It can also be used to identify configurations that can help us obtaining most stability for a self-balancing bicycle, the simulationof self-balancing bicycle using a single gyroscopesystem and double gyroscope system (moving in the same direction) was done to find theoptimal values for turn rates[3].The centripetal force experiencedby riders taking turns can be balanced by leaning slightly toward the center of the turn.The more the velocity more is the rate of lean. In certain cases the mass of the object (such as a pillionrider) and the trail of the front wheel might disturb the stability and will then show unstable roll behaviour. In such cases, applying torque to the handle bars can be very helpful[4].The axis of rotation if perpendicular to the direction of motion causes a fictitious forcecalled the Coriolis force. It causes transfer of energy along frames of reference.The LaGrange method can be utilized to arrive at a standard frame of reference thereby simplifying the analysis involved, and also to manipulate roll angle forUnmanned vehicles[5].But when using lean to steer mechanism it is crucial the resistance to the handle bar beaccentuated as to allow discrete steps in bending forward/backward by the rider failing to do so mightresult in faulty steering mechanisms that can seriously under-perform [6]. A PID controller can be used to measure displacementsof the CMG, the vehicle and angular velocities, which then can be fed to the control input. Thesimulations then will show a two second transitioning period which can be reducedby tuning but doing so will generate oscillations. Practical testing does not seemto agree completely due to inaccuracies in gimbal motor encoding[7].DC motors are predominantly used as they have least starting time and also high initialtorque which are required for smooth transition response and quick stabilization ofvehicle. Also efficiency and light-weight of an electric motor puts it ahead of all otheractuators. And thus can be used to study and fabricate a self-balancing two wheeler and to experiment the different effects of torque it has onthe flywheel[8]. Expensive electronic used in bikes these days can be eliminated by using lean-to-steer mechanism instead of electronic guidance. The operation requires a rider to lean to direction of the turning until the turning is complete. This cuts down the manufacturing cost and opens self-stabilizing vehicles like Segway PT to the Indian market so that use for it in industries and personal use can be justified[9].A stationary bike can be balanced by applying torque in the opposite direction i.e. controllingthe handle of the bike. This can be done by using counter-rotating wheels, mass distribution, etc.[10].The tilt angle measured by a gyro integratedwith accelerometer sensors can be used to give the angle of tilt as output with least errorthan when used independently. A PID controller can beemployed to remove the noise fromthe system and to dampen wobbles. Since real time data output is sent to the microcontroller[11].A flywheel can be compared to that of a capacitor in the sense it stores rotational energyand releases it after certain specified rotations. At instances of high rpm the flywheelcan deform whereas at low rpm it would not give the two-wheeler the required "lift" to stabilize.Mild steel iron can be used as it is resistant to deformation under the range of momentof inertia required[12].The all-silicon single-wafer technology method can be utilized for the fabrication of a high aspect ratio (20:1) poly-silicon ring gyroscope. Vertical electrodes can produced of electrically isolated nature with various air size gaps rangingfrom sub-microns to tens of microns. Using HARPSS technology provides featuresthat are able to reach high performance. Electronic tuning is an attractive feature of thevibrating ring gyroscope. Any frequency mismatch between the sense and drive modesthat occur during the fabrication process can be electronically compensated using thetuning electrodes around the structure[13].A Piezoelectric vibrating disc gyroscope based on the Coriolis system, which requires lesser power consumption, short start up time and low operational noise can also be utilized. An assembly made using stepper motor can be used to validate the piezoelectricvibrating gyroscope. There is a transfer of energy from drive mode to the sense modeduring operation and this transfer of energy provides a measure of the applied rotationrate [14]. Gyroscopic equations can also be employed for the design and fabrication of seat less electric unicycle. The vehicles aredriven by a brush-lessDC motor monitored by a micro-controller. The main advantages of such a unicycleare good efficiency and pollution control. DC Motors of brush-less types are found tohave better weight, precise and accuracy control alongside with good firm response.In the long run they have high dependability,maintenance free and greater efficiency.Instead of standard 12v batteries, Li-ion batteries were used which are very efficient andprovides a good assistance to the motor [15].

In the current study we have designed and fabricated a self-balancing two wheeler which is stabilized with the help of a gyroscope. Study was done to check the flywheel's motion about the gimbal frame. A detailed study was focused on the ideal placement of the rotor and flywheel to the frame. The study has been done by taking various factors into consideration. The mass of flywheel and the speed of rotation was varied to obtain a optimum result. Thus a stabilized model of gyroscopic stabilized two wheeler was made.

