

Design and Analysis of a Reinforced Swing Arm Suspension System with Single-Axle Integrated Drive and Brake Assembly

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Abstract: *Conventional electric two-wheeler rear drivetrains rely on multiple axles for the swing arm, intermediate pulleys, brake drum, and wheel hub, leading to elevated part count, unsprung mass, assembly complexity, and misalignment risks. This study introduces an integrated single-axle architecture where the swing arm and intermediate pulleys share one axle, while the rear drum brake and driving pulley form a unified assembly on the rear wheel axle, targeting a 1000W motor for 35 km/h top speed. SolidWorks CAD modeling, ANSYS finite element analysis, prototype fabrication, and vehicle testing validates the design against drivetrain torque, braking loads, and durability requirements. Compared to the multi-axle baseline, the approach yields 12% unsprung mass reduction, 25% reduction in part count, 40% faster assembly, and improved alignment tolerance, lowering manufacturing costs by 15-20%. This reinforced swing arm also provides the necessary strength and flexibility to handle dynamic loads. These gains enhance reliability and manufacturability for retrofit and production platforms*

Keywords: Swing Arm, Suspension, ANSYS, SolidWorks

I. INTRODUCTION

The rear wheel assembly in an EV scooter plays a dual role: it transmits power from the motor to the wheel and absorbs road irregularities through the suspension system. An efficient and well-integrated design not only improves ride quality and safety but also contributes to packaging efficiency and vehicle durability.

It demands compact rear drivetrains to accommodate batteries and motors within tight packaging, yet conventional setups use separate axles for swing arm pivot, intermediate pulley support, brake drum, and wheel hub. This multi-axle configuration (typically three or four) increases the unsprung mass, bearing interfaces and tolerances raising vibration, wear, and service costs. The innovation consolidates the swing arm and intermediate pulleys on one axle, eliminating redundant supports and integrates the brake drum with the driving pulley on the rear wheel axle for inherent coaxiality. SolidWorks optimized packaging and interfaces; ANSYS confirmed factor of safety under peak loads; prototypes underwent bench and vehicle tests for NVH and endurance.

II. LITERATURE REVIEW

A lot of work has been done in the field of development of various parts of the electric vehicle for enhancing the range, power and compactness of the drive of the vehicle and the work continue towards the betterment of the drive train. Many researchers are working in this direction. The work of Spanoudakis et al. [1] focused on designing a motorcycle swingarm that is both strong enough to withstand operational forces and lightweight. Using CAE software and finite element analysis, different loading scenarios were evaluated, with special emphasis on emergency braking conditions.



A topology optimization process was applied to refine the design and reduce weight. Tayong et al. [2] developed an optimized rear swing arm for foldable urban e-bikes in collaboration with Flit Bike Cambridge Ltd, utilizing 7075-T651 aluminum and FEA to enhance strength-to-weight ratios. The study highlights that maximum stress concentrations occur around design singularities like axle holes, while providing a framework for comparing dual-sided and single-sided configurations. Chen et al. [3] in their work presented a novel high-response Integrated Electronic Braking System (EBS) for commercial vehicles. Their research focused on reducing braking time and improving safety through a highly integrated, one-piece rear axle control unit. Heydrich et al. [4] presented a case study on mechatronic chassis systems for battery electric vehicles, focusing on brake-by-wire technology and in-wheel propulsion with integrated chassis control. Using integral sliding mode (ISM) and proportional-integral (PI) strategies for wheel slip control, the controller was developed in MATLAB/Simulink and validated in real-time simulations, incorporating robust observers to estimate critical vehicle states for improved safety and stability. Mahith et al. [5] analyzed stresses and deformations in motorbike/bicycle swing arms using ANSYS for simulation and CATIA for modeling. Materials such as iron and carbon fibre were tested under varying loads to evaluate performance, identify potential failure points, and suggest design improvements for strength, stability, and weight reduction. The work of Gupta et al. [6] focuses on designing a lightweight swing arm for the Yamaha FZ-S V2 using aluminum alloys (Al 6061, Al 6061-T6, and Al 7075). Employing generative design and static analysis in Autodesk Fusion 360, their study optimized material use, weight reduction, and maintaining mechanical strength under varied load conditions. Raval et al. [7] applied generative design in Autodesk Fusion 360 to optimize a lightweight swing arm capable of withstanding real-world load conditions. Multiple design iterations were evaluated under defined constraints to achieve mass reduction without compromising strength or performance.

