Batch_11_DESIGN AND FABRICATION OF CONTROL MOMENT GYROSCOPE FOR STABILITY IN TWO WHEELERS (1).pdf

by

DESIGN AND FABRICATION OF CONTROL MOMENT GYROSCOPE FOR STABILITY IN TWO WHEELERS

A Major Project Thesis Submitted

In Partial Fulfillment of the Requirement for The Award of the Degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

By

Badesab Mohammed Touseef Hussain	18071A0303
B. Chandan	18071A0305
G. Giridhar Sai	18071A0321
P. Pavan Kalyan Reddy	18071A0344

Under the guidance of

Sri. H. Naresh, Assistant professor

Department of Mechanical Engineering

VNR VIGNANA JYOTHI INSTITUTE OF ENGINEERING & TECHNOLOGY

(Autonomous) Vignana Jyothi Nagar, Bachupally, Nizampet (SO), Hyderabad – 500090 (Approved by AICTE & Govt. of T.S and Affiliated to JNTU, Hyderabad) April 2019.

VALLURUPALLI NAGESWARA RAO VIGNANA JYOTHI
INSTITUTE OF ENGINEERING AND TECHNOLOGY
An Autonomous Institute, NAAC Accredited with 'A++' Grade
NBA Accredited for CE, EEE, ME, ECE, CSE, EIE, IT B.Tech Courses
Approved by AICTE, New Delhi, Affiliated to JNTUH
Recognized as "College with Potential for Excellence" by UGC
VignanaJyothi Nagar, Pragathi Nagar, Nizampet (S.O), Hyderabad – 500 090, TS, India.
Telephone No: 040-2304 2758/59/60, Fax: 040-23042761
E-mail: postbox@vnrvjiet.ac.in, Website: www.vnrvjiet.ac.in

Estd.1995

Department of Mechanical Engineering

CERTIFICATE

This is to certify that the project report entitled **"Design and Fabrication of Control Moment Gyroscope for Stability in Two Wheelers"** has been carried out at VNR VJIET, Hyderabad, and submitted by the following Students

S. No	NAME OF THE STUDENT	HALL TICKET NUMBER
1.	Badesab Mohammed Touseef Hussain	18071A0303
2.	B. Chandan	18071A0305
3.	G. Giridhar Sai	18071A0321
4.	P. Pavan Kalyan Reddy	18071A0344

In partial fulfillment of the requirements for the award of the Bachelor of Technology in Mechanical Engineering to Jawaharlal Nehru Technological University Hyderabad at **VNR Vignana Jyothi Institute of Engineering & Technology** during the period of 2018-2022 is a bonafide work carried out by them under the guidance and supervision of the undersigned. The results embodied in this project report have not been submitted to any other University or institution for the award of any Degree.

Signature of Supervisor
Sri. H. Naresh
Project guide
Assistant professor
VNR VJIET

Signature of HOD
Dr. Bollu Sathyanarayana
Head of the Department
Mechanical Engineering
VNR VJIET

APPROVAL CERTIFICATE

Viva-Voce examination conducted for the dissertation work entitled **“Design and Fabrication of Control Moment Gyroscope for Stability in Two Wheelers”** is conducted on 14-6-2022 and the work is approved for the award of **Degree of Bachelor of Technology in Mechanical Engineering.**

INTERNAL EXAMINER **EXTERNAL EXAMINER**

VNR VIGNANA JYOTHI INSTITUTE OF ENGINEERING & TECHNOLOGY
(An Autonomous Institution, Accredited by NAAC with 'A++' grade; Recognized as "College with Potential for Excellence" by UGC; Approved by AICTE; Affiliated to JNTUH)
Bachupally, Nizampet (S.O.), Hyderabad – 500090, Telangana

DEPARTMENT OF MECHANICAL ENGINEERING

DECLARATION

We hereby declare that the Major Project report entitled "**DESIGN AND FABRICATION OF CONTROL MOMENT GYROSCOPE FOR STABILITY IN TWO WHEELERS**" submitted by us to VNRVJIET, Hyderabad in partial fulfillment of the requirement for the award of the degree of **B. TECH** in **MECHANICAL ENGINEERING DEPARTMENT** is a record of Bonafide project work carried out by us under the guidance of **Sri. H. Naresh**.

We further declare that the work reported in this project has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

PLACE: HYDERABAD	**BMD Touseef Hussian**	**18071A0303**
DATE:	**B. Chandan**	**18071A0305**
	G. Giridhar Sai	**18071A0321**
	P. Pavan Kalyan Reddy	**18071A0344**

ACKNOWLEDGEMENT

We would like to thank our institution VNRVJIET, Hyderabad, which has created a great platform to attain profound technical skills in the field of Mechanical Engineering, thereby fulfilling our most cherished goals.

We would like to convey our sincere thanks to **Sri. H. Naresh**, Guide and Professor in Mechanical Engineering, for his precious guidance, constant inspiration, and kind cooperation at every step of this Major Project.

We would like to convey our sincere thanks to **Dr. B. Satyanarayana**, Head of the Department, Mechanical Engineering, for his inspiration, and successful completion of our Major Project.

We are extremely thankful to **Dr. C. D. Naidu**, Principal, VNRVJIET, and Management of VNRVJIET for giving us permission to carry out this Major Project.

We would also like to thank all of them who have helped us either directly or indirectly during the project tenure

ABSTRACT

Two-wheeled vehicles have many advantages over other vehicles such as being more efficient, smaller in size, and more maneuverable, but lack stability and safety. To improve the stability of a two-wheeled vehicle, the Control Moment Gyroscopic Stabilization is considered. As the vehicle tilts from its upright position, Control Moment Gyroscope is expected to generate sufficient gyroscopic reaction moments to bring the vehicle back and stabilize it.

The project aims to design and fabricate a control moment gyroscope model for two-wheeled vehicles. The two-wheeler would be able to balance itself and can be stabilized against any impact and in zero velocity as well. A motion processing device is used to measure the tilt angle of the chassis. The data is then sent to an Arduino, using the input signals, the vehicle can be balanced by controlling the gyroscope through the Arduino UNO which determines the precession direction and angle of the rotating disks. This system is designed to provide the stability that is currently lacking in two-wheelers.

This paper consists of a detailed analysis, design, and fabrication of the control moment gyroscope system. Firstly, a study is conducted on the availability of different control mechanisms. Next, the gyroscopic manufacturing and fabrication techniques are discussed. An optimal Arduino code is developed to control the tilt. The detailed calculations and prototype preparation is discussed.

KEYWORDS: Gyroscope, Mechanism, Stability, Arduino, Moment, Control moment gyroscope (CMG).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The gyroscope has been vital in applications in physics (for example, Larmor precession in atomism), energetics (kinetic energy buildup by turbines, mechanical batteries), and astronomy (lunisolar precession of Earth). A gyroscope is a device that measures or keeps track of orientation and angular velocity. In [1,] gyroscope applications are classified as follows: stabilisers, energy storage, gyrocompass, attitude and heading indicator, gyrostat, Control moment gyroscope (CMG), and MEMS Gyroscope. They are categorised into two uses, as previously stated: passive (sensor) and actuator stabilisation of an unstable dynamic system. Navigation systems and passive stabilising systems used in ships are examples of sensor uses, while the gyroscope may also be employed as an actuator by utilising the precession phenomena.

The control moment gyro (CMG) is an angular momentum exchange device that can generate massive output torque on the body and is used in this investigation. It consists of a motorised rotor and a gimbal. The spin axis of the flywheel can rotate perpendicular to its spin axis (the gimbal axis). Complex dynamic derivations are employed to develop a relationship between the torque input to the gimbal axis and the required output torque on the body. The rate of change of angular momentum between the CMG and the body is affected by the gimbal velocity.