PROJECT METHODOLOGY

2D model sketch is made according to the dimensions. With the help of 2D sketch, 3D model is made in Solid edge and Sketch up. The design was subjected to analysis and defects were scrutinized. Different stresses acting on the components were found out. Accordingly the components required for the model is bought and tested. The base was made from the wooden plank and slots were cut to accommodate the wheels according to the 3D model.Rubber wheels were attached at the front and rear ends on the slots made with the help of screw and bolt.They are arranged in such a way to enable free forward and backward motion.A motor (DC motor) is attached near to the rear wheel with the aid of a driving mechanism (belt driven) in order to drive the rear wheel.Supporting frame is fabricated out of the Perspex acrylic according to the dimensions. Suitable mild steel frame is tooled, by measuring the distance between two supporting frame.The assembly of the GIMBAL frame is done by combining the mild steel A36 and Perspex acrylic sheet, to which the main driving motor and flywheel is fixed, which has free axis of rotation and allows precession.A 12v DC battery is connected to both the motor by the aid of connecting wires and was mounted on the base frame. A voltage regulator which is connected between the battery and the motor is monitored and the rpms were calculated.The gyroscope two-wheeler was fabricated and tested for stability. Calculations and analysis were carried out based on the output which was obtained from the model.

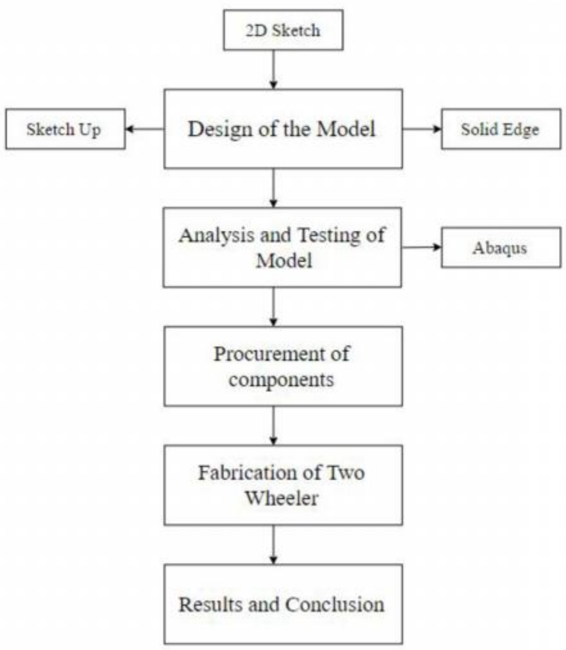

Fig 1:Flow chart of methodology

1. FLOORBOARD

Table 1. Specifications of the floorboard

FLOORBOARD CHARACTERISTICS	ABC FLOORBARD
1.Material	PLYWOOD
2.Thickness	2.5 CM
3.Length	40 CM
4.Breadth	6.5 CM

2. BATTERY

Table 2.Specifications of the battery

Battery Characteristics	ABC Battery
1.Battery type	Valve-regulated lead acid
2.Voltage	12v
3.Maintenance type	Free
4.Dimensions (L x W x H)	97 x 43 x51mm
5.Weight	0.56kg
6.Nominal capacity	1.20mAh/20hours
7.Rated Capacity	1.10/10, 1/5 and 0.75mAh/1 hour
8.Container Material	ABS Material
9.Terminals	Silver-coated copper terminlas (T1 and T2 terminal)

3. A DC MOTOR

Table 3.Specifications of the DC motor

Characteristics	**CSES DC Motor**
1.DC SUPPLY	4 to 12 v
2.RPM	30 at 12v
3.Total Length	46mm
4.Motor Diameter	36mm
5.Motor Length	25mm
6.Brush Type	Precious metal
7.Gear head diameter	37mm
8.Gear head length	21mm
9.Output shaft	Centered
10.Shaft diameter	6mm
11.Shaft length	22mm
12.Gear Assembly	Spur
13.Motor Weight	100gm

