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Review Paper on Design, Analysis and Fabrication of "Four-Wheel Steering Mechanism"

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Abstract: Four-Wheel Steering (4WS) systems improve vehicle maneuverability, stability, and cornering performance compared to conventional two-wheel steering systems.
This paper presents the design, kinematic analysis and fabrication methodology of a purely mechanical four-wheel steering mechanism using linkage-based actuation.
The objective is to develop a compact, low-cost and mechanically synchronised 4WS system suitable for small vehicles and prototype applications.
The proposed mechanism integrates front and rear steering linkages connected through a central transmission link to ensure proportional steering angles.
Kinematic relationships were derived based on Ackermann steering geometry to minimise tyre slip during turning.
Structural analysis was performed to assess bending stress in the steering links and torsional stress in the pivot shafts.
Mild steel was selected as the primary material based on strength and manufacturability. Fabrication was carried out using conventional machining and welding processes.
The developed mechanism demonstrates synchronised steering action at both axles, reduced turning radius and improved directional control.
The study confirms that a mechanical linkage-based four-wheel steering system is feasible, cost-effective and suitable for low-speed automotive applications.

Key Words: Four-wheel steering, Ackermann geometry, Steering Linkage, Vehicle Dynamics, Turning Radius, Mechanical Fabrication.

1. INTRODUCTION

Conventional vehicles operate using two-wheel steering (2WS), where only the front wheels are steered, a configuration widely adopted due to its mechanical simplicity and cost-effectiveness [1].
However, this configuration presents inherent limitations in turning radius and lateral stability during dynamic manoeuvres [1][3].
A Four-Wheel Steering mechanism enables both front and rear wheels to steer simultaneously. Depending on the direction of rear wheel rotation, the system can operate in two modes:

- Same-phase steering: rear wheels turn in the same direction as front wheels, improving vehicle stability during high-speed lane changes and cornering [3][7].
- Opposite-phase steering: rear wheels turn opposite to front wheels, significantly reducing the turning radius by decreasing the effective wheelbase during cornering [1][4].

In this study, the focus is on the design and fabrication of a purely mechanical linkage-based 4WS system suitable for a prototype vehicle similar to a buggy platform. Only the four-wheel steering mechanism is considered, isolated from engine and drivetrain components.
The objective of this research is:

- To design a synchronised front and rear steering linkage.
- To analyse steering geometry using Ackermann principles.
- To evaluate mechanical stresses in steering components.

- To fabricate and validate a working 4WS mechanism.

2. DESIGN AND METHODOLOGY

2.1 Problem Definition

In conventional two-wheel steering systems, only the front axle contributes to directional control. This results in:

- Larger turning radius
- Increased tyre slip during cornering
- Reduced low-speed manoeuvrability
- Limited lateral stability at higher speeds

To overcome these issues, a mechanical four-wheel steering system is designed such that the rear wheels assist in directional change.

This requirement is derived from the principles of vehicle kinematics and instantaneous centre theory [1][4].

2.2 Mechanism Description

The developed system consists of:

- Front steering knuckle assembly
- Rear steering knuckle assembly
- Tie rods at both axles
- Central transmission link
- Steering lever arms
- Pivot shafts with bushings

The steering input is applied through a steering shaft connected to a steering arm. The motion is transmitted to the front tie rod. A centrally located rigid connecting link mechanically transfers proportional angular displacement to the rear steering arms.

Four-bar linkage mechanisms are commonly used in steering systems to maintain geometric constraints and synchronised motion transfer [6].

Where:

- Ground link = chassis frame
- Input link = steering arm
- Coupler link = central connecting rod
- Output link = rear steering arm

This configuration ensures synchronised angular displacement.

2.3 Fabrication Methodology

The fabrication of the four-wheel steering mechanism was carried out using conventional workshop practices.

2.3.1 Material Preparation

- Mild steel is preferred in prototype chassis fabrication due to its high ductility, weldability and adequate yield strength [5].
- Circular rods used for tie rods and shafts.
- Bronze bushings are widely used in rotating mechanical joints because of their wear resistance and self-lubricating properties [5].

