Design and Analysis of Gyro Wheel for Stabilization of a Bicycle

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Abstract— This paper contains detailed description of designing and analysis of Gyrowheel used for the stabilization of the bicycle. The Gyrowheel is a special kind of wheel which is designed as an alternative to the training wheels used in bicycle for new learners.The Gyrowheel works on the principle of Gyroscopic effect cause by the rotating flywheel .The Gyrowheel consists of a solid disk flywheel inside it which is spinning independently. The flywheel rotates at a high speed and creates a gyroscopic effect known as gyroscopic precession. The Gyrowheel detects the direction of fall and precession the direction of fall and re-stabilizes the wheel. It is design as a special type of wheel working on mechanical aspects that would be able to balance itself i.e. it would maintain vertical position because the rotating flywheel nullified all the forces acting upon the wheel. For designing of the Gyrowheel, 3d modeling software used is CATIA V5.0. Structural analysis is done to find thestress distribution and the deformation on the model. For structural analysis ANSYS software is used.

Key words: Gyro Wheel, Bicycle

I. Problem Statement

To design a special kind of wheel working on gyroscopic effect which could resist itself from falling down, that would replace the front wheel of bicycle and would eliminate the use of training wheels for a new bicycle learner. In order to do so we are designing a Gyrowheel inside which a flywheel would be rotating at high rpm with the help of battery operated motor. This rotational motion would create a self-balancing effect due to which wheel would remain stable. Hence, a new learner would not hesitate or fear to ride a bicycle.

II. Objectives of the Project

A. To Maintain the Wheel in Vertical Position

The Gyrowheel consists of a flywheel which is co-axially aligned with the wheel. The flywheel needs to be rotated at a desired speed to obtain the required gyroscopic effect. When the flywheel rotates at the respective all the forces acting on it are nullified due to the rotation. The flywheel is coupled to a DC motor with friction drive method and this motor drives the flywheel which creates gyroscopic effect and helps in processing of the wheel in vertical direction.

B. To Replace the Training Wheels Used for Bicycle Learners

The Gyrowheel works on the simple principle of a gyroscope. Gyroscopes are spinning wheels which have a special property called precession. Due to the this effect it helps the wheel from falling down. As a result, the learners experience the effect and avoid falling down while learning the bicycle. This completely cuts off the use of training wheels used for supporting learners.

C. To Rotate the Flywheel to the Desired Speed

To create the gyroscopic effect in the Gyrowheel the flywheel needs to be rotated at the respective speed (rpm). This is done by using a D.C motor. D.C motor has a high starting torque and starting time is also less so it is used for the purpose. The D.C motor is coupled to the flywheel by a friction wheel.

III. Design and Selection of Components

Following general components of Gyrowheel are to be designed and selected:

1) Flywheel
2) Bearing
3) Axle
4) Motor
5) Motor Clamps
6) Friction Wheel
7) Mounting Strips
8) Battery
9) Wheel

IV. Calculations

A. To Find Out the Required Actual Speed of Flywheel

Considering that bicycle remains stable at the speed of 30 km/hr.
Diameter of the front wheel = 14 inch=14" = 0.355 m
Therefore, Rpm of the wheel at this speed

$$V = \frac{\pi DN}{60}$$

$$N = \frac{30\times1000\times1000}{\pi\times355.6\times60} = 447.48 \text{ rpm}$$

Moment of inertia, $I = MK^2$

$$M = 0.2 \text{ kg}, K = \frac{14"}{2} = 0.1778 \text{ m}$$

Therefore, $I = 0.2\times (0.1778)^2 = 0.0063226$ kg-m^2

$$\text{And, } \omega = \frac{2\pi N}{60} = 46.83 \text{ rad/s}$$

Therefore, Angular Momentum:

$$L = I\omega = (6.32\times10^{-3}) \times 46.83 = 0.2961 \text{ kg-m}^2/\text{s}$$

Flywheel:

$$D = 0.175 \text{ m} \qquad M' = 0.5 \text{ kg}$$

Therefore, moment of inertia

$$I' = \frac{M'R^2}{2} = \frac{0.5}{2} \times (\frac{0.175}{2})^2 = 0.001914 \text{ kg-m}^2$$

Comparing with the angular momentum of the bicycle wheel,

$$L = I'\omega' = 0.2961 = 1.9140 \times 10^{-3} \times \omega' \quad \omega' = 154.64 \text{ rad/s}$$

But, $\omega' = \frac{2\pi N'}{60}$

Therefore, $N' = \frac{154.64\times60}{2\pi}$

N'=1478 rpm.