RESULTS, DISCUSSIONS AND CONCLUSIONS

MODELING, ANALYSIS & DESIGN

2D Modeling of Two Wheeler

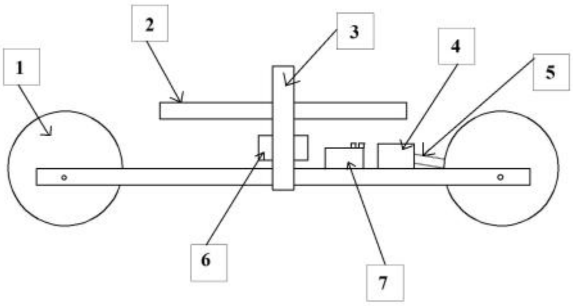

Fig 2:2D Sketch of a two wheeler

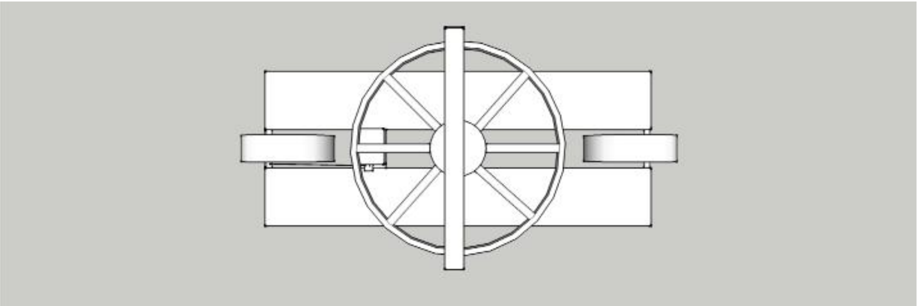

Fig 3: Top view of the two wheeler in 3D(Top View)

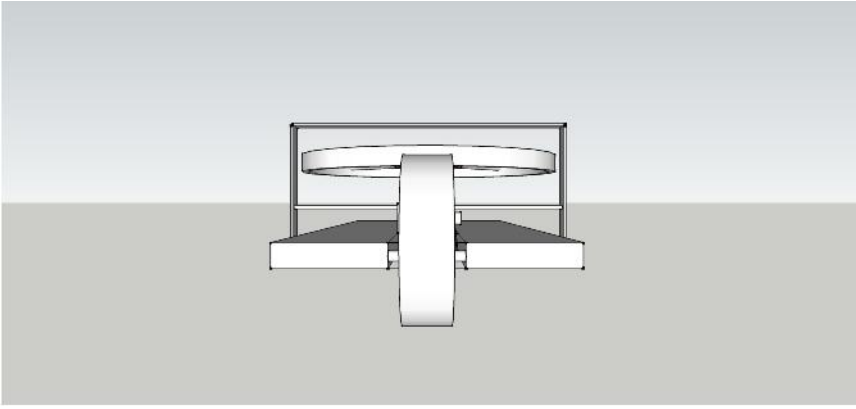

Fig 4: Front view of the two wheeler in 3D (Front View)

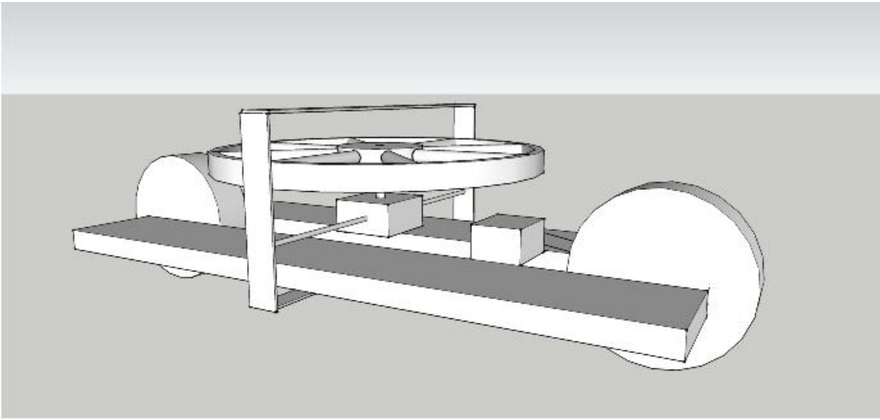

Fig 5: Isometric view of the two wheeler in 3D (Isometric View)

Calculations and Dimensions of the Model Two Wheeler

Dimensions of Different Parts of the Self Balancing Two Wheeler

Torque Calculation for the Model

Weight of flywheel = .04kg

Frame weight =

Base weight including batteries = .942kg

Therefore, total weights = .912kg

Coefficient of friction between surface and wheel = 0.3

Torque required = Coefficient of friction*Friction Force*Radius of wheel

$T = \mu \times f \times R$

$T = 0.3 \times 1.01\times .02$

T = .00606 Nm approx.