Since the twentieth century, CMG stabilisation has been utilised, but development has been slow due to high motor prices, restricted electric motor technology, and a lack of sensor feedback at the time. The first important use of gyroscopic stabilisation is linked to two individuals: Louis Brennan [2] and Pyotr Shilovsky [3][4],[5], who built large-scale prototypes. The Shilovsky Gyro car (Figure 1.1) from Russia in 1912 and Brennan's Monorail (Figure 1.2) from the United States in 1962 are the most well-known vehicles.

Figure 1.1: Shilovsky's Gyrocar

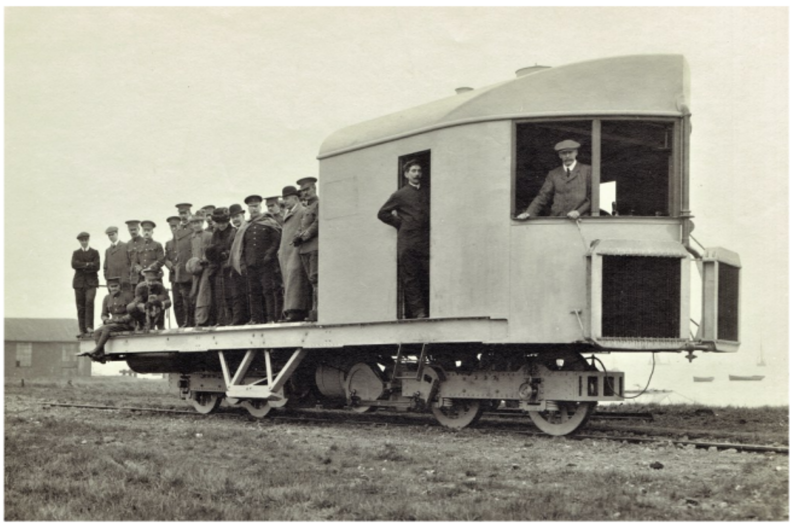

Figure 1.2: Brennan's Monorail

1.2 OBJECTIVES

- To develop the control moment Gyroscope to balance the two-wheeled vehicle.
- Compare the vehicle stability with and without CMG.

1.3 MOTIVATION TO WORK

Motorcycles are a highly common mode of transportation all around the world. It is quite popular because of its energy efficiency, small design, convenience, and appealing appearance. Many young people regard it as a trendy ride, while citizens in poor nations frequently utilise it as a low-cost vehicle with improved fuel economy.

Even if only one person rides in a vehicle at a time, the major reason for this has been discovered through a poll, which reveals that many people regard automobiles to be safer and more luxury than motorcycles, which is accurate to some extent. However, with a constantly rising population, the number of automobiles on city streets is continually increasing. The underlying issue is that when more automobiles are brought onto roadways, more space is used, resulting in extremely congested roads. As a result, one may expect to wait longer on the road to reach his destination near traffic signals; during rush hour, practically every automobile waits for more than one session.

At some point, riding a motorbike can help you travel shorter routes and keep ahead of traffic because bikes are easier to handle and take up less space on the road, resulting in less traffic jams. Despite their advantages and popularity, motorcycles lack safety and are extremely dangerous. As a result, motorcycle accidents are lethal. An injury is unavoidable, but death is a more likely outcome.

However, many people do not consider it a method of transportation because it lacks the comfort and luxury elements of a car, but two-wheel vehicles can save energy and space.

1.4 SCOPE OF PROJECT

The scope of this research is described as follows:

- The gyroscopic control moment is employed as a balancing vehicle.
- Development of the Arduino code
- Modeling and simulation using Solidworks.

1.5 DIFFERENT MECHANISMS

In this section, different design choices are evaluated and the optimal one is chosen for the design.

1.5.1 No Active Gimbal Control

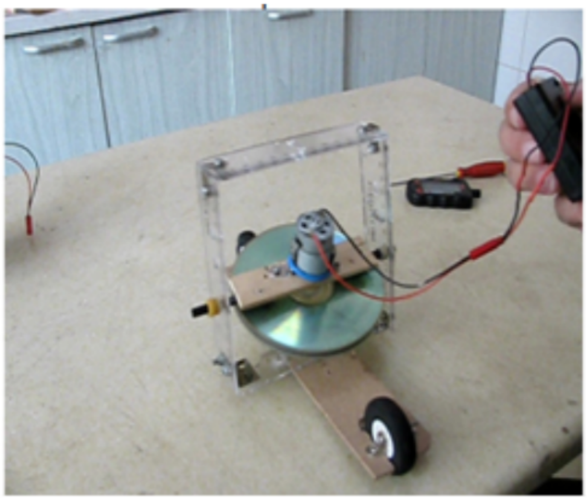

Figure 1.3: Toy balancing by natural precession [10]

No active gimbal control but balancing by using the flywheel's natural precession, the same as the spinning toy, which balances itself when spun to high RPM. In this mechanism, there is no servo mechanism that controls the rotation of the precession axis of the flywheel. For this mechanism to be used the angular momentum of the flywheel must be high. This is only possible by increasing the RPM or mass of the flywheel. If the mass of the flywheel is increased, then it reduces the vehicle efficiency. To achieve high RPM, we need a high-speed motor. This mechanism does not produce high torque. So, the vehicle can't balance on external impact.

Advantages: 1) Simple mechanism, easy to design.
2) Easy to manufacture, not many electric parts.

Disadvantages: 1) Can't balance the vehicle under impact.
2) High mass and RPM flywheel must be used.

1.5.2 Counter-Weight Balancing

This is the same way humans balance the vehicle by shifting the body weight based on the vehicle position. The bike shown in the figure below moves the weight attached to the frame below, to actively balance the bike. The mechanism does not produce much torque. So, the vehicle does not withstand external impact.

Figure 1.4: Yamaha self-balancing bike [20]

Advantage: 1) No Vibrations are produced on the vehicle.

Disadvantages: 1) Mass of the vehicle is increased.

2) Can't balance the vehicle under the impact.

1.5.3 Active Control Moment Gyroscope

In this mechanism, a servo is used to control the rotation of the precession axis of the flywheel. Based on the position of the vehicle the orientation of the flywheel is changed based on the vehicle position. This mechanism produces high torque. So, the vehicle can be balanced under external impact.

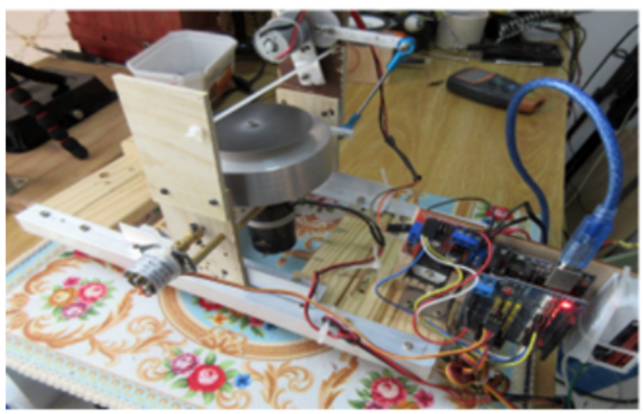

Figure 1.5: Active control moment Gyroscope [10]

Advantage: 1) Balances the vehicle under external impact.

Disadvantage: 1) Complex design.

Conclusion

The active control moment gyroscope Mechanism is selected as it can balance the vehicle under external impact.

Active Control Moment Gyroscope Orientation

There are two gyro rotor orientations:

1. Horizontal rotor axis
2. Vertical rotor axis

1.5.3.1 Vertical Rotor Axis

Advantages: If a heavy gyroscope (one where the CG is slightly lower than the gimbal axis) is allowed to spin, it can use natural precession to keep its balance, in addition to the electrical assistance offered by the servo. The great thing about natural precession is that it is instantaneous.