Existing work on collocated drive-brake integration focuses on high-end mechatronic chassis or in-wheel motors, overlooking retrofit-compatible single-axle architectures that consolidate swing arm, intermediate pulleys, and unified brake-pulley units to achieve part count reduction and mass savings. This work fills the gap by validating a manufacturable, single-axle rear, enabling seamless retrofit while enhancing alignment and durability absent in modular baselines.

III. METHODOLOGY

Electric Vehicle Specifications

The design requirement, constraints and vehicle specifications of electric vehicle is listed in Table 1 and 2 below.

TABLE I: Design requirements & constraints

Vehicle Type	Electric Two-wheeler
Drive Type	Belt & pulley (R)
Suspension Type	Dual Shock (R)
Mounting Concept	Single-axle (for swing arm & intermediate pulleys)
Brake System	Integrated rear brake drum with drive pulley
Intended Usage	Urban commuting and fleet applications

TABLE III: Vehicle Specifications

Gross Weight	180 kg
Top Speed	35 km/hr
Wheel Dia	0.467 m
Static rear axle load	882.9 N
Dynamic load factor	2207 N
Motor rated power	1000W
Motor rated torque	3.18 Nm
Braking torque (R)	360.5 Nm (Max)



Material Selection

Material is very important for the various parts of the EV. There are many materials which are used in EV, so it is necessary to select the right material and hence the material selection plays a critical role. Some materials are compared based on the requirement and applications; material selection is optimized. AISI 4130 chromoly steel is a superior choice over mild steels such as AISI 1020 or 1018 for high-performance EV two-wheeler chassis due to its excellent strength-to-weight ratio. It allows thinner wall sections while maintaining equivalent strength, resulting in significant weight savings, higher tensile and yield strength, improved fatigue resistance, and better crash toughness. Simulation studies show that under identical chassis designs and loads, 4130 experiences notably lower peak stresses compared to mild steels, while offering weldability advantages over AISI 4140. These properties make 4130 an optimal material for lightweight, durable, and safe EV chassis construction [8-9].

Static structural analysis was conducted on the prototype chassis CAD model (Fig.1, 2) to evaluate various materials, comparing AISI 4130 Alloy Steel against a common alloy under static loading from 180 kg, where equivalent Von Mises stresses remained significantly low.

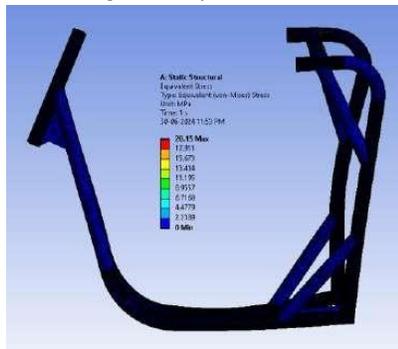


Fig. 1. other alloy material

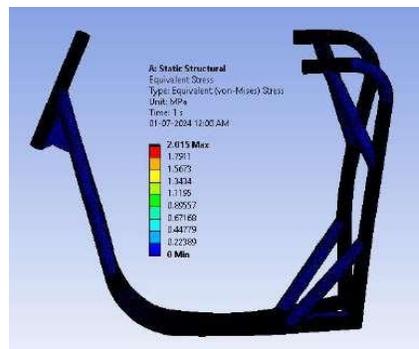


Fig. 2. AISI 4130 alloy steel

Stress and Deflection Calculations of Swing Arm:

The swing arm is modelled in SolidWorks software and Table 3 represent the key design parameters and their values of swing arm while Fig. 3 depict the CAD model of swing arm. Given the forces acting on the swing arm, including rider weight, motor torque, and road impacts: the bending stress is given by eq. 1. [10-11]

$$\text{Bending Stress} = \frac{M \times c}{I} \tag{1}$$

where:

M = Bending moment (force × lever arm)

c = Distance from neutral axis

$$I = \text{Moment of inertia of the cross-section for a square hollow section: } I = \frac{(b^4 - d^4)}{12} \tag{2}$$

$$I = \frac{25.4^4 - (25.4 - 2 \times 1.25)^4}{12} \approx 2.84 \times 10^6 \text{ mm}^4$$

Given a maximum moment of 300 Nm (considering dynamic loading):

$$\text{Bending Stress} = \frac{(300000 \times 12.7)}{2.48 \times 10^6} \approx 1.54 \text{ MP}$$

This is well within the allowable stress for AISI 4130, which can handle over 500 MPa, ensuring the swing arm is