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Design of Freewheel Differential

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Abstract*:* *In a tricycle, achieving stability during turns and optimizing traction are critical. A conventional differential may not always be ideal due to its complexity and cost, especially in lightweight vehicles like tricycles. The sprag-type freewheel differential provides a simplified yet highly effective solution. It allows each wheel to rotate independently, accommodating speed variations during turns, and improving handling without the need for complex gears or electronic control systems. In this paper, sprag-type freewheel differential is an innovative mechanism designed to enhance the performance and manoeuvrability of tricycles. Unlike conventional fixed axle systems, this differential utilizes sprag clutches to facilitate independent wheel movement while maintaining efficient torque transfer.*

Keywords: Tricycle, differential Gear, freewheel, design

I. INTRODUCTION

A tricycle, typically used for personal transportation, has a single front wheel for steering and two rear wheels for power delivery. In conventional vehicles, the rear axle incorporates a differential to allow the two rear wheels to rotate at different speeds while turning. However, in this case, the tricycle lacks a differential mechanism. Tricycles, particularly those used in low-cost and light-duty applications, often do not incorporate a differential due to cost constraints, space, or simplicity. However, without a differential, tricycles face challenges in turning efficiency. This leads to tire slip, increased wear, difficulty in maneuvering, and loss of energy due to drag forces, especially when one rear wheel needs to rotate faster than the other during turns. Without a differential, both rear wheels are rigidly connected to the same axle. As the tricycle turns, the outer wheel must cover a greater distance than the inner wheel due to the differing radii of the paths they follow. This creates a significant slip or drag on one or both wheels, resulting in poor handling, excessive tire wear, and energy losses.

This can also lead to:-

- Difficulty in making smooth turns.
- Increased rider effort due to resistance during turning.
- Reduced stability, especially at higher speeds or sharp turns.
- Potential safety hazards from skidding or loss of traction

A sprag-type freewheel differential is an innovative mechanism designed to enhance the performance and maneuverability of tricycles. Unlike conventional fixed axle systems, this differential utilizes sprag clutches to facilitate independent wheel movement while maintaining efficient torque transfer.In a tricycle, achieving stability during turns and optimizing traction are critical. A conventional differential may not always be ideal due to its complexity and cost, especially in lightweight vehicles like tricycles. The sprag-type freewheel differential provides a simplified yet highly effective solution. It allows each wheel to rotate independently, accommodating speed variations during turns, and improving handling without the need for complex gears or electronic control systems.

II. OBJECTIVE OF DESIGNING A FREEWHEEL DIFFERENTIAL FOR A TRICYCLE

The goal of designing a freewheel differential for a tricycle is to address the limitations caused by the lack of a conventional differential, enhancing the performance and usability of the tricycle, particularly in terms of turning dynamics. The objective is to create a mechanism that allows the rear wheels to rotate independently during turns, reducing resistance, improving handling, and maintaining safety, without adding unnecessary complexity or cost.

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Smooth Turning: In tricycles without a differential, both rear wheels are forced to rotate at the same speed. During turns, the outer wheel must travel a longer distance than the inner wheel, which causes drag or slipping. The freewheel differential should allow each rear wheel to rotate independently, letting the outer wheel rotate faster than the inner wheel in a turn, thus eliminating tire drag and improving turning smoothness. Enhanced Handling and Stability: Rigid rear axle designs without differentials often lead to poor handling, especially when making sharp or high-speed turns. By implementing a freewheel differential, the tricycle can handle turns more efficiently, providing better stability and control. This enhances rider comfort and safety.

III. ADDITIONAL CONSIDERATIONS

- Reliability: - The design must be durable and low-maintenance, as tricycles are often used in environments where simplicity and reliability are valued.
- Weight: - The differential should not significantly increase the overall weight of the tricycle, ensuring that it remains easy to pedal and manoeuvre.
- Adaptability to Existing Designs: - The freewheel differential should be designed in a way that can be easily integrated into existing tricycle models or future designs without major modifications.