Disadvantages: While the vehicle is traveling on an inclined plane the natural precession of the flywheel tries to make the vehicle fall to one side, This can be controlled by actively rotating the flywheel while climbing the inclined plane.

1.5.3.2 Horizontal Rotor Axis

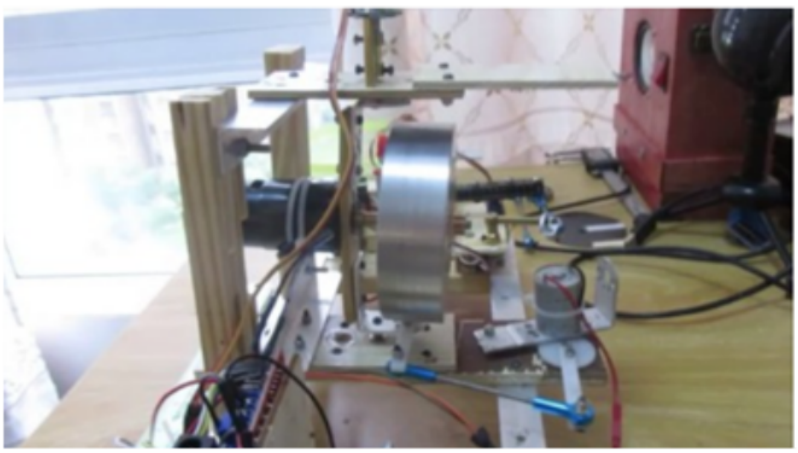

Figure 1.6: Horizontal rotor axis [10]

Advantage: 1) This orientation does not affect the vehicle while it's climbing the inclined planes.

Disadvantage: 1) This orientation does not allow natural precession to be used to help balance the gyroscope so you must rely only on Electrical means.

1.5.3.3 Dual Gyroscopes

In this arrangement, the flywheels are rotating in opposite directions, So that the natural precession does not affect while the vehicle is traveling on an inclined plane.

Advantages: 1) This arrangement uses the natural precession to balance the vehicle in addition to the precession produced by the servo mechanism.

Disadvantages: 1) Complex to design.

2) Weight increase is high.

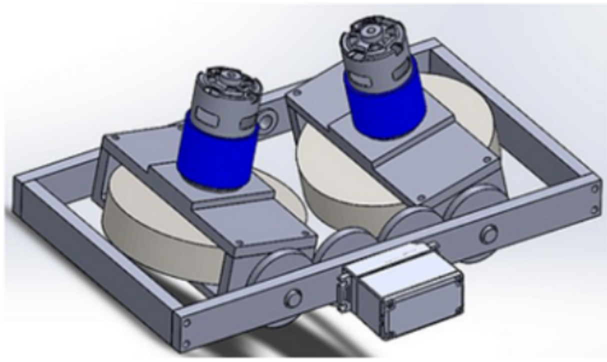

Figure 1.7: Dual gyroscope [10]

CHAPTER 2

LITERATURE REVIEW

Ghosh et al., (2009) [6] Two-wheelers contain a variety of adaptable characteristics. They are statistically unstable, but as speed increases, roll instability vanishes. The simplified model is used to investigate the impact of forwarding speed and brake power on roll instability when changing two-wheel angles. Understanding some of the basic ideas relating to two wheels negotiating turning while under braking force is beneficial. Another method is to use the opposite steering wheel, where the handle is rotated against the desired position and a centrifugal torque based on two wheels is perfectly matched.

Jeyaprakash et al., (2015) [7] The inertial system features UVW and base O axes. The UVW system is embedded in an inertial frame, whereas the XYZ system originates at the area where the rear wheel contacts the XY plane. The x-axis is straight and points to the rear axle contact line with the XY plane, while the y-axis is perpendicular to the x and has 12 positives on the left side of the two-wheeler. When you lean right, the roll angle for the rear frame is correct, and when you turn left, the roll angle is correct. The angle formed by the axes x and u represents the shape of the back plane.

James Demello et al., [8] vehicle information data displays the vehicle's frame, the shape of the vehicle's front wheel in relation to the frame, the shape and rotation speed of the flywheel mounted on the gyroscope attached to the frame, and the frame's speed. The vehicle's condition may be assessed based on the data gathered. One of the flywheel locations and rotation speed are modified based on this conclusion. This modification may be further refined dependent on the vehicle's speed and direction.

Gallaspy et al., (2000) [9] The control moment gyro (CMG) is used as an actuator in this function. Gyro control time (CMG) is frequently utilised to guide a space shuttle. Using CMG as an actuator to balance the bike is a unique and innovative technique to measure a bicycle, and it is the first of its type. The PD controller is adequate to balance the bike, according to simulation results. For baby bike size, real-time control was employed, and the bike was successfully measured and able to travel forward, backward, and rotate at a modest angle. The graph depicts the angle's fluctuation with regard to time.

[9] The control moment gyro (CMG) is used as an actuator in this function. Gyro control time (CMG) is frequently utilised to guide a space shuttle. Using CMG as an actuator to balance the bike is a unique and innovative technique to measure a bicycle, and it is the first of its type. The PD controller is adequate to balance the bike, according to simulation results. For baby bike size, real-time control was employed, and the bike was successfully measured and able to travel forward, backward, and rotate at a modest angle. The graph depicts the angle's fluctuation with regard to time.

Nenner et al., (2008) [10] James is a hobby developer who created 4 versions of gyroscope car models on his blog giving us a clear understanding of all the steps he took while building 4 versions by reviewing all the car changes from time to time on his blog.

There is another option that some have used and that uses two gyroscopes, usually at a straight axis orientation. They should be connected to each other using a connection and then they can use natural precession and allow the car to turn right and left without problems. Material for Gyroscope Rotor: the material needs to be dense, so aluminum, steel, and brass are ideal.

Jackson Wahl et al., (2012) [11] We may deduce from this that the authors were able to operate the automobile using an Android mobile app and boost the car's safety in the case of a collision. Batteries, a gyro sensor, a metal disc disc, a control motor hub, Arduino, an Android mobile phone, and an HC-05 Bluetooth module connect the phone to Arduino in this two-wheeled car. The numerous automotive system components necessary for this job will be outlined. The following features will be included: equipment usage, power consumption, control, power, and system communication.

Amato Parsa et al., [12] LIT has presented a clear comparison between the conventional bike and car with their C-1 motorbike model which made us clearer on what we are going to do in our project [9]. This comparison includes the fuel type and the size and power of the vehicle which made us clear how this project is going to help the people. Figure 2 shows the design developed by lit motors. This vehicle is stabilized using the Control moment Gyroscopic. Vehicle information data shows the frame of the vehicle, the shape of the vehicle with respect to the frame, the shape and rotation speed of the flywheel mounted on the gyroscope attached to the frame, and the speed of the frame. Based on the data obtained, the condition of the vehicle can be determined. Based on this determination, one of the flywheel positions and rotation speed are adjusted. These adjustments may be based on the adjustment of the input to change the speed and direction of the vehicle.

J. G. Bitterly et al., (1998) [13] This study analyses probable possibilities and assumptions based on powerful combinations and sophisticated technologies, as well as the present status of flywheel energy storage technology, or mechanical batteries. The development and application of flywheel mechanical energy technology began a few hundred years ago and continued throughout the Industrial Revolution. The whole function of A. Stodola's first English translation was done in 1917. It was one of the earliest "modern" publications on the theoretical boundaries of the theory of rotating discs (isotropic only). Energy-saving flywheels were advertised as the primary suppliers of space equipment in sponsored initiatives. However, microelectronics, magnetic systems, and generators did not have the capacity to become technologically advanced until the 1980s. The next 10 years shown that mechanical batteries can outperform chemical batteries.batteries in many applications.

