DESIGN CALCULATIONS OF A TWO WHEELER SELF BALANCED VEHICLE

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Abstract – *The present paper illustrates a technique of gyroscopic stabilization in a two inline wheels system. The factors which affect balancing are mass distribution, the center of mass of the system, steering of the vehicle towards left or right, acceleration & most importantly gyroscopic effect. The paper deals with an experiment carried out to produce the gyroscopic effect on a small prototype. The prototype is a two-wheel vehicle in which rotating discs imparted act as a gyroscope to produce a counterbalancing force (gyroscopic effect) when the vehicle prototype loses balance on either side. Thus the vehicle stabilizes itself. The gyroscopic couple, an angular velocity of precession and balancing couple due to a moment of the weight of this vehicle is determined and analyzed. This paper also gives a brief of a concept vehicle developed on similar grounds with an added feature. Wherein even if an external force is applied to the system the force sensors deployed in it sense the force and develop a force of similar magnitude but in opposite direction due to presence of a gyroscopic disc used in the Self- Balanced Two Wheeler (SBTW) thus the vehicle does not lose it's balance even if the external force is applied to it.*

Key Words: **Gyroscopic Stabilization, Gyroscopic Effect, *Self-Balanced Two Wheeler (SBTW)***

1. INTRODUCTION

Motorbike is a very popular transport around the globe. It has been very popular due to its energy efficiency, compact design, convenience and attractive look. Many youngsters consider it as fashionable ride while people in the developing country often use it as a low priced vehicle with better fuel efficiency. However, despite the features and popularity motorbike has lack of safety and is very risky. Therefore, motorbike accidents are fatal. An injury is a must while death is the more frequent scenario. The major lacking in motorbike addressing the safety features are the passenger's body is exposed during ride time which allows the passengers to get off the vehicle and exposes him to impact with roadside elements and the chance of damage is limitless. On the other hand, many people do not consider it as a transport as it does not have the comfort features like the car while two-wheel vehicle can save energy and space.

The balancing of self-stability of two- wheeler is achieved by the gyroscopic effect. A mechanical gyroscope works on the principle of inverted pendulum and employs the use of electromechanical components which can be used as a means of transportation for a single person. The two- wheeled, self-balancing vehicle is naturally an unstable system. Controlling such a system is a hard task and thus it is the topic of research. The gyroscopic effect is widely used in air or sea vehicles such as airplanes and ships; wherein always external disturbing couple is acting on the vehicle. Thus, for the stability of such vehicles, it is essential to neutralize the effect of an external disturbing couple which can be done by applying equal and opposite couple.

2. PROPOSED DESIGN OF SBTW

A 3D model sketch is made according to the dimensions in Solidworks. Accordingly, the components required for the model were bought and tested. The base is made from the mild steel and slots were cut to accommodate the wheels according to the 3D model. Round edge rubber wheels are fitted to the steel base at the bottom, the holes in the frame are drilled in order to fit the gimble of the gyroscope assembly; the DC motor supported on a U bracket is placed on the gimble. The only pre-requisite for this setup to work is that the mass distribution, the mass should be dominant on the upper side (setup should be top heavy) of the gimble. The center of gravity is thus just above the gimble axis, stainless steel disc used as gyroscope are fitted to the shaft of the motor[1]. The DC motor is bolted to the U-bracket due to which it remains intact with it and the shaft of the DC motor is fixed to a steel hub which has got holes drilled on its top flat surface to be used to finally fix the gyroscope disc by bolting it with the hub. The material used in making the gyroscope disc, hub, steel frame, and U-bracket is Mild Steel. To finally assemble the entire model, various sizes of nuts and bolts were used. One important design consideration that was made in this model is that the gyroscope disc should be freely suspended in the U-bracket connected to the steel frame.