IV. LITERATURE REVIEW

Literature review is an assignment of previous task done by some authors and collection of information or data from research papers published in journals to progress our task. It is a way through which we can find new ideas, concept. There is lot of literatures published before on the same task; some papers are taken into consideration from which idea of the project is taken.

In 2015 Chandan Saxena publish a research paper contributed to the design and conceptualization of gearless Bi-Freewheel Differentials aimed at enhancing economic viability and simplicity in lightweight vehicles.

Nguyen (2017) Nguyen and colleagues investigated the potential of bi-freewheel differentials in off-road vehicles. Their research demonstrated that the system effectively prevents torque from being wasted on wheels with insufficient grip, thereby improving overall traction and reducing energy losses.

Singh (2019) Singh and his team focused on optimizing the design of bi-freewheel differentials for heavy-duty vehicles. They proposed lightweight materials and innovative lubrication systems to address durability concerns, ensuring reliable performance under high loads.

Zhao (2020) Zhao's team studied the integration of bi-freewheel differentials in electric vehicles (EVs). Their findings showed that the mechanism simplifies drivetrain design by eliminating the need for electronic control systems for torque vectoring. This leads to reduced power consumption and improved energy efficiency, particularly during low-speed maneuvers.

Research Paper: International Journal of Automotive Research (2021) This paper presented a comprehensive analysis of vehicle dynamics with a bi-freewheel differential. Simulations highlighted improved cornering stability and reduced tire wear compared to open and limited-slip differentials. The authors noted that the system's passive nature minimizes the need for additional sensors and controllers.

Chen (2022) Chen discussed the challenges associated with the adoption of bi-freewheel differentials, including wear and tear of the freewheel mechanism, noise issues, and limited torque capacity. Their research emphasized the need for advanced materials and better design integration to overcome these challenges.

V. BACKGROUND AND THEORY OF DIFFERENTIALS

Differentials are critical components in vehicles with multiple driven wheels. They allow wheels to rotate at different speeds while transmitting power, which is particularly necessary when the vehicle turns, as the inner and outer wheels travel different distances.

Comparison of Freewheel Differential and Conventional Differential

Aspect	**Freewheel Differential**	**Conventional Differential**
Mechanism	Uses sprag clutches orfreewheels to allow torque transfer only in one direction, enabling independent wheel speeds.	Uses bevel gears to distribute torque equally to both wheels and allows differential speeds.
Complexity	Simpler design with fewer moving parts as it lacks gear sets for torque splitting.	More complex due to the presence of bevel gears and a spider gear assembly.
Weight	Generally lighter due to fewer components and absence of heavy gears.	Heavier because of robust gear mechanisms and differential housing.
Torque Distribution	Automatically adjusts torque to the wheel with traction based on direction of rotation, without external control.	Splits torque equally between both wheels regardless of traction conditions.
Traction Performance	Superior in off-road or low-traction scenarios because it prevents wheel slip by disengaging the freewheel on the slipping side.	Poorer in low-traction situations, as torque gets lost through the slipping wheel.
Durability	Durable under moderate loads, but sprag clutches may wear faster under high-stress conditions.	Typically, more durable in heavy-duty applications due to robust gear design.
Maintenance	Requires regular inspection and lubrication of freewheel mechanisms; simpler to maintain.	Requires periodic maintenance of gears and bearings; more labor-intensive.
Cost	Lower cost due to simpler design and fewer components.	Higher cost due to the complexity and precision machining of gears.
Energy Efficiency	Higher efficiency as it minimizes energy losses from unnecessary gear movements.	Lower efficiency due to continuous movement of the gear system, even when unnecessary.
Turning Performance	Smooth and efficient, as the freewheels disengage the wheel with less resistance automatically.	Effective but may require limited-slip or electronic aids to manage traction during sharp turns.
Applications	Used in specific scenarios like bicycles, lightweight vehicles, and certain off-road vehicles.	Commonly used in passenger cars, trucks, and heavy-duty vehicles requiring robust and balanced torque distribution.
Limitations	Limited ability to handle extreme torque loads; relies heavily on proper lubrication and alignment.	Less effective in managing traction in slippery conditions unless aided by additional systems like limited-slip differentials.