To Find Out The Required Actual Speed of the Flywheel

Consider the model two wheeler remains stable at the speed of 18 km/hr or 5m/s.

Diameter of wheels = 4cm

Therefore the rpm of the wheels at this speed,

$$\frac{\pi.}{60}$$

$$5 = \frac{\pi \times .0 \quad \times N}{6}$$

N = 2500 rpm approx.

Moment of inertia, $I = M \times K^2$
M = 0.07kg , K = .04/2 = .02m
$I = .07 \times .02^2$
$I = .000028\ kgm^2$

Angular Velocity,
$\omega = \frac{2\pi}{6}$
$\omega = \frac{2\pi \times 2}{6}$
ω = 261.79 rad/s

Therefore, Angular Momentum,
L = I×ω
L = .000028×261.79
$L = .00733\ kgm^2/s$
Flywheel,
D = .08m
M'= 0.175kg
Therefore moment of inertia,
$I' = \frac{M' R^2}{2}$
$I' = \frac{0.1 \quad \times .0 \quad ^2}{2}$
$I' = .000035\ kgm^2/s$

Comparing with the initial angular momentum,
L = I'×ω'
.00733 = .000035× ω'
ω' = 209.42rad/s
$\omega' = \frac{2\pi \quad '}{6}$
$209.42 = \frac{2\pi \quad '}{6}$
N'= 2278 rpm

To Find Out Reactive Gyroscopic Couple
The flywheel should be rotating at above speed in order to be stable. Assume the model two wheeler tilts by 15 degrees at 2278 rpm.

$\omega' = \frac{2\pi}{6}$

$\omega' = \frac{2\pi \times 2}{6}$

ω' = 238.55 rad/s

Total mass = .912kg

Assume that two wheeler tilts by 15 degrees from the vertical axis.

F = Mgsin15˚

F = .912×9.81×sin15˚

F = 2.31N

Now angular velocity of precession,

$\omega_p = \frac{T}{L}$

$\omega_p = \frac{0.0}{.0}$

ω_p = 49.604rad/s

Reactive gyroscopic couple is given by

C = I× ω' ×ω_p

C = .00733×238.55×49.604

C = 86.7kgm^2/s

This couple will cause the two wheeler to tilt to the right. To compensate this couple,we will have to apply the active gyroscopic couple i.e. forced precession so that the two wheeler is balanced.

Actual Work

The following figure shows the isometric model of the finished model

Fig 6: Isometric view of finished model

This paper deals with two main aspects of a self-stabilizing two-wheeler. They are :

1. The speed of rotation of flywheel required to achieve stability
2. The mass of flywheel to produce required gyroscopic effect

A trial-and-error method on different flywheels driven at varying velocities gave an appropriate range of mass and velocity required. An optimum solution was found to be the intersection ofthese two variables. A heavy

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flywheel leads to wobbles at the base of vehicle whereas a light flywheel did not possess the power to produce the effect and drag accompanied. A medium mass flywheel with high inertial resistance is seen to be most fit. A low velocity spin produces vehicle unbalance to the sides. It was found that a medium to low velocity spin is the most desirable.

Test Matrix

Test was conducted on the two wheeler to check it's self-balancing capacity under various rpm supplied to the flywheel. The optimum rpm was established through manual trial and error method. The maximum work load capacity of the flywheel is also found out. The following observations were noted:

• The mass of flywheel used was .04kg.

• The mass of the vehicle model was .912 kg.

• The minimum speed of flywheel at which the gyroscope was able to stabilize the vehicle was2500 rpm.

• The model was found to stabilize by itself at 2500 rpm at a weight of .912kg.

Table 4.Test matrix of Model

SL NO.	RPM	Observation
1	1000	Self-balance is not achieved
2	1500	Self-balance is not achieved
3	2000	Self-balance is achieved with minor tweaks
4	2500	Self-balance is achieved and model is stable
5	3000	Self-balance is not achieved
6	3500	Self-balance is not achieved and the connection between flywheel and motor is found to be weakened
7	4000	The flywheel is disassembled from the rotor shaft, compromising the entire structure

ABAQUS Analysis

The following figure shows the ABAQUS analysis of the flywheel rotating about theDC Motor.