Table -1: Specifications and Dimensions of Components

Component	Length(L) x Width(W) x Height(H) (L, W, H in cm)	Diameter (cm)	Weight (kg)	Power/Capacity, Voltage	RPM/ Speed
Base (Mild Steel)	50 x 15 x 0.76				
Frame (Mild Steel)	22 x 8 x 15				
Disc (Mild Steel)	W = 0.76	16			
Wheels (Rubber)	W= 4.5	12			
MY1016 DC Hub Motor			1.92	250 W, 24 V	2650 RPM
Servo Motor			0.055	4.8 V	0.17 sec/60 degrees
Lead Acid Battery			2.12	7.2Ah @ 20 hour, 12 V	
Hub Motor Controller				350 W, 24 V	

3. IMPLEMENTATION AND WORKING

The prototype of a self-balanced gyroscopic vehicle is so designed that whenever an impact occurs on it, due to the production of the gyroscopic couple it gets stabilized. Once the motor starts rotating, the disc fitted on the motor shaft start rotating. The rotation of the disc leads to the production of the gyroscopic effect (as mentioned for a disc in the introduction) thus, when the wheels lose their balance due to the active gyroscopic couple a counteracting reactive gyroscopic couple is produced in the opposite direction due to gyroscopic effect thus stabilizing the prototype. This occurs on both left as well as the right-hand side.

Thus, due to rotation of the gyroscope, a counteracting reactive gyroscopic couple leads to the stabilization of the prototype.

The motor & gimble axle assembly is designed in such a way that it is having a heavy top. That means the center of gravity lies above the gimble axle [2]. So the motor & gyroscope assembly tries to attain the position such that the C.G. of the core will move downwards. But at the same time, the motor & gimble assembly is arranged within the frame having the bearing reaction at ends. So the only possible way for the motor to attain the stability is to either lean forward or backward. So when the motor is started the body is about to fall on either side & also the motor assembly is leaning this causes the precession of spin axis. Due to this precession, according to right-hand rule, the reactive gyroscopic couple acts on the frame which nullifies the effect of the disturbing couple & thus stabilizes the vehicle. After few rotations & oscillations of the motor, the motor & frame attains the stationary position and gyroscope is subjected to pure rolling motion about the spin axis.

Fig-1: Design of the Prototype

3.1 Mechanical Implementation

Chassis

The Chassis has been built using Mild Steel in the form of a ladder. At the middle of the Chassis, a Mild Steel U frame has been welded. Two rubber wheels are attached to the base, one at the front end and other at the rear end. The rotating disc along with the hub motors is set up at such a location so that it can move easily during tilt of the structure. The structure has 6 inches clearance from the ground.

U Frame

The mild steel frame used is welded on the bottom mild steel base (chassis) at the mid-section. The U-Frame consists of a similar smaller U-Frame which is free to rotate about the gimble axis. The gyroscopic disc along with the hub motor is mounted on the smaller U-Frame.

Gyroscopic Disc

It is a mild steel disc mounted over the U-Frame. The hub motor is attached at the center of the disc which keeps the disc in continuous rotatory motion. It behaves as a gyroscopic disc. Whenever there occurs an impact force over the vehicle, the rotating disc tilts either forward or backward to produce a reactive gyroscopic couple.