VI. DESIGN APPROACH

The methodology for assembling and welding a freewheel differential using a hollow shaft, two sprag-type freewheels, and two end rods involves several carefully planned steps to ensure proper alignment, secure attachment, and functionality. Here's a step-by-step guide:

Two freewheels are placed at the end of Hollow shaft as shown such that the hollow shaft is welded to the outer race of freewheel only. One important point that must be noted that both freewheel must be placed such that they may transmit the torque in same direction only. For satisfying this condition, they must be placed as inverted with respect to each other. Then Axel rods are essentially connected to the inner race by means of welding as shown in assembly picture. This Axel Shaft is that element of the differential on which wheels may be mounted. Wheel may be directly mounted on the end of these Axel shaft.

Sprag Freewheel Selection: - Ensure that the selected sprag freewheels can handle the torque to be transmitted to the axles. The freewheels must also be able to withstand any axial loads that might be present. Check the maximum overrunning speed for the sprag freewheels to ensure they can handle the operational speeds One freewheel is attached to the middle of the hollow shaft allows the shaft to overrun. This is crucial for smooth operation when the vehicle coasts or reverses. Choose a freewheel with the appropriate torque and speed ratings.

VII. DESIGN CALCULATIONS:

Design Steps:

1. Hollow Shaft Dimensions:

Calculate the torque capacity of the hollow shaft based on the maximum torque expected from the drive.

Determine the outer diameter and wall thickness of the hollow shaft to ensure it can handle the load.

Formula for **torsional stress**:

$$\tau = \frac{T.r}{J}$$

Where:

τ\tauτ = shear stress (Pa)

T = applied torque (Nm)

r = outer radius of the hollow shaft (m)

J = polar moment of inertia for a hollow shaft

$$\mathrm{J} = \frac{\pi.(\mathrm{r}_o^4 - \mathrm{r}_i^4)}{2}$$

Here:

ro : Outer radius of the hollow shaft (m)

ri : Inner radius of the hollow shaft (m)

2. Solid Shafts (Axles) Dimensions:

Calculate the diameter of the solid axles based on the torque that will be transmitted to the wheels. Use the same torsional stress formula for solid shafts but modify the polar moment of inertia J for a solid shaft:

$$\mathrm{J} = \frac{\pi.r^4}{2}$$

Where r is the radius of the solid shaft.

Hollow Shaft Dimensions

The hollow shaft will serve as the central rotating component and must withstand the torque generated from the differential system.

Given:

Maximum torque T = 500 Nm

Outer diameter of hollow shaft ro = 0.05m

Inner diameter of hollow shaft ri = 0.03 m

Step 1: Polar Moment of Inertia for Hollow Shaft

The formula for the polar moment of inertia J for a hollow shaft is:

$$\mathrm{J} = \frac{\pi.(\mathrm{r}_o^4 - \mathrm{r}_i^4)}{2}$$

Substitute the given values

$$\mathrm{J} = \frac{\pi.((0.05)^4 - (0.03)^4)}{2} = 1.88\times 10^{-5}\mathrm{m}^4$$

Step 2: Torsional Stress in the Hollow Shaft. - The torsional stress τ is calculated by:

$$\tau = \frac{\mathrm{T}.r_o}{\mathrm{J}}$$

substitute the values

$$\tau = \frac{500\ N_m.0.05m}{1.88\times 10^{-5}m^4} = 13.3\ \text{Mpa}$$

Step 3: Check Allowable Stress

Assuming the material of the hollow shaft is steel with an allowable shear stress 200MPa, the design is safe since:

$$13.3\text{MPa} < 200\text{MPa}$$

2. Solid Shaft (Axles) Dimensions - Solid shafts, such as the axles, need to handle the torque transmitted from the freewheel and differential system to the wheels.