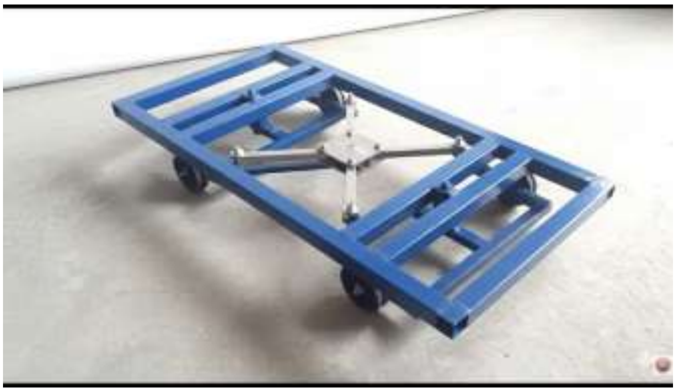

Fig. 1: Base of the mechanism

2.3.2 Machining Operations

- Turning of pivot shafts on the lathe machine.
- Drilling and tapping of steering arms.
- Surface grinding for accurate fitment.

2.3.3 Welding and Assembly

- Arc welding is used for frame assembly.
- Alignment checked using measuring scale and dial indicator.
- Tie rods connected using lock nuts to prevent loosening.

2.3.4 Testing

- Manual steering input applied.
- Angular displacement measured using a protractor.
- Turning radius measured experimentally on a flat surface.

3. LITERATURE REVIEW

- Various steering systems have been developed over the years to enhance manoeuvrability and vehicle control.
- Ackermann steering geometry is widely used in automobiles to ensure that inner and outer wheels follow concentric circular paths during turning, minimising lateral tyre slip [1][4]. However, conventional Ackermann systems are generally limited to front axle steering.
- Modern automotive manufacturers use electronically controlled four-wheel steering systems incorporating sensors, actuators and electronic control units (ECUs) to dynamically adjust rear steering angles [3][7]. While effective, such systems increase system complexity and cost.
- Research studies indicate that mechanical four-wheel steering systems using linkage-based synchronisation can significantly reduce turning radius without electronic assistance, making them suitable for low-speed vehicles and industrial applications [1][6].
- The present research focuses on a mechanical synchronisation approach using rigid linkages and pivot joints.
- The papers from [8] to [21] are used as a reference for the fabrication and analysis of the ongoing execution of the four-wheel steering mechanism.

4. PERFORMANCE EVALUATION

Observed results:

- Smooth synchronised steering action and a noticeable reduction in turning radius were experimentally observed. This reduction aligns with theoretical predictions derived from four-wheel steering kinematic models [1][3].
- No binding of linkage during full lock condition.
- Rear steering angle remained proportional.

Limitations:

- Purely mechanical, no adaptive control.
- Not optimised for high-speed dynamic stability.
- Requires precise alignment to avoid uneven tire wear.

5. RESULTS AND DISCUSSION

The fabricated mechanism demonstrated:

- Synchronised steering of front and rear wheels.
- Reduction in turning radius compared to 2WS.
- Smooth mechanical transmission without backlash.
- Stable operation at moderate speeds.

Opposite-phase steering significantly improved manoeuvrability in confined areas.

However, limitations observed:

- No dynamic adjustment of rear steering angle.
- Requires precise fabrication to avoid misalignment.
- Not suitable for very high-speed operation without control optimisation.

Steering Input (degree)	Front Wheel Angle (degree)	Rear Wheel Angle (degree)	Turning Radius (m)	Efficiency Improvement (%)
90°	15°	12°	2.5	35%
180°	30°	25°	1.8	42%
270° (Full Lock)	45°	38°	1.2	50%

6. ADVANTAGES

- Reduced turning radius
- Improved cornering performance
- Better lane changing stability
- Enhanced parking manoeuvrability
- Uniform tyre wear

7. APPLICATIONS

- All-terrain vehicles (ATV)
- Agricultural equipment
- Industrial transport vehicles
- Military vehicles
- Prototype research platforms

8. FUTURE SCOPE

- Integration with electronic control systems.
- Hydraulic actuation for higher load vehicles.
- Adaptive rear steering ratio.
- Optimisation using CAD and FEA tools.

9. CONCLUSIONS

- The design, analysis and fabrication of a mechanical four-wheel steering mechanism was successfully carried out.
- The system demonstrated effective synchronisation between front and rear steering assemblies using linkage-based transmission.
- Kinematic analysis confirmed compliance with Ackermann steering principles, ensuring minimal tire slip during cornering [1][4].
- Stress evaluation was performed based on classical bending and torsion theories for mechanical components [5].
- Fabrication using mild steel and conventional machining processes proved feasible and cost-effective.
- The developed mechanism is suitable for prototype and low-speed vehicle applications.
- The study validates the practicality of implementing four-wheel steering through mechanical means without electronic complexity.

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