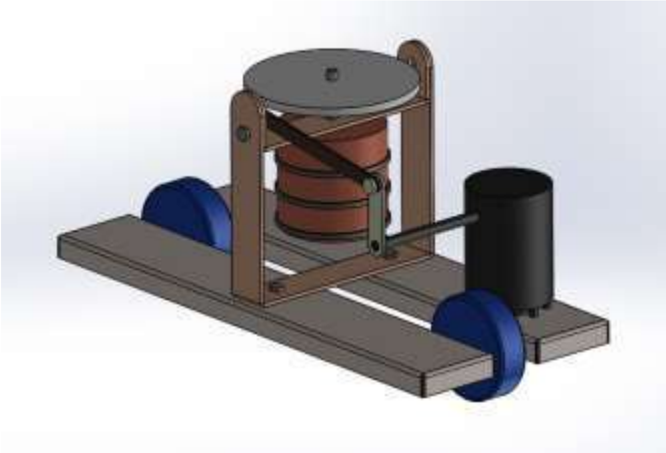
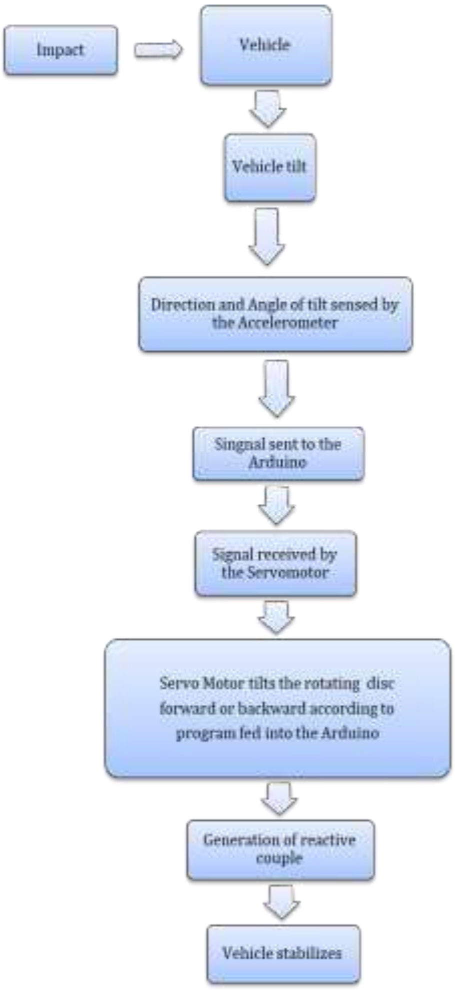


Fig-2: Isometric View of the vehicle prepared in Solidworks

3.2 Control Implementation



4. DESIGN CALCULATIONS AND OBSERVATIONS

Let mass of the system = m kg

Distance/Location of center of mass (m) from the ground

= h (m)

When angle of Tilt = θ

Then Torque induced = $m\, g\, h \sin\theta$

$\therefore$ Reactive Gyroscopic Torque = $m\, g\, h \sin\theta$ (opposite direction)

$\therefore \tau' = I\, \omega\, \omega_p$

$\Rightarrow m\, g\, h \sin\theta = I\, \omega\, \omega_p$

$\Rightarrow \omega_p = m\, g\, h \sin\theta / I\, \omega$

$\because F'_{max} = \mu N = \mu\, m\, g$

$\therefore$ At Limited Condition

$m\, g\, h \sin\theta = F'\, h \cos\theta$

$\Rightarrow m\, g\, h \sin\theta = \mu\, m\, g\, h \cos\theta$

$\Rightarrow \mu = \tan\theta$

If $\theta = 15^o$ then μ should be 0.267

If $\theta = 30^o$ then μ should be 0.577

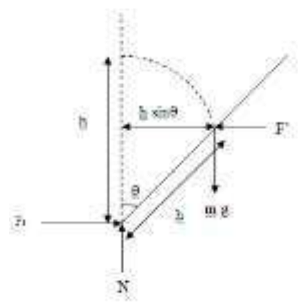


Fig-3: Forces acting on SBTW

Mass of Hub Motor = 1.92 kg

Mass of Batteries = 2.12*2 kg = 4.24 kg Mass of Wheels = .25 kg *2 = 0.5 kg Mass of Disc = 1.5 kg

Mass of Frame = 1 kg

Mass of Chassis = 1.25 kg

Miscellaneous (Linkage, accelerometer, servo motor, Arduino etc) =1.1 kg

Mass of the whole system, m = 1.92 + 4.24 + 0.5 + 1.25 + 1

+ 1.5 + 1.1

=11.51 kg

Centre of Mass (CM) from the ground, h = (CMwheel * Mwheel) + (CMchassis * Mchassis) + (CMframe * Mframe)

+ (CMdisc * Mdisc) + (CMhub motor * Mhub motor) + (CMbattery * Mbattery) + (CMlinkage * Mlinkage)

Where, CM = Centre of Mass; M_x = Mass of x;

