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Design of an Innovative Steering Mechanism for Tilting Three-Wheel Motorcycles

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Abstract: *In regular vehicles, the wheels turn when you steer — straightforward and what we're all used to. But with some newer types, like tilting trike, it works differently. Instead of just turning the wheels, the whole vehicle leans into the curve, kind of like what happens when you're riding a bike or a motorcycle. We found this concept interesting, especially since companies like Toyota and Harley-Davidson are working on it. Tilting gives a few big advantages — it helps the vehicle stay stable in turns, makes it less likely to skid, and lets you take sharper corners. But there's a catch — tilting doesn't really help much when the vehicle is going slow. At lower speeds, the lean just isn't strong enough to keep things stable, and honestly, it can feel a bit awkward or even unsafe.*

That got us thinking. What if we didn't have to pick just one system? Maybe there's a way to mix both tilting and traditional turning. The idea was to take the good parts of each and see if we could make them work together, so the vehicle handles better no matter what speed it's going. As part of developing this hybrid steering setup, we also made sure it wasn't just about how it worked on paper — it needed to be strong, safe, and reliable in real-world use. To check this, Finite Element Analysis (FEA) was used to test how different parts of the steering mechanism would hold up under various loads and stresses. This helped us refine the design, improve weak points, and confirm that the final mechanism could handle actual driving conditions without compromising safety or performance.

Keywords: Tilting Mechanism, Three-Wheel Motorcycle, Steering Geometry, Vehicle Dynamics, Lean-to-Steer System

I. INTRODUCTION

In regular vehicles, steering works by turning the wheels — simple and familiar. But some newer designs, like tilting trikes, handle corners differently. Instead of only turning, the entire body of the vehicle leans into the turn, much like a bicycle or motorcycle does. In addition to reducing skidding and making the vehicle easier to control when navigating tight corners, the leaning motion makes turning feel more stable and smoother.

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Motorcycles are more versatile than cars and are frequently utilized for law enforcement, daily travel, and even military purposes. As safety becomes a bigger concern in modern transportation, three-wheel tilting motorcycles are starting to get more attention. They combine the stability of a three-wheeler with the nimble handling of a two-wheeler. Companies like Toyota and Harley-Davidson are getting involved in this technology, which shows it could be a promising direction for the future of transportation.

That said, the development of tilting systems is still evolving. Low-speed stability and steering response remain ongoing challenges. The lean isn't always effective at lower speeds, which can make the ride feel awkward or unbalanced.

That's what sparked our interest. We started to wonder if we could mix the best parts of both tilting and regular turning into one system. The idea was to come up with a steering setup that's not only stable and responsive at higher speeds but also easy to control and safe when you're going slower.

This project takes a practical approach, designing and testing five different steering prototypes — each version aimed at solving specific issues like stiffness, tilt-delay, or steering imbalance. We kept improving the mechanism through iteration, refining both its physical design and performance. In the process, we also referred to established research and modelling methods, like those by Cossalter et al. (1998), who used simulation to study dynamics such as roll angle and steering torque. Others, including Sponziello et al. (2009) and Bartolozzi et al. (2009), contributed by exploring how different riding conditions and driver postures affect vehicle stability.

II. LITERATURE REVIEW

Sutar, S. S., Shinde, N. A., Patil, S. R., Patil, R. N., & Patil, N. D. (2017). [1] "Design of a Steering Mechanism for the Three-wheel Vehicle." International Research Journal of Engineering and Technology (IRJET). — This study focuses on the development of a steering mechanism tailored for a three-wheeled vehicle configuration. Addressing the unique challenges posed by the single front-wheel design, the research proposes a modified Ackermann steering geometry to optimize turning radius and enhance stability during manoeuvring. The design process involved theoretical calculations, CAD modelling, and validation through simulation. Results indicated improved handling characteristics and reduced steering effort compared to conventional designs, making it suitable for compact, urban transportation applications. Shubham Namadeo Raut, Ketan Rajkumar Chougule, Nilesh Vijay Sabnis. [3] "Design, Modification & Implementation of Tilting Steering System." International Journal of Advance Research and Innovative Ideas in Education (IJARIIE). — This study presents the development of a hybrid steering system for three-wheeled vehicles, combining both tilting and traditional turning mechanisms to improve maneuverability and cornering stability. The research identifies limitations in existing single-mode steering systems, particularly at high speeds and on wet or uneven surfaces. By integrating an Ackermann steering mechanism for turning and a Davis mechanism for tilting, the proposed system allows drivers to select the appropriate mode based on road conditions. The design was validated through CAD modeling, simulation animations, and practical prototyping, achieving a lean angle of up to 35 degrees and enhancing the vehicle's handling, safety, and turning radius performance compared to conventional steering systems.Mane, A. M., Salunkhe, J. M., Chorge, A. S., Muragode, A., & Bamankar, P. (2017). [3] "Design and Fabrication of Universal Tilting Three-Wheeler Mechanism." International Engineering Research Journal (IERJ). — This study introduces a universal tilting mechanism for three-wheeled vehicles employing a tilting frame structure and detachable bracket mount, making it adaptable to various motorcycle chassis. The research highlights the advantages of a tadpole (reverse trike) configuration, where the vehicle leans while cornering, thereby stabilizing the centre of gravity against centrifugal forces, enhancing traction on slippery roads, and improving braking performance through the third wheel. The mechanism allows up to a 32° lean angle on either side and integrates Ackermann steering geometry combined with double wishbone front suspension and twin rear dampers. The project achieved its objectives, offering improved ride comfort, stability, and adaptability for applications including vehicles for differently abled users.

