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IN-WHEEL EPICYCLIC REGENERATIVE BRAKING SYSTEM

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Abstract

In the response to changing global landscape, energy has become a primary focus of the major world powers. One such technology which has proved to be a very efficient way in energy recovery is the regenerative braking system. However, the efficiency of a conventional regenerative braking lies in the range of 1 to 1.5% with respect to the braking effort, i.e. from maximum to minimum.[1] This is where we find the purpose of our project in increasing the range of generative braking torque at the point of maximum braking effort. The major modification that we have done in the system is that we have introduced an in-wheel planetary gear train. With the help of this mechanical modification, we are aiming to achieve energy recovery thrice that of the conventional regenerative braking system. When the rider applies the brake, the vehicle's motor is made to work as a generator and the wheel transmits the energy to the generator through the planetary gear train which is in turn converted to electrical energy. This electrical energy is stored in the battery packs. With this we are aiming to achieve a 226% of increase in the recovery of energy with respect to conventional regenerative braking system. [2]

I. Introduction

In response to the changing global landscape, efficient energy generation, its utilization and storage has become a primary concern for mankind. Making the energy recovery systems efficient by developing new

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and better systems, methods and techniques are the factors to be aimed for. Taking the mentioned factors into the account we have designed a regenerative braking system which is capable of acquiring and transmitting a huge chunk of energy, by contributing thrice the braking torque that of the conventional regenerative braking system with the help of a planetary gear set with a velocity ratio of 1:3 embedded inside the hub of a motorcycle's rear wheel. In this system the shaft is connected to the wheel though an overrunning clutch and that same shaft shares a solid connection with the sun gear. So, when the power is transmitted from the battery to the wheel through the vehicle's transmission it looks like a straight path as the sun gear and ring gear shares the same connection while rotating anticlockwise but as we apply brakes the supply of power to the motor is stopped which causes the wheel to get free off the shaft with the help of its connection through overrunning clutch. Meanwhile, the motion of the carrier i.e. revolution of the planets is constrained by a miniature disc brake which helps the transmission of energy back from the wheel rim i.e. ring gear to the sun gears via planets. As the gear ratio given is 1:3, the sun gear is made to rotate in clock-wise direction with thrice the speed of wheel and at the same time the wheel will be experiencing a resisting torque which will be thrice that of the resisting torque offered by the 250w motor, eventually contributing towards the overall braking torque required to stop the vehicle in a speci fied distance while supplying the energy from the wheel to the battery via the same D.C. motor, which would else go wasted.

II. Objectives

- The recovery of kinetic energy in the form of electricity during the application of brakes to stop a vehicle's motion, which would else go wasted.

- The project is based on the usage of an in-wheel planetary gear train which uses torque reduction from ring to sun gear which is helpful for increasing generator shaft speed. Hence generating more electrical energy while braking.

- Applications like Solid works and Creo are used for designing and the analysis of the model.

- The designed model is compared with the existing Regenerative

braking system.

III. Literature Survey

- Tijani H Peng (2008). This work presented the major advantages of planetary gear system one of which is splitting the power among the shafts by constraining the motions of various gears, as per the path for the power to be transmitted.

- AJ Walenty (2011). In this work they discussed about the regenerative and friction brake blend control method for use in a vehicle with at least one hydraulic brake actuator for achieving friction braking and an electric motor capable of converting kinetic energy to electrical energy by providing some resistance.

- Mohit Singh et al. (2016). This paper discusses about the use of composite material to provide adequate strength with weight reduction. They compared different composite material and their properties and suitable material was selected by analyzing on materials

- S. Mahendran et al. (2014) In this work they have design spur gear model using design software and studied impact analysis for cast steel and composite material they have also studied torque loading for cast steel and composite material.

- Robert F. Handschuh et al. (2012). In this work it is given about the comparison of the hybrid gear with all steel gear. As result of which it was found that the hybrid gears were more convenient in all aspect i.e. weight reduction without affecting strength

IV. Significance

As the project “In wheel epicyclic regenerative braking system” is mainly focused on increasing the efficiency of a conventional regenerative braking. The usage of the in-wheel epicyclic gear train led us to recover the energy almost 2.5 times to that of the conventional regenerative braking which was calculated as 3 times theoretically.

The conventional regenerative braking has an efficiency of about 1 to

1.5%. [4] In this model we have been able achieve an efficiency of about 3.5%.