Thus,

Centre of mass from the ground, h= {(5*0.5) + (6*1.25) + (10*1) + (19*1.5) + (15*1.92) + (12*4.24) + (15*1.1)

}/11.51

=12.56 cm = 0.126 m

≈0.13 m

Moment of inertia of the disc, $I=m_d r^2/2$

=1.5*0.075*0.075/2

=0.00422 kg-m^2

Speed of Disc, N = 2650 rpm

Angular Speed of Disc, ω= 277.366 rad/sec

Since We Know That

$mgh\sin\theta = I\omega\omega_p$

The vehicle is designed for the maximum tilt angle= 15^o

Therefore the highest precision speed of the disc is

$\omega_p = mgh\sin\theta/I\omega$

= 11.51*9.81*.13*sin15/0.0042*277.366

= 3.26 rad/sec

So Highest Required Gyroscopic Torque

$\tau' = I\omega\omega_p$

= 0.0042*277.366*3.26

= 3.8 kg m^2/sec^2

5. RESULTS AND DISCUSSIONS

Initially, an experiment was conducted to determine whether the structure can be balanced on its own or not. The research found that with high RPM hub motor the structure can be stabilized. Then the concern was switching it manually after letting the structure lean. With the help of the hub motor, we could balance the chassis.

Due to the mounting of the servo motor and its linkage over the chassis, the chassis became heavy on one side. To compensate for the overweight on one side, the other side was loaded with the help of batteries. The disc used as gyroscope was balanced and centered properly to prevent any vibrations and wobbling of the disc.

The project is so far has managed to discover the principle of self-balancing. It is managed to design an algorithm to keep the frame straight all time. However, the frame is not quite able to balance fully on its own. It creates a force in a certain direction on the change of orientation of hub motors. But the hub motors are a bit overweighed after adding some additional weight. This large weight along with the force due to the change of orientation of rotating disc creates such a momentum to get the frame to the other side rather than keeping it straight. Switching fast does not help, as the initial impact force is enough to create the big momentum which pushes the frame beyond our expected limit. The disc is tilted to the other direction to compensate for this event. However, until the total frame is leaned close to our threshold angle it generates greater momentum to diminish the force provided by the rotating disc and fell on the other side. The whole system worked perfectly. However, the wiper motor draws much current due to its high torque and the amount of load it has to handle. So the motor driver circuit burns immediately after providing few outputs. The system is designed to stabilize the car while standing still. The dynamics are totally different when the wheels of the car are rolling. The higher the speed of the car the lesser the threshold angle would be. From the project some certain observations are provided:

a) The higher the RPM, the bigger the counterforce. That means the counterforce is much larger when the RPM of the hub motor is larger.

In case the 24 V hub motor is driven with a single 12 V

battery, the RPM of the motor decrease to N’ = 1690

Thus, $\omega' = 176.887$ rad/sec

New mass of the system = m’ = 9.39kg

New Centre of Mass from the ground = h’= 0.126 m

≈0.13 m

Therefore new Highest Precision Speed of the Disc is, ω'_p =

4.17 rad/sec

So the new Highest Required Gyroscopic Torque

$= I\omega\omega_p$

$= 0.0042 * 176.887 * 4.17$

$= 3.09$ kg m^2/sec^2

This reactive torque obtained at N’ = 1690 rpm is less as compared to the torque required to balance the vehicle. As a result it is essential for the battery to attain 2650 rpm to produce the required reactive torque.

b) The more the tilt angle, the more force is needed to stabilizes the chassis

When $\theta = 10^o$

$\omega_p = 2.19$ rad/sec

τ' = 2.6 kg m^2/sec^2

When θ = 20^o

ω_p = 4..3 rad/sec

τ' = 5.02 kg m2/sec2

Thus, when θ = 10^o, the reactive gyroscopic torque produced is less than that required to balance the vehicle. When θ = 20^o, the reactive gyroscopic torque produced is more than that required to balance the vehicle. Hence an intermediate value θ = 15^o is chosen up to which the tilt of the vehicle can be balanced.