Sang K. Ha et al., (2012) [14] The rim design of the hybrid composite flywheel rotor used to measure power is discussed in three distinct scenarios in this research. The rotor is constructed from four hybrid composites. These rims are built of carbon-glass/epoxy with varying volume components to reinforce the circular wounds. The maximum power intensity between the two rotor locations was reduced, as was the maximum permissible rotational speed. High usable power (35 kW h), rotating speed (15,000 rpm), length, and internal radius are the installation requirements. The rims are damaged in the first example as a result of constant bending. The rims are injured independently in the second scenario, and distortions are imposed to their mechanical equilibrium. In the third example, a hybrid of the first two Cases are employed in which two pairs of rims are injected simultaneously, and the first pressure is delivered to the second in the second operation. Each case has a varied operating cost and power rating. The third case rotor is successfully manufactured by twisting the filament and curing it in situ, followed by a combination of press-fit and mechanical rims.

J. Park et al., (2008) [15] a hybrid control, which includes a model-based feedforward control and a compact-compensated feedback component, of a solid engine/generator compliant to the machine/generator in a flywheel-based uninterruptible flywheel power system is proposed in this paper. The feedforward controller occupies a large part of the current control output based on the machine model, and PI controllers compensate for the possible accuracy of the model to improve the performance and robustness of the complete control system. The current machine tracking error caused by parameter accuracy in the model-based controller is statistically analyzed and used to compensate for the relative flexibility of the variables to eliminate the instability error in the current control. Strength analysis is also introduced, and the control and performance of the system are enhanced by the proposed integrated controller. Simulations and test results that include a flywheel power storage system ensure control of the controller.

Robert j. Bauer et al., (2002) [16] control moment gyroscopes (CMGs) are torque-generating mechanisms that can be used to visualize and control spacecraft vibrations. CMGs include a rotating flywheel and an actuator that tilts the wheels. Many CMG designs allow the flywheel spin axis to move only about one axis CMG with a single axis. This paper develops and analyses the kinematics and dynamics of CMG novel design twice. The integrated CMG design incorporates four-bar connections allowing the rotating axis of the rotating flywheel to have two degrees of freedom.

E. Mumm et al., (2014) [17] Honeybee Robotics Spacecraft Mechanisms Corporation has developed a Control Moment Gyroscope product suitable for a small spacecraft. Each CMG shows an angular force of 56 mNm-s with a maximum value of 86 mNm-s, and a corresponding output torque of 112 mNm and 172 mNm respectively. Each unit measures 48 × 48 × 91 mm and weighs 600 grams. Control electronics can drive 4 CMGs and use a guiding principle to combine the commands of each actuator from a three-dimensional torque or torque quaternion command. The industry will see a growing role soon for small satellites at a range of 20-100 kg. We build CMG list capability by introducing a basic application - using the concept of the Coral Reef Ecosystem Spectro-Photometric Observatory (CRESPO) (100 kg satellite) satellite compliant with the requirements of the Hyperspectral Imager for the Coastal Ocean (HICO) at the International Space Station. We show how a small CMG team can make a representative drive beyond the required kill limits of 0.75 deg/s with the "Soak and Shoot" flight system, and high kill rates above 1.5 deg/s. This paper will discuss the demonstrated performance of the system, which includes the results of environmental testing, as well as the initial application.

J. Chen et al., (2016) [18] Despite the tremendous work done in recent years to investigate and build various types of circular robots, there are few viable programmes. Existing round robots frequently lack uncommon sensors such as laser, sight camera, and sonar since they are limited to a totally enclosed round shell and a specific rolling manner. As a result, they have poor eye acuity and poor motor control. The Control Moment Gyroscope (CMG) team is controlled by a circular robot in this research. The robot will have a high potential for navigating obstacles and ascending slopes, as well as a steady field of sensory development. The circular robot's mechanical design is presented. A simpler dynamic model is also built during reasonable speculation. Robotic movement command The CMG team teaches by imitation. Imitation effects validate a structural design's practicality. The job provided here is a step toward the ultimate aim of an autonomous circular robot.

Hsieh, Ming-Hung, et al.,(2014) [19] used fuzzy sliding mode control to create a riderless bicycle with a gyroscopic balancer (FSMC). They created the bicycle dynamics model using the gyroscopic balancer in order to run a simulation. in accordance with the cycling system the bicycle system is regarded as an inverted pyramid. pendulum system with two independent masses (the bicycle's mass center and the gyroscopic balancer's mass center). To ensure the control stability. They did the experiment on a bicycle equipped with a gyroscopic balancer controlled by FSMC. Matlab is used to execute the simulation. Figure 2.4 depicts the balancing of the Impact disturbances struck a stationary bicycle. The maximum possible lean angles of the Gaussian noise disturb the bicycle, and impact disturbances are around 4.0. and 5.8, respectively, and the bicycle remains balanced. The control voltage quickly increases at the 10th and 15th seconds to prevent the bicycle from collapsing due to impact disruptions. Even when disturbed, the immobile vehicle can still be stabilized during the experiment.

Chu and Chen presented the concept of an active stabilizing system (ASAS) for a single-track vehicle in ref. [20]. The mathematical model for the inverted pendulum is generated using Lagrange's equation and then validated by comparing the closed-loop response to a model built with the commercial program ADAMS. A model predictive control technology is utilized to synthesize the controllers for controlling the flywheel's gimbals and producing stabilizing torque.

Linearizing the nonlinear inverted pendulum yields the MPC prediction model. In three examples, they examined the performance of MPC control techniques. Straight running and disturbance rejection, circular motion, and path following are all options. The system's operating point is upright, and the gimbal angles are zero. The gyroscopic inverted pendulum, shown in Figure 2.6, is made up of two rotating flywheels coupled to gimbal frames, four electric motors, and bevel gears. Both flywheels are moving in the opposing direction at a constant speed of 4000 rpm. The findings of this study's real-time implementation show that the suggested controllers may be included in standard hardware.

CHAPTER 3

WORK METHODOLOGY

In this chapter, the work methodology is explained in detail. So that the project can be finished in the given time effectively.

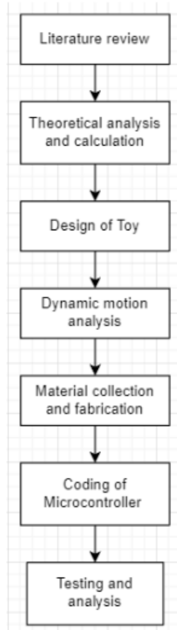

Figure 3.1: Block diagram of the workflow

3.1 LITERATURE REVIEW

Stability is a serious concern in two-wheelers, a system to control a vehicle is necessary, hence by conducting research on different mechanisms, by referring to many research papers. Finally concluded that the control moment gyro (CMG) is the safest and most reliable.

3.2 THEORETICAL ANALYSIS AND CALCULATIONS

While conducting theoretical analysis, various design options are evaluated and a suitable design model is selected. The parameters are calculated with the help of the research papers and literature survey.

3.3 DESIGN OF TEST RIG

After referring to many research papers it has been noted that it is important to build a test rig to optimize the microprocessor code. The test is designed by scaling down the actual model of a two-wheeler. Once the design parameters are determined through calculations, a CAD design has been generated.

3.4 SIMULATION

The 3D CAD design of the test rig is imported into Solidworks simulation software to perform dynamic motion analysis and structural simulation.
The motion of the gimbal and response from the servo is animated while balancing the test rig on two wheels.