Another fact about this project which makes it a topic of research is that the planetary gear set which is used in the wheel is acting as a braking torque multiplier, which is providing RPM three times at the motor shaft than that of wheel during the application of brakes in the vehicle while maintaining the same stopping distance of the motorcycle with the help of torque blending.

V. Design Specifications

- Planetary Gear set

Table 1. Gear specifications.

Parameters	Ring	Planet	Sun
Pitch Circle Diameter(mm)	120	40	40
Teeth	96	32	32
Clearance(mm)	0.3125	0.3125	0.3125
Addendum(mm)	1.25	1.25	1.25
Dedendum(mm)	1.5625	1.5625	1.5625
Thickness(mm)	15	15	15

Gear Ratios:

Epicyclic gear ratio = 1:3

Final drive gear ratio = 1:4

Overall gear ratio = 1:12

Bearings

- Shaft bearing (6003-2Z/C3)

Outer diameter- 35mm

Internal diameter-17mm

Thickness-10mm

- Planetary gear bearing (608ZZ)

Outer diameter-21mm

Internal diameter-17mm

Thickness-7mm

- Material Properties-

Table 2. Material Properties.

Sr. No.	Properties	20mncr5	Aluminium 7075
1.	Density (g/cc)	7.75	2.7
2.	Hardness	335	87
3.	Tensile Strength (MPa)	1158	510
4.	Yield Strength (MPa)	1034	500
5.	Modulus of Elasticity (GPa)	190	71.1
6.	Poisson's Ratio	0.3	0.34

VI. Software Used

- **Creo 5.0.**

Computer Aided Three-Dimensional Interactive Application also abbreviated as CATIA. It is amongst the top designing software available in the market right now and has been used by multiple mechanical industries varying from small basic ones to the topnotch sophisticated industries. It offers many easy-to-use features for different requirements:

- Designing of parts: With the help of this feature one can easily design any part according to the specified dimensions.

- Wireframe: For any complex designing, this feature comes into the play and helps the designer to construct any complex geometry with ease.

- Dynamic Simulation: As just designing is not enough, world class industries requires dynamic/kinematic solutions too.

Figure 1. 3D Model design.

- **Ansys:**

This is one of the most user-friendly and easy to use software amongst its competitors in the market and is capable of solving any type of complex problems, may it be for structural or thermal analysis. It can determine every bit of flaw in great depth with the help of its various engines performing simultaneously some of the parameters it provides are stresses, deformations, modal analysis for vibrational characteristics of the component. While its advanced features are useful for the determination of complex material behaviour properties and various dynamic effects.

The geometries of various complex components designed in designing tools like Creo, CATIA or solid-works can be imported with just a click and then the desired type of analysis can be performed along. As far as, results are concerned, it provides us with the easy to understand graphical images, signifying the areas to be modified for optimal performance.

Note: Total deformation plots have been formed for sustainability expectations of all the gears which includes: sun gear, planet gear and sun gear. The carrier of the gear set has also been analysed.

Carrier:

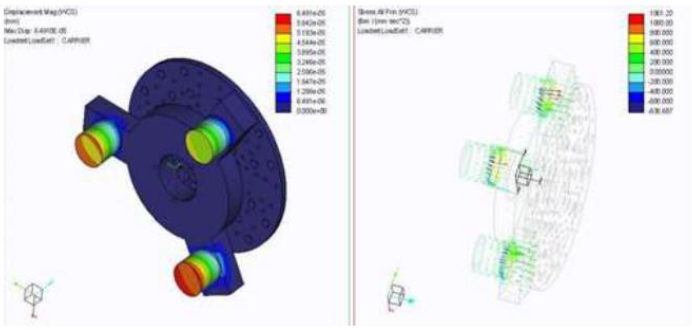

Figure 2. Total deformation.

- **Planet gear:**

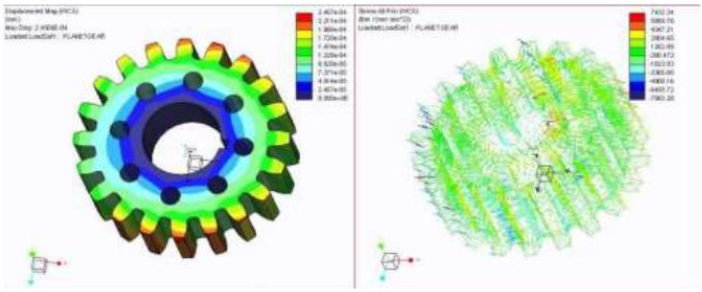

Figure 3. Total deformation.