c) The direction of rotating wheel tilt determines the force direction of when spinning is in a particular direction.

d) The hub motor could be driven even by using only one battery but the RPM of the motor decreased in this case. To keep the RPM to the rated RPM of the motor, it has to be driven by using two batteries (12V each) in parallel.

e)The threshold angle up to which the vehicle on tilting, gets stabilized is 15^o from vertical.

delay(10);

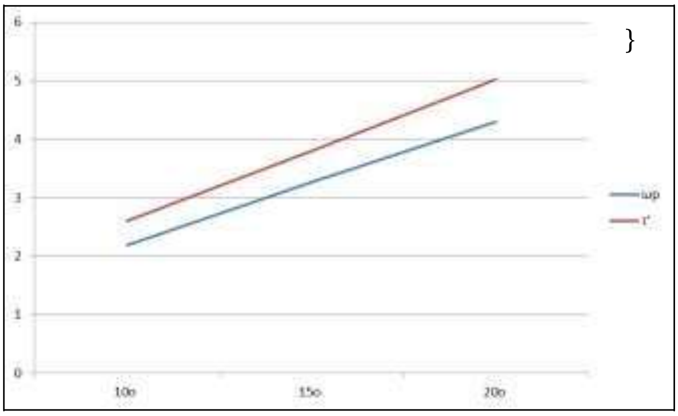


Chart-1: Variation of τ' and ω_p with θ

6. ARDUINO CODE

```
#include <Servo.h> int sensorPin1 = A0; int sensorPin2 = A1; int sensorPin3= A2; int sensorValue1 = 0; int sensorValue2 = 0; int sensorValue3 = 0; int x=0,y=0,z=0; Servo myservo;

void setup()

{

  Serial.begin(9600); myservo.attach(9); myservo.write(90);

}

void loop() {

int x1=65,y1=65,z1=60;

sensorValue1 = analogRead(sensorPin1); sensorValue2 = analogRead(sensorPin2); sensorValue3 = analogRead(sensorPin3);

x=(sensorValue1)/5;
```

```
y=(sensorValue2)/5;

z=(sensorValue3)/5; Serial.print("X value="); Serial.print(x); Serial.print("\tY value="); Serial.print(y); Serial.print("\tZ
 value="); Serial.println(z);

    if(z<=55&&x>=67)

  {

   for(int i=0;i<=(z1-z);i++)

   { myservo.write(90+i); delay(10);

   }

   delay(1000);

   for(int i=90+z1-z;i<=90;i--)

   {

   myservo.write(i);

 else  if(z<=70&&x<=62)

 {

 for(int i=0;i<=(z-z1);i++)

 {

 myservo.write(90-i);

 delay(10);

 }

 delay(1000);

 for(int i=90-z+z1;i<=90;i++)

 { myservo.write(i); delay(10);

 }

}

else

{

 myservo.write(90);

} Serial.flush();

}
```

7. CONCLUSIONS

Now a day, if a person has to commute from one place to another he has to use a bike or a car. Those who commute with a car don't need effort for self-balancing of a vehicle but in case of bikes balancing is very important particularly at low speed. The balancing of two-wheeler is achieved by the gyroscopic effect.

The gyroscopes which are conventionally used in airplanes and ships mainly for stabilization purpose can be effectively used for self-stabilization of a two-wheeled vehicle [3]. The prototype mentioned above was thus designed and fabricated to validate the same point. The concept with advanced electronics is further evolved to development of a concept car by Lit motors that not only stabilizes but also self-balances even if the external force(s) is applied.

The design of prototype has been tested at different RPM of the disc and also with different weights to see that the vehicle is balancing. This report presents design and fabrication of the two-wheeler self-balancing vehicle which is capable of balancing itself under application of external forces and loads. The vehicle balances itself under various conditions like the forced tilt of the vehicle. Thus the proposed system can be much helpful for two-wheeled vehicles reducing accidents or unwanted falls and increasing safety to the rider. This system reduces the work of humans as well as provides the eco-friendly environment.

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