3.4 FABRICATION OF TEST RIG

The test rig is fabricated by laser cutting and welding the parts as per requirement. The support frame is then fixed with a gimbal and motor. The flywheel is machined and mounted onto the motor using an M10 arbor. The motor is powered with the help of an adapter. The gimbal is further supported by a bearing and nut which are connected to the frame. While testing the CMG one end is supported with a servo to control precession. The sensor and microcontroller are then placed appropriately and the tests are performed.

3.6 CODING THE MICROCONTROLLER

The microcontroller used in this project is Arduino UNO. The sensor MPU6050 is wired to the Arduino as shown and the code is uploaded to the Arduino. The test rig is then balanced through a feedback system and servo control.

3.7 TESTING AND ANALYSIS

A force is applied to the test rig, to determine the reaction of the gyroscope. The precession of the gyroscope is controlled through the servo, which in turn depends on the rotation of the sensor placed on the test rig.

CHAPTER 4

THEORETICAL ANALYSIS AND CALCULATIONS

In this chapter different design options are evaluated and a suitable design model is selected. The design calculations are based on the calculation methods used in research papers.

4.1 DESIGNING THE CMG SYSTEM FOR CONVENTIONAL ELECTRIC SCOOTERS

These values are produced by averaging the parameters of the top 5 electric scooters in the current market i.e, 2021-2022.

Table 4.1: Input Values of the electric scooter

Average weight of an electric scooter	125 kg
Average weight of control moment gyroscope	30kg
Average load	200kg
Height of center of gravity of electric scooter	0.5m
Maximum angle of lean permitted	30°
Total mass	325 kg

4.1.1 Maximum Torque required to Stabilize the Two Wheeler

$$T = m \times g \times h \times sin(angle) Nm \qquad (4.1)$$

$$T = 325 \times 10 \times 0.5 \times sin(30^{\circ})\ Nm$$

$$T = 812\ Nm$$

Minimum angular speed at which the motor as to rotate the flywheel

$$\omega = \frac{T}{I \times W_p}\ \text{rad/s} \qquad (4.2)$$

Moment of inertia of flywheel

$$I = 0.5 \times M \times r^2 \; kg\,m^2 \tag{4.3}$$

Mass of flywheel:

It has been determined that greater the mass of the flywheel more the stability, but this reduces the efficiency of the vehicle, also increases the torque required which in turn increases the motor mass and rating. An optimal mass of 10kg is selected.

The radius of the flywheel:

More the radius the more stability, but this increases the amount of space occupied by the system. and also increases the torque that has to be delivered by the motor. Based on this factor radius is taken as 15cm

Type of flywheel:

The rimmed type flywheel geometry has more moment of inertia for the same mass when compared with solid disc type geometry.

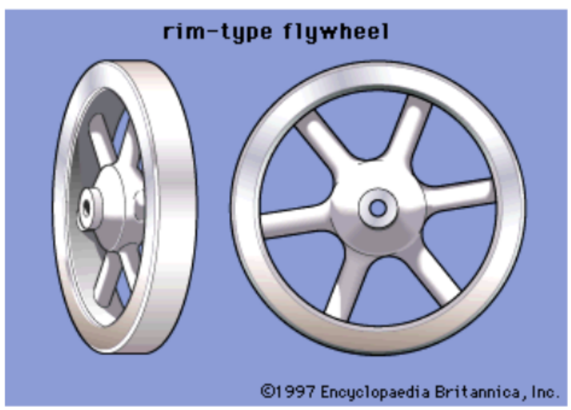

Figure: 4.1 Rimmed flywheel

$$I = 0.5 \times 10 \times 0.15^2 \; kg\,m^2$$

$$I = 0.1125 \; kg\,m^2$$

Wp = 200 RPM

W = 2000 RPM

Minimum Angular speed at which the motor as to rotate the flywheel

$= \frac{800 \times 0.5}{0.1125 \times 21}$ rad/s

= 178 rads/s = 1700 RPM

Torque produced by single flywheel

$$T = I \times W \times Wp \; Nm \qquad (4.4)$$

$$= 0.1125 \times 21 \times 210 \text{ Nm}$$

$$= 496 \text{ Nm.}$$

Total torque produced by 2 flywheels = 992 Nm.

Required Specification:

Based on the requirements and availability of components, the following specifications are selected.

Motor: 500 W, 2000 RPM.

Step Motor: 250 W, 200 RPM, 300 Nm.

4.2 FOR A FULLY ENCLOSED VEHICLE

Table 4.2: Input Values for fully enclosed vehicle

Mass of vehicle	200kg
Load capacity	200kg
Taking center of gravity height	0.7
Considering maximum lean angle	30°

Mass of vehicle = 200 kg

Load capacity =200 kg

Taking center of gravity height = 0.7 m

Considering maximum lean angle = 30°

T = $M \times g \times h \times \text{Sin}(30^{\circ})$ Nm

T =$400 \times 10 \times 0.7 \times 0.5$ Nm

T = 1400 Nm

Wp = 21 rad/s

W= 366 rad/s

Minimum Angular speed at which the motor as to rotate the flywheel = $\frac{1400\times0.5}{0.1125\times21}$ rad/s

= 315 rad/s = 3000 RPM

Torque produced by the flywheel =$I \times W \times Wp$ Nm

= $0.1125\times 366 \times 21$ Nm

= 864 Nm.

Total torque produced by 2 flywheels = 1729 Nm.

Required Specification :

Based on the requirements and availability of components, following specifications are selected.

Motor:1000 W,3500 RPM.

Step Motor:300 W,200 RPM,300 Nm.

4.3 FOR THE TEST RIG

Table 4.3: Input Values for test rig

Mass of the flywheel	500gm
Radius of flywheel	10cm
Mass of test rig	4kg
Center of gravity height	15cm
Maximum lean angle	30°

Mass of the flywheel = 500 gm

Radius of flywheel = 10 cm

I = $0.5 \times 0.5 \times 0.10^2$

I = 0.0025 kgm^2

Mass of test rig = 4 kg

Center of gravity height = 15 cm

Considering maximum lean angle = 30°

T=$M \times g \times h \times$Sin($30^\circ$)

T = $4 \times 10 \times 0.15 \times 0.5\, Nm$

T = 3 Nm

Minimum Angular speed at which the motor as to rotate the flywheel

= $\frac{3}{0.0025 \times 8}$ rad/s

=150 rad/s

=1400 RPM

W=4000 RPM

Wp = 8 rad/s

Torque produced by the flywheel =$I \times W \times Wp$ Nm

= $0.0025 \times 418 \times 8$ Nm

= 8 Nm

Required Specification:

Based on the requirements and availability of components, the following specifications are selected.

Motor: 775 motors,9000 RPM

Step Motor: MG 995,15 kg-cm, 8 rad/s

CHAPTER 5

DESIGN

5.1 PART DESCRIPTION

5.1.1 Flywheel

A solid piece of mild steel in the shape of a disc with a bore in the geometric center. This is an important component of the CMG because its rotation aids in the gyroscopic effect required to keep the two-wheeler balanced.

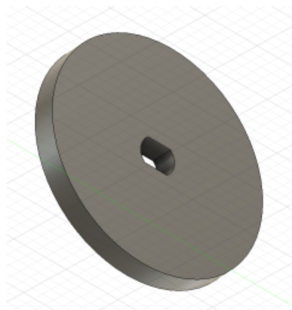

Figure 5.1: Flywheel

5.1.2 Gimbal

This mild steel item is required to provide the second axis of the gyroscope with the necessary free movement to assist the development of precession force.

5.1.3 M10 Arbor

It links the flywheel to the motor. This aids in the rotation's retention. This is constructed of mild steel.

Figure 5.2: M10 Arbor

5.1.4 Motor

A DC motor with a maximum speed of 6000 rpm. The Arduino may be used to control the motor's speed and acceleration.