- Sun gear:

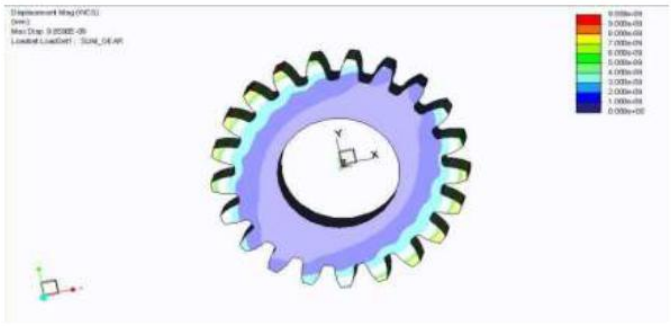

Figure 4. Total deformation.

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- **Ring gear:**

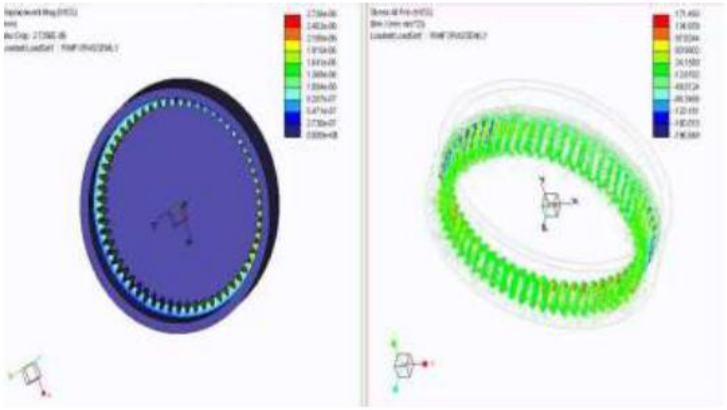


Figure 5. Total deformation.

VII. Calculations

Considerations:

Vehicle model: Honda CB Shine

Average rider's weight: 62kg [6]

Vehicle's weight: 123kg [7]

Assembly's weight: 3kg

Overall weight considered of the vehicle: 188kg

Wheel diameter: 457mm ≡ 0.457m

Wheel radius: 0.228m

Initial velocity of the vehicle: 50 km/h or 13.88m/s

Required time stated to stop the vehicle: 1.6 seconds [8]

Required deceleration can be calculated by equation:

$$v = u + a * t$$

$$13.88 = 0 + a * 1.6.$$

By the above equation we get $a = -8.675\text{m/s}^2$

The total braking force required will be $= m * a$

$$= 188 * 8.675$$

$$= 1631N$$

Hence, total torque required will be:

$$f * r = 1631 * 0.228$$

$$= 371Nm.$$

Total Kinetic Energy in possession of the vehicle while moving at a velocity of 50km/h or 13.88m/s

$$= \frac{1}{2} * m * v^2$$

$$= \frac{1}{2} * 188 * (1388)^2$$

$$= 18.11Kj.$$

Losses considered [1]

- Rolling resistance ~ ex.: energy getting lost in heating the road ~ 4.2%.
- Mechanical friction ~ ex.: losses in bearing ~ 5.6%.
- Aerodynamic resistance ~ ex.: energy lost in heating the surroundings ~ 2.6%.

Available kinetic energy that can be recovered after the above-mentioned losses:

= Total kinetic energy – (rolling loss + mechanical loss + aerodynamic loss)

$$= 18.11 - (0.76 + 1.01 + 0.47)KJ$$

$$= (18.11 - 2.24)KJ$$

$$= 15.87KJ.$$

Manufactured Model

Figure 6 down below represents the isometric view of the working model for the proposed concept.

Figure 6. Manufactured model.

VIII. Results

The motor used in this setup is 250w, 24v dc motor with a rated torque equal to 1Nm.

Comparing both the systems:

Case I.