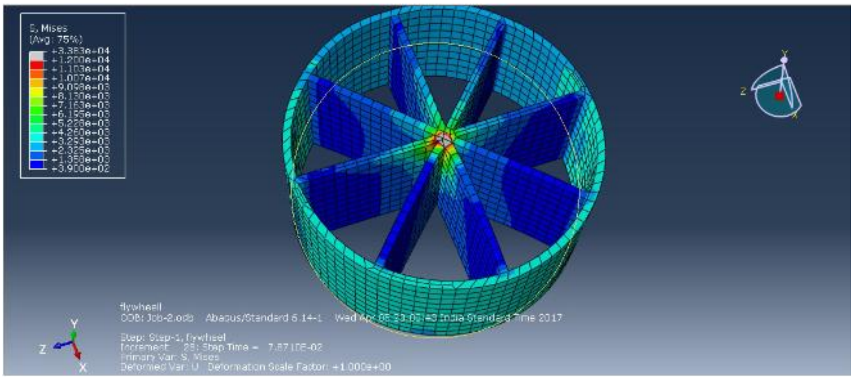

Fig7: ABAQUS Analysis

The simulations results that which is obtained for the model by the application of one centrifugal force and the boundary condition as central is depicted in the figure. The stress was computed by averaging the stress elements at the centre of the flywheel. It is clear that the stress tends to be maximum at the centre axis according to the figure.

The following conditions were used in order to attain the results as follows:

Table5. Analysis of Flywheel

Characteristics	FLYWHEEL
1.Material used	ABS Plastic
2.Density	1052 Kgm^3
3.Young's Modulus	2×10^6
4.Poisons Ratio	0.35
5.Force	100N

Bolting down of gimbal frame to floorboard was found more efficacious than welding or gluing. Vibrations and oscillations found in the gimbal axis during operation is reduced drastically. Connecting the flywheel to motor required a motor with long shaft. Although motor with shorter shaft yielded the same results, the flywheel tends to move out of position over long working hours under required rpm. Adjustments in bearings were made to make sure the flywheel is allowed to rotate freely. Moment of inertia about the motor and moment of inertia about the flywheel needs to be same for optimum operation without oscillations Since a gyroscope is an inertial navigation device it is required that the system is in motion for it to be effective. Whereas a GPS and a e-gyro unit has no such requirements. The project does notcompletely prevent the falling of the bike as two-wheeler un-stability is inherent in the system. Our project instead aims at reducing the chances of tilt considerably compared to normal system. The work was focused on the mass of flywheel and the speed required to keep it upright and stable. The radius of flywheel, stress and temperature endured by flywheel were not considered. As the centre of gravity can shift, it is imperative that precision machining is used to fix the axis of rotation. Steering mechanism wasn't implemented in the model. This is because it can't reach the high speeds required to produce the necessary couple to counter balance the forces due to steering.

Conclusions

A self-stabilizing gyroscopic two wheeler was designed and fabricated. The model is able to stabilize itself under 2500rpm supplied by the DC Motor to the flywheel.In the course of this project suitable frameworks were taken into account.The most suitable frame is that of a single axis on the ends of which are the wheels and perpendicular to this is the spin of the flywheel. This was found to be the most optimum design in terms of vibration and effectiveness. The design of the gyroscopic stabilized two-wheeler was made and was analyzed in abaqus software. The area where the most amount of stress developed was found to be around the axis of rotation of the flywheel. It was also found that the flywheel mounted perpendicular to the axis of rotation of the moving wheels provides the required gyroscopic action to maintain a plane of balance. Experimental results have shown that when the flywheel achieves a speed of 2500 rpm.The theoretical calculation of the speed and experimental results were compared and studied. The experimental results were found to be in close proximity to that of the theoretical calculations. The gyroscopic effect created by the flywheel rotating at 2500 rpm or above generates enough angular momentum to stabilize the two wheeler prototype.

Scope for Future Work

- The flywheel can be made more compact and concealable to accommodate the existing structure and chassis of motorcycles.
- Accelerometers can be implemented to have a refined and real time input of the position of different segments of chassis. The feedback data thus generated can be used to modulate the flywheel to utmost accuracy
- Powerful high speed torque motors can be used for smooth operation even under extreme terrain.

- The theoretical calculations can be further improved by comparing it to other gyroscopic devices such as systems used in ship stabilizers and flight control.
- The control properties of the two wheeler can be further studied by comparing the performance of mechanical feedback system to that of a digital feedback system such as e-gyros.
- Simulations for a full scale two wheeler can be performed and the results from scaled model two wheeler can be analyzed.

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