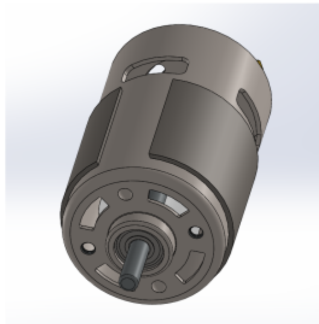

Figure 5.3: motor

5.1.5 Chassis Bottom

The middle chassis and the wheels are connected to this part.

5.2 ASSEMBLY

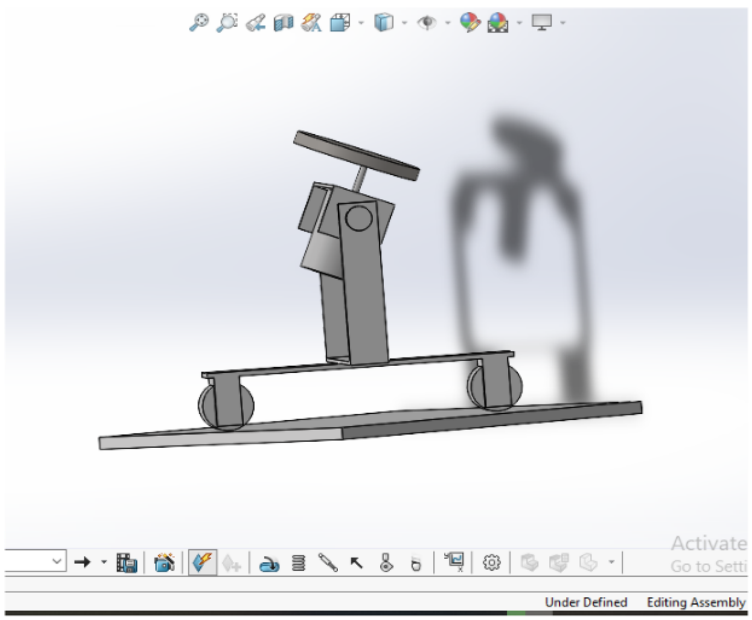

Figure 5.4: 3D model of Test Rig

5.3 ARDUINO CODE

The following code is used to control the servo based on the input values of the sensor.

Finalservompu

```
#include "Wire.h"
#include <MPU6050_light.h>
#include <Servo.h>
float x = 0;
Servo myservo;  // create servo object to control a servo
// twelve servo objects can be created on most boards

int pos = 0;    // variable to store the servo position


MPU6050 mpu(Wire);

long timer = 0;

void setup() {
  Serial.begin(9600);
  Wire.begin();
  myservo.attach(9);
  myservo.write(90);

  byte status = mpu.begin();
  Serial.print(F("MPU6050 status: "));
  Serial.println(status);
  while(status!=0){ } // stop everything if could not connect to MPU6050

  Serial.println(F("Calculating offsets, do not move MPU6050"));
  delay(1000);
  mpu.calcOffsets(true,true); // gyro and accelero
  Serial.println("Done!\n");

}

void loop() {
  mpu.update();
    x = mpu.getAngleX();
    Serial.println(x);
    if(x>2||x<-2){
      myservo.write(90-5*(x));
      Serial.println(90-5*(x));
      delay(100);
      }

  }
```

Done compiling.

Figure 5.5 Arduino code

CHAPTER 6

FABRICATION

In this section the development process of the toy is discussed.

6.1 PART DESCRIPTION

6.1.1 Frame

Based on the requirement, mild steel material is selected. To reduce the dimension error as much as possible frame parts are produced using laser cutting.

6.1.2 Flywheel

Dimensions of the flywheel are a radius of 10cm and a thickness of 5mm. The flywheel is produced by laser cutting a 5mm thick mild steel plate.

6.1.3 Shaft Connector

M10 Arbor is used to connect the motor with the flywheel.

Figure 6.1: M10 Arbor

6.1.4 Motor

Based on the calculation 775 motors is selected.

Figure 6.2: 775 motor

6.1.5 Arduino

Arduino is used to take the input from the position sensor and to control the servo motor to balance the vehicle.

6.1.6 MUP6050

The MUP6050 sensor is used to find the position of the frame.

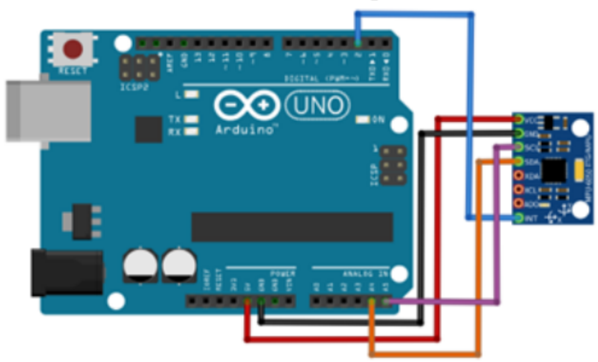

Figure 6.3: MPU6050 sensor along with Arduino

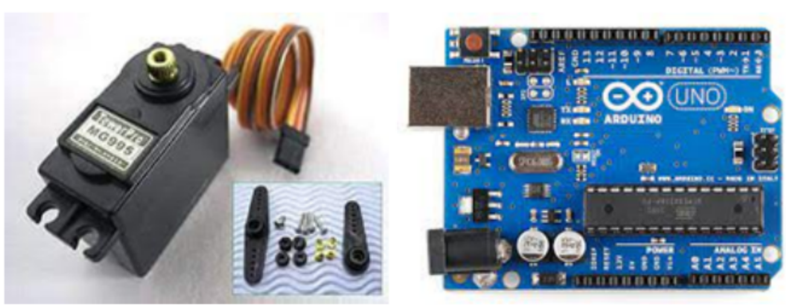

Figure 6.4 & 6.5: Servo MG990 & Arduino Uno

6.1.7 Servo Motor

Servo motor is used to control the precession axis.

6.2 FABRICATION

Assembly of motor, flywheel, and sensor.

The frame parts are joined and welded together.

6.2.1 Laser Cutting

The parts are designed as shown in figure 6.5 with the help of AutoCAD.

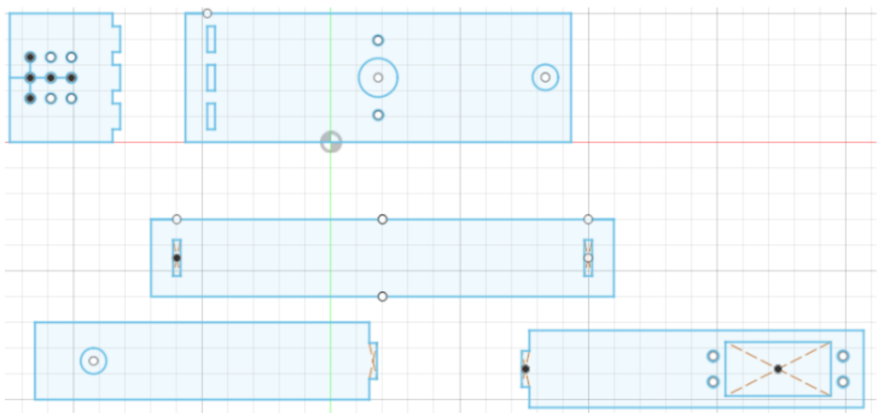

Figure 6.6: Frame and Gimbal Design in AutoCAD

Parts are laser cut and welded as in figure 6.6.

6.2.2 Assembly

The servo is attached to one end of the frame and is connected to the gimbal. The DC motor is then attached to the gimbal. The flywheel is then connected using the M10 Arbor to the shaft.