When conventional regenerative braking system is installed, the braking torque contribution will be

$$= rated\ torque * gear\ ratio$$

$$= 1Nm * 4$$

$$= 4Nm.$$

Its overall contribution will be $= \frac{4}{371} * 100$

$$= 1.078\%.$$

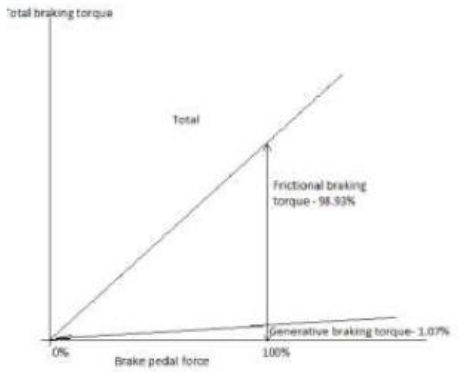


Figure 7. Conventional torque biasing.

Case II: When in-wheel epicyclic regenerative braking system is installed, the braking torque contribution will be

$$= rated\ torque * gear\ ratio$$

$$= 1Nm * 4 * 3$$

$$= 12Nm.$$

Its overall contribution will be $= \frac{12}{371} * 100$

$$= 3.25\%$$

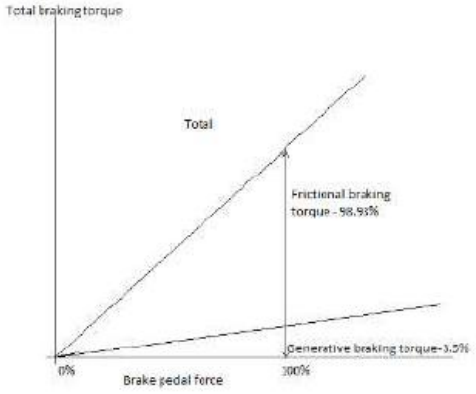


Figure 8. Torque biasing with proposed concept.

IX. Comparison

Here, as we know that energy is directly proportional to torque while keeping the angular displacement constant:

$$E = T * \theta.$$

Case I:

Energy recovered by conventional regenerative braking system

$$= \frac{1.07}{100} * K.E \ of \ the \ vehicle$$

$$= \frac{1.07}{100} * 15.87KJ$$

$$= 0.1698KJ \approx 170J.$$

Case II:

Energy recovered by in-wheel epicyclic regenerative braking system

$$= \frac{3.5}{100} * K.E \ of \ the \ vehicle$$

$$= \frac{3.5}{100} * 15.87KJ$$

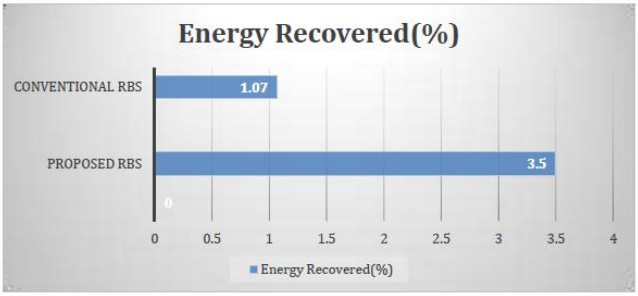
$$= 0.55545KJ \approx 555.45J.$$

Percentage increase in recovery of energy by using the proposed concept

$$= \frac{555.45 - 170}{170} * 100$$

$$= 226\%.$$

*Theoretically, we are able to achieve a 226% of increase in the recovery of energy with respect to conventional regenerative braking.



X. Conclusion and Future Scope

The energy recovered from the vehicle's kinetic energy is expected to be more than twice with respect to energy recovered through conventional regenerative braking system while making the vehicle come to rest from a speed of 50kmph. Even with low oil prices, the future of electric vehicles seems to be bright. Decreasing battery prices, availability of longer-range models and more charging stations are the reasons for the exponential growth of the electric vehicle sales and alongside auto industry is investing in billions of dollars to reduce the strong pollution levels globally, the oil industry has good reasons to be nervous. Also, as per the predictions of experts, the EV sales is expected to grow 60% worldwide last year, Bloomberg new energy finance, which predicts in an article that the EVs will account for 35% of new car sales globally by 2040. Hence the efficiency of regenerative braking system will be matter of concern.[9] Furthermore, this system is relatively reliable as compared to the conventional system.

The future work can be carried out by:

- It can be used for high end electric bikes to increase their range.
- Further the weight of the assembly can be reduced.
- The analysis and simulation of the system at higher speeds can be performed.
- It can be made more efficient by just increasing the gear ratio of the planetary gear set.

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