Given:

Torque T = 500 Nm

Outer radius of axle r = 0.05 m (same as the hollow shaft outer radius)

Step 1: Polar Moment of Inertia for Solid Shaft

The polar moment of inertia J for a solid shaft is:

$$J = \frac{\pi . r^4}{2}$$

Substitute the value:

$$J = \frac{\pi .(0.05)^4}{2} = 4.91 \times 10^{-6}\text{m}^4$$

Step 4: Torsional Stress in Solid Shaft

The torsional stress τ is:

$$\tau = \frac{\text{T.r}}{\text{J}}$$

Substitute the values:

$$\tau = \frac{500\text{Nm} \,.\, 0.05\text{m}}{4.91\times10^{-6}\text{m}^4} = 5.1\times 10^{7}\text{pa} = 51\text{Mpa}$$

Step 5: Check Allowable Stress

Assuming steel material with an allowable shear stress of 200MPa, the design is safe since:

$$51\text{MPa} < 200\text{MPa}$$

Sprag Type Freewheel Design Calculations - The sprag type freewheel will allow torque transmission in one direction and free motion in the opposite direction.

Step 6: Load and Torque Transmission

To calculate the force on each sprag, use:

$$T = F \cdot r$$

Where:

T = torque (Nm)

F = force (N)

r = radius at which force acts (m)

Given:

T = 500 Nm

Outer race radius r = 0.05 m

Force on each sprag:

$$\text{F sprag} = \frac{T}{r} = \frac{500\text{Nm}}{0.05\text{m}} = 10{,}000\text{N}$$

Step 7: Number of Sprags

Assume the freewheel uses 10 sprags. The force on each sprag:

$$\text{F sprag} = \frac{10{,}000\text{N}}{10} = 1{,}000\text{N}$$

Step 8: Contact Stress (Hertzian Stress)

Hertzian stress between the sprags and races is calculated by:

$$\sigma h = \sqrt{\frac{\text{F Sprag}}{\text{l. d}}}$$

Where:
σh = Hertzian contact stress (Pa)
Fsprag = force on each sprag (N)
l = contact length (m)
d = equivalent radius of curvature (m)

Assume:
Contact length l = 0.01 m
Equivalent radius d = 0.005 m
Substitute the values:

$$\sigma h = \sqrt{\frac{1{,}000\text{N}}{0.01\text{m} \,.0.005\text{m}}} = 447.2 \text{ Mpa}$$

Step 9: Material Yield Stress Check
Assuming material yield stress for the sprag is 500 MPa, the design is safe because:

$$447.2\text{MPa} < 500\text{MPa}$$

Coefficient of Friction and Locking Mechanism
The friction force between the sprags and the races will be essential in determining the locking behavior of the freewheel.

Step 10: Friction Force Calculation
The friction force Ffriction is:
F friction = μ·Fnormal
Where:
μ = coefficient of friction (typically around 0.2-0.3 for steel)
Fnormal = normal force between the sprags and races
Assuming μ = 0.3 and Fnormal = 1,000 N
Ffriction = 0.3·1,000 = 300N
This frictional force will contribute to the locking mechanism and the efficiency of the freewheel.
Fatigue Life (L10 Life) of Freewheel
The L10 life of the freewheel is calculated by:

$$L_{10} = \left(\frac{C}{P}\right)^3 \times 10^6$$

Where:
- C = dynamic load capacity (N)
- P = applied load (N)

Assuming the dynamic load capacity C = 2,000N and the applied load P = 1,000 N

$$L_{10} = \left(\frac{2{,}000}{1{,}000}\right)^3 \times 10^6 = 8 \times 10^6 \text{ revolutions}$$

This ensures a robust and durable freewheel system, with a long operational life.
This design ensures a safe, efficient, and reliable differential mechanism using sprag type freewheels, Hollow Shaft and solid shaft.

VIII. CONCLUSION

The conclusion summarizes the design and analysis of the freewheel differential presented in this paper demonstrate its potential to significantly enhance the performance and efficiency of modern tricycle. By integrating freewheel mechanisms into the rear wheel power transmission, the design achieves improved traction, reduced energy losses, and greater adaptability to varying road conditions. The freewheel differential was shown to offer several advantages over conventional differentials. The incorporation of freewheels eliminates the need for complex electronic control systems in certain configurations, reducing manufacturing costs and maintenance requirements.

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