CHAPTER 7

RESULTS

7.1 THEORETICAL RESULTS:

Vehicle Type	Mass of disc (kg)	Radius of the disc (cm)	W (rpm)	Wp (rad /s)	Mass of Vehicle(Kg)	Height of COG (cm)	Torque Required (Nm)	Torque Produced (Nm)
Test Rig	0.5	10	1400	8	4	15	3	8
Fully enclosed vehicle	10	15	3500	21	400	70	1400	1729
Electric scooter	10	15	1700	21	325	50	812	992

Table 7.1: Specification of components selected

7.2 SIMULATION RESULTS

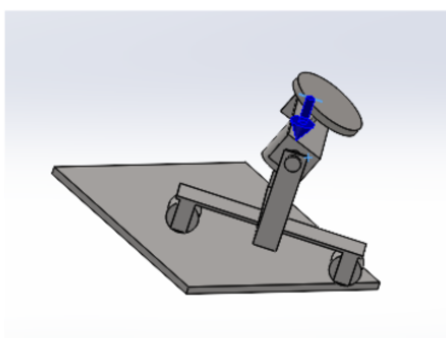

Figure 7.1: 3D CAD Model indicating the force applied

40N force is applied as shown in figure 7.1 and the reaction force generated by precession is shown in figure 7.2.

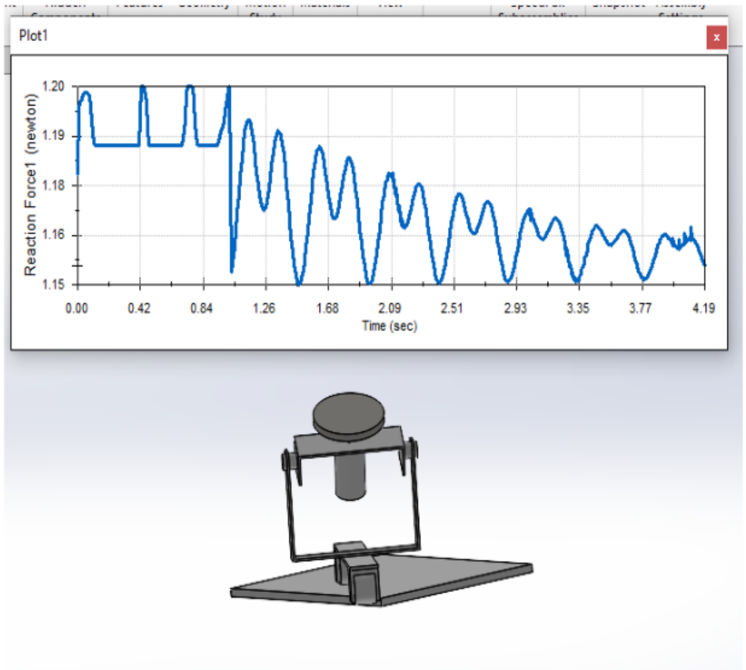

Figure 7.2 : Reaction force generated by precession

7.3 GRAPHICAL RESULTS:

Variation of the torque produced with respect to change in the parameters.

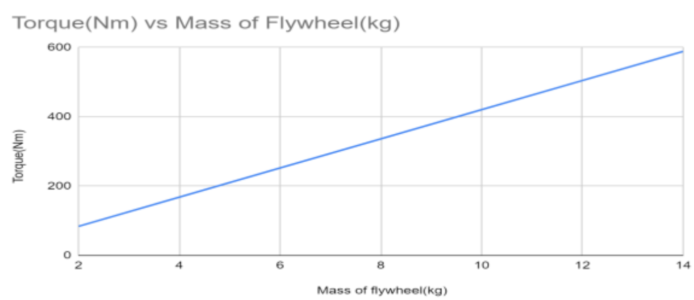

Figure 7.3: Graph of variation of torque with respect to the mass of the flywheel.

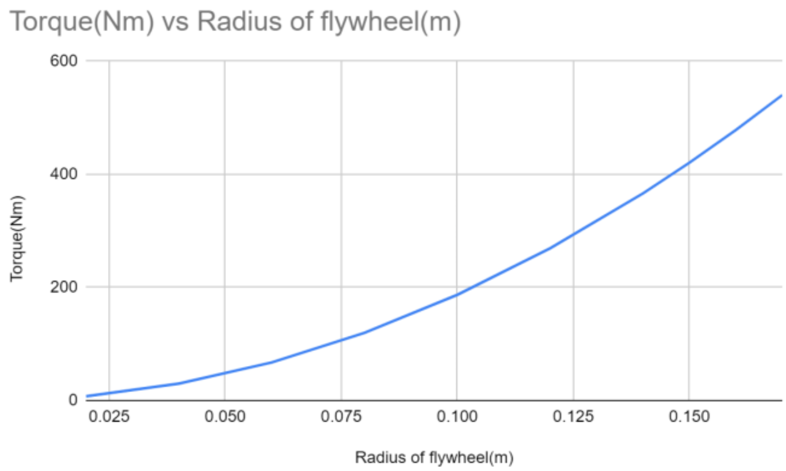

Figure 7.4: Graph of variation of torque with respect to the radius of the flywheel.

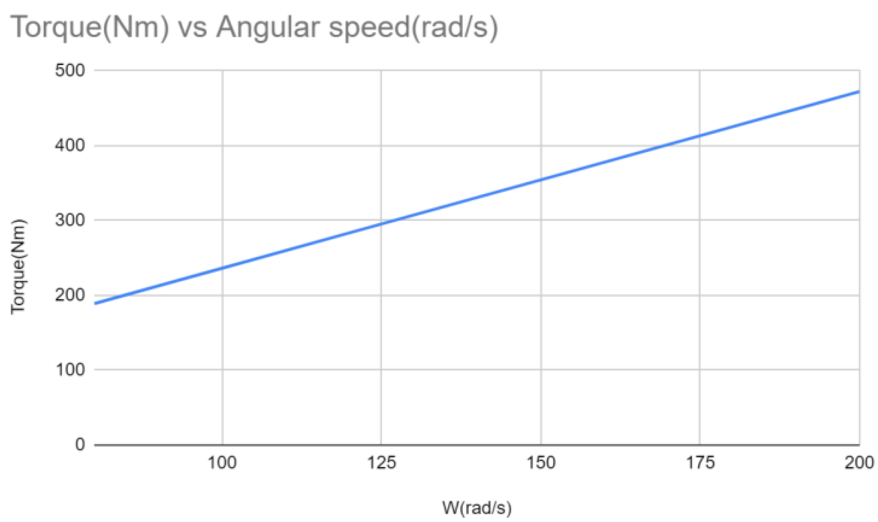

Figure 7.5: Graph of variation of torque with respect to the angular speed.

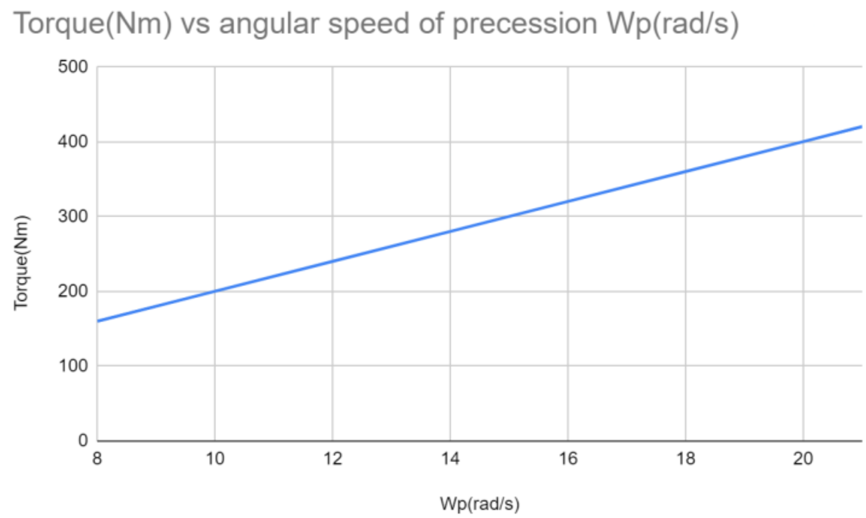

Figure 7.6: Graph of variation of torque with respect to the angular speed of precession.