B. To Find Out Reactive Gyroscopic Couple

So the gyrowheel should be rotating at the above speed to be stable.
So let's rotate it at 1500 rpm

Therefore, $\omega' = \frac{2\pi \times 1500}{60} = 157\ rad/s$
Now let mass of the rider &bicycle be 20.5kg.
Assume that bicycle tilts by 15' from the vertical axis.
$F = MgSin15°$
$= 20.5 \times 9.81 \times sin15°$
$= 52.04$ N
Now angular velocity of precession,
$\omega_p = \frac{T}{L} = \frac{52.04 \times 0.0875}{0.2961} = 15.38$ rad/s
Reactive Gyroscopic Couple:
$C = I\omega'\omega_p$
$= 0.2961 \times 154.64 \times 15.3 = 704.23\ kg - m^2/s$
This couple will cause the handle of the bicycle to turn to the right. To compensate , we will have to apply the active gyroscopic couple i.e. forced precession so that the bicycle is balanced.

C. *Friction drive*

D_1 , Diameter of driving wheel = 75 mm = 0.075 m
D_2 , diameter of driven wheel = 175 mm = 0.175 m
Speed of driving wheel, N_1 = 6000 rpm
Let the speed of driven wheel i.e. Gyrowheel be N_2
Therefore, $\frac{N_1}{N_2} = \frac{D_2}{D_1}$
Therefore, $\frac{6000}{N_2} = \frac{175}{75}$
Therefore, N_2=1909.85rpm
But actual speed of gyrowheel is 1400rpm
Therefore, Drive efficiency is
$\eta = \frac{Actual\ output\ speed}{Theorotical\ output\ speed} = \frac{1400}{1909.85}$
η = 73.30%

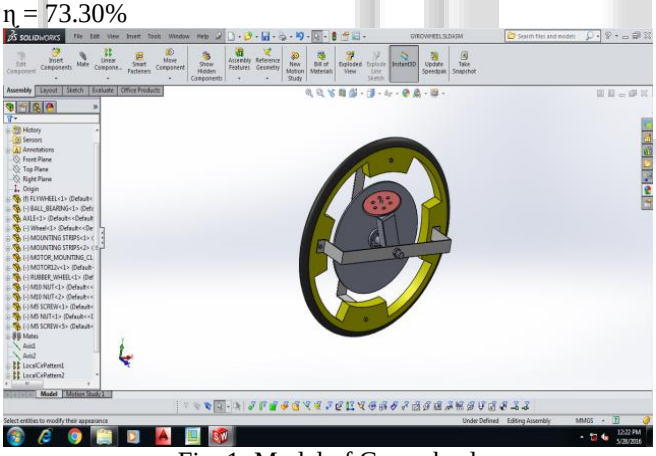

Fig. 1: Model of Gyrowheel

V. ANALYSIS

In this work a simple structural analysis has been done for the designed Gyrowheel model. Software used for the analysis of Gyrowheel is ANSYS 14.5 Workbench module. Structural analysis to find maximum stress values and maximum deformation on the flywheel, ball-bearing and axle. The analysis is done by FINE MESH technique with fully defined state. The Geometry is Modeled in Solid-works and Step format file is imported into ANSYS design modeler. The imported geometry is meshed with FINE MESH in ANSYS MESH module in Workbench. We have assumed the mass of rider and bicycle be 20kg. Hence the force equal to 50.78N is applied along the direction of spin axis and this force helps to lean the bicycle in either direction.

From the ANSYS software the total number of nodes genearated are 226986 and the total number of elements are 111227. Total volume is 85118mm^3 and mass is 0.66817kg. The representative stress and deformation contours for principal stresses on flywheel, ball-bearing and axle along with the deflection are shown in figure 2 and 3.