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III. METHODOLOGY

The methodology for this study, aimed at the design and finite element validation of an innovative steering mechanism for tilting three-wheel motorcycles, was structured into a systematic multi-phase approach, combining conceptual design, virtual simulation, and physical prototyping. The following steps were undertaken:

1. Conceptual Development:

Preliminary ideas for steering mechanisms compatible with the tilting dynamics of three-wheel motorcycles were generated. This phase involved brainstorming sessions and the application of mechanical design principles to propose multiple conceptual solutions capable of meeting functional and safety requirements.

2. Concept Selection:

The proposed concepts were critically evaluated based on criteria such as feasibility, mechanical simplicity, ease of fabrication, and predicted performance. A decision matrix was employed to objectively select the most promising design concept for further development.

3. CAD Modelling:

The selected concept was transformed into a detailed three-dimensional computer-aided (CAD) model using [Solid Works /Catia].

4. Problem Identification:

Analysis of the initial CAD model and animations revealed several design limitations, such as motion inconsistencies, mechanical interferences, and stress concentration points. These issues were systematically identified through simulation diagnostics and motion studies.

5. Problem Solving and Design Modification:

Solutions to the identified issues were developed, which involved modifying linkage dimensions, joint placements, and material selections. Problem-solving techniques such as root cause analysis and iterative redesign were applied to resolve each limitation.

6. Iterative Verification:

The updated design was re-simulated to verify the effectiveness of the modifications. This iterative process continued until the mechanism achieved the desired range of motion and functional reliability in the virtual environment.

7. Performance Optimization:

Further refinements were made to enhance the design's operational efficiency, weight distribution, and manufacturability. Finite element analysis (FEA) was conducted to assess structural performance under simulated load conditions, ensuring the mechanism met safety and durability standards.

8. Component Procurement and Fabrication:

Based on the finalized design, a bill of materials was prepared. Required components and raw materials were sourced from certified suppliers, and custom parts were fabricated in-house or through professional machining services.

IV. CALCULATION

Assumed weight of cycle with rider = 90 kg

Assumed speed during turning = 10 km/h = 10,000 m / 3,600 s = 2.78 m/s Wheel radius = 6 inches = 0.1524 m

Track width (distance between two front wheels) = 2 feet = 0.6096 m Length of four-bar linkage = 2.5 feet = 0.762 m

Height of linkage = 1 foot = 0.3048 m

1. Power (P)

Power = Force × Velocity

Force = mass × acceleration due to gravity = 90 kg × 9.81 m/s^2 = 882.9 N Power = 882.9 N × 2.78 m/s = 2454.46 Watts ≈ 2.45 kW

2. (This is the mechanical power required to move the total load at that speed on flat ground, ignoring friction and wind resistance.)

3. Torque (T)

Torque = Force × Radius

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Torque at the wheel = 882.9 N × 0.1524 m = 134.53 Nm
4. Load on each front wheel (assuming equal load distribution)
Total weight = 90 kg
Weight on each front wheel = 90 kg ÷ 2 = 45 kg
Force on each front wheel = 45 kg × 9.81 m/s² = 441.45 N
5. Bending moment on linkage arm (worst case at midspan)
Assume arm acts as a simply supported beam with point load at centre Length of arm = 0.762 m
Force = 441.45 N
Moment = Force × (Length ÷ 2) = 441.45 N × (0.762 ÷ 2) = 441.45 × 0.381 = 168.24 Nm
6. Selection of mild steel tube
Tube size = 1 inch × 1 inch = 25.4 mm × 25.4 mm Assumed wall thickness = 2 mm
Section modulus (approx.) = $(b \times h^2) \div 6$
$= (25.4 \times (21.4)^2) \div 6 = (25.4 \times 457.96) \div 6 = 11640.18 \div 6 = 1940.03\ mm^3 = 1.94 \times 10^{-6}\ m^3$
7. Bending stress = Moment ÷ Section modulus
$= 168.24 \div (1.94 \times 10^{-6}) = 86721.65\ N/m^2 = 86.72\ MPa$
8. Yield strength of mild steel = ~250 MPa Factor of safety = 250 ÷ 86.72 ≈ 2.88
9. Steering angle consideration Assume turning radius = 1.5 m Using track width = 0.6096 m
Turning angle θ (approx.) = $\tan^{-1}$ (Track width ÷ (2 × turning radius))
$= \tan^{-1}(0.6096 \div (2 \times 1.5)) = \tan^{-1}(0.6096 \div 3) = \tan^{-1}(0.2032) \approx 11.5°$

V. CONCLUSION

Creating an appropriate steering system on tilting three-wheel motorcycles from the perspective of a rider's comfort, stability, and manoeuvrability exercise needs deep understanding and analysis, particularly in the current urban transportation scenario. This proposed system combines the quickness of a two wheeled vehicle and the added security of a three wheeled vehicle which makes lean into turns naturally. It doesn't matter whether the electronic tilt control or mechanical linkage offers the desired result, either way, the approach stands to be an answer to modern mobility needs. The approach provides a holistic and user friendly riding experience.

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