REFERENCES

[1] .T. Náhlík and D. Smetanová, “Applications of Gyroscopic Effect in Transportation,” NAŠE MORE Znan. časopis za more i Pomor., vol. 65, no. 4 Special issue, pp. 293–296, 2018.

[2] L. Brennan, “Means for imparting stability to unstable bodies.” Google Patents, Aug. 08, 1905.

[3] P. Schilowsky, “Gyroscope.” Google Patents, Apr. 27, 1915.

[4] M. P. Schilowsky, “Demonstration of Some Applications of the Gyroscope,” Proc. Phys. Soc. London, vol. 35, no. 1, p. 125, 1922.

[5] P. Schilowsky, “Monotrack-vehicle.” Google Patents, Oct. 15, 1912

[6] Ghosh, M. and Mukhopadhyay, S., 2009, December.Stability Analysis of a Two-wheeler during Curve Negotiation under Braking. In Proc. The 14th National Conference on Machines and Mechanisms (NaCoMM09).Rajan Verma, Tapas Sharma, Aishwarya Vardhan, Pravin Kumar Singh,(2016), ―Designing and Fabrication of Hybrid Bicycle‖, IJESC, Volume 6

[7] Jeyaprakash, N., Haile, A. and Arunprasath, M., 2015. The parameters and equipment used in TIG welding: A review. The

International Journal of Engineering and Science (IJES), 4(2), pp.11-20.

[8] James Demello, How to Build a Self-Balancing Gyroscopic Vehicle

[9] Gallaspy, J.M., 2000. Gyroscopic stabilization of an unmanned bicycle (Doctoral dissertation, Auburn University).

[10] r, U., Linker, R. and Gutman, P.O., 2008, September. t stabilization of an unmanned motorcycle. In 2008 IEEE ence on Robotics, Automation, and Mechatronics (pp.)6). IEEE.

[11] Jackson Wahl, Dhanush Madabusi & Scout Stohrer Lit Motors & A New Power in Personal Transport Case Study

[12] Professor Amato Parsa Hoghooghi Chiara Settineri Trilok Sadarangani Lit Motors & A New Power in Personal Transport Case Study I&E 352

[13] J. G. Bitterly,Aug. 1998, "Flywheel technology: past, present, and 21st century projections," in IEEE Aerospace and Electronic Systems Magazine, vol. 13, no. 8, pp. 13-16, doi: 10.1109/62.707557.

[14] Sang K. Ha, 2012,Design optimization and fabrication of a hybrid composite flywheel rotor.

[15] J. Park, C. Kalev and H. F. Hofmann, "Control of High-Speed Solid-Rotor Synchronous Reluctance Motor/Generator for Flywheel-Based Uninterruptible Power Supplies," in IEEE Transactions on Industrial Electronics, vol. 55, no. 8, pp. 3038-3046, Aug. 2008, doi: 10.1109/TIE.2008.918583

[16] Robert J.Bauer,2002, Kinematics and dynamics of a double-gimbal control moment gyroscope

[17] E. Mumm, K. Davis, M. Mahin, D. Neal and R. Hayes, "Miniature Control Moment Gyroscope development," 2014 IEEE Aerospace Conference, 2014, pp. 1-9, doi: 10.1109/AERO.2014.6836474.

[18] J. Chen, P. Ye, H. Sun and Q. Jia, "Design and motion control of a spherical robot with control moment gyroscope," 2016 3rd International Conference on Systems and Informatics (ICSAI), 2016, pp. 114-120, doi: 10.1109/ICSAI.2016.7810940.

[19] M.-H. Hsieh, Y.-T. Chen, C.-H. Chi, and J.-J. Chou, “Fuzzy sliding mode control of a riderless bicycle with a gyroscopic balancer,” in 2014 IEEE International Symposium on Robotic and Sensors Environments (ROSE) Proceedings, 2014, pp. 13–18.

[20] T.-D. Chu and C.-K. Chen, “Design and implementation of model predictive control for a gyroscopic inverted pendulum,” Appl. Sci., vol. 7, no. 12, p. 1272, 2017

Batch_11_DESIGN AND FABRICATION OF CONTROL MOMENT GYROSCOPE FOR STABILITY IN TWO WHEELERS (1).pdf

ORIGINALITY REPORT

19%	15%	8%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	repository.its.ac.id Internet Source	5%
2	www.academia.edu Internet Source	3%
3	ieeexplore.ieee.org Internet Source	2%
4	Jae-Do Park, C. Kalev, H.F. Hofmann. "Control of High-Speed Solid-Rotor Synchronous Reluctance Motor/Generator for Flywheel-Based Uninterruptible Power Supplies", IEEE Transactions on Industrial Electronics, 2008 Publication	1%
5	www.coursehero.com Internet Source	1%
6	www.ijesrt.com Internet Source	1%
7	Liang Yan, I-Ming Chen, Chee Kian Lim, Guilin Yang, Kok-Meng Lee. "Empirical formulation of torque output for spherical actuators with	1%

low-cost rotor poles", 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2009
Publication

8	R Sidharth, V K Pranav, G Nitheesh Kumar, Pramod Sreedharan, G Gayathri. "Investigations on the Stability of a Two-Wheeled Vehicle with a Tendency to Topple Sideways", Journal of Physics: Conference Series, 2021 Publication	1 %
9	Submitted to October University for Modern Sciences and Arts (MSA) Student Paper	1 %
10	Submitted to Campbellsville University Student Paper	<1 %
11	Submitted to Universiti Teknikal Malaysia Melaka Student Paper	<1 %
12	digitalcommons.du.edu Internet Source	<1 %
13	Submitted to Amity University Student Paper	<1 %
14	hrcak.srce.hr Internet Source	<1 %
15	Submitted to Da Yeh University Student Paper	<1 %

16	Hsieh, Ming-Hung, Yen-Ting Chen, Cheng-Hung Chi, and Jui-Jen Chou. "Fuzzy sliding mode control of a riderless bicycle with a gyroscopic balancer", 2014 IEEE International Symposium on Robotic and Sensors Environments (ROSE) Proceedings, 2014. Publication	<1 %
17	Submitted to Korea University of Technology and Education Student Paper	<1 %
18	Www.cakeresume.com Internet Source	<1 %
19	www.osti.gov Internet Source	<1 %
20	Submitted to VNR Vignana Jyothi Institute of Engineering and Technology Student Paper	<1 %
21	J.G. Bitterly. "Flywheel technology: past, present, and 21st century projections", IEEE Aerospace and Electronic Systems Magazine, 1998 Publication	<1 %
22	Limei Tian, Dengyun Wu, Dazhong Wei, Yuewei Hu, Hao Wu, Zhiqiang Lv. "Fault diagnose and tolerance technology for position detecting system based on dual resolvers", Proceedings of 2014 IEEE Chinese	<1 %

Guidance, Navigation and Control Conference, 2014
Publication

23	betterbicycles.org Internet Source	<1 %
24	Erik Mumm, Kiel Davis, Matt Mahin, Drew Neal, Ron Hayes. "Miniature Control Moment Gyroscope development", 2014 IEEE Aerospace Conference, 2014 Publication	<1 %

Exclude quotes	On	Exclude matches	< 3 words
Exclude bibliography	On		