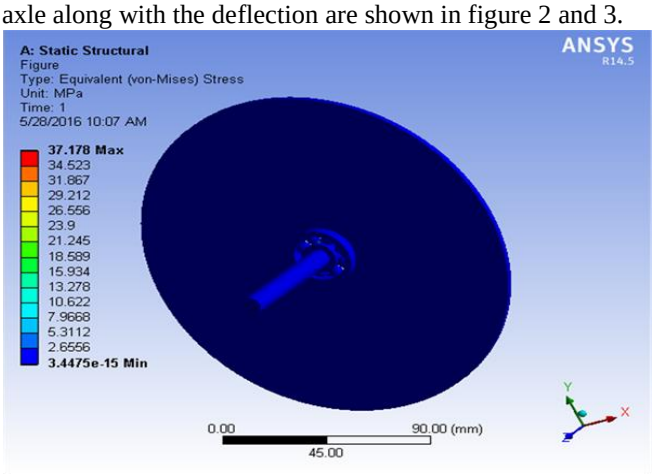

Fig. 2: Stress Analysis

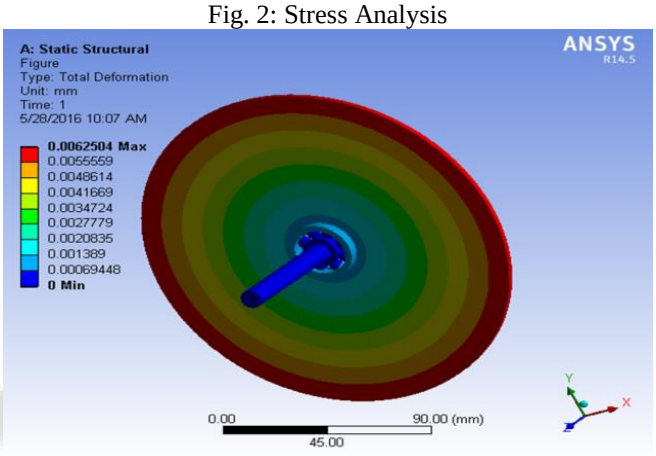

Fig. 3: Displacement Analysis

A. *Analysis of Flywheel*

The Flywheel is an important part of the gyrowheel. A flywheel is a mechanical device with a significant moment of inertia used as a storage device for rotational energy. Here diameter of the flywheel is 175mm and weight of the flywheel is 0.5kg. Maximum and minimum deformations are shown in figure 3. From the total deformation contour plot the maximum value of 0.0062504mm deformation is found on outer periphery of the flywheel. Minimum occurs at the centre of the flywheel.

B. *Analysis of Ball-Bearing*

From von-Mises stress contour plot the maximum value of 37.178Mpa is found on the contact point of balls and the outer race of bearing. Minimum occurs at inner race of the bearing.

C. *Analysis of Axle*

Axle is the component of the Gyrowheel in which flywheel and regular wheel of bicycle is mounted. From von-Mises stress contour plot the minimum value of 3.4475×10^{-15} Mpa is obtained.

VI. CONCLUSION

In the course of this project, the design and analysis of Gyrowheel was done. The attempt to replace or find an alternative to training wheels used in bicycle for new learners was successfully completed. This project is implemented with an idea to find an effective solution for safety of children while learning to ride a bicycle. The main objective is to achieve space utilization, making it cost efficient, less complicated and simpler in use. The use of Gyrowheel has a wide range of applications that can be harnessed in the near future.

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APPENDIX

[1] Analysis- Detailed examination of the elements or structure of something.
[2] Angular Momentum- It is the physical analogy of linear momentum. It is a conserved quantity.
[3] Factor of safety- It is the ratio of the ultimate strength of a member or a piece of material to the actual working strength of the material.
[4] Flywheel- A heavy revolving disc in a machine used to increase momentum and provide greater stability to it.
[5] Gyroscope- A device consisting of a wheel or disc so mounted that it spins rapidly about an axis that is free to alter its direction.
[6] Gyrowheel- The wheel designed based on the gyroscopic effect to stabilize itself. It is used to determine the orientation of true north.
[7] Monocycle- A cycle having a single wheel.
[8] Precession- The slow moving of axis of a spinning body around another axis due to torque acting to change the direction of the first axis.
[9] Prototype- A first or preliminary version of a device or technology that is used for analysing and then the other forms are made from it.
[10] Stress- The pressure or tension that is exerted on a body that causes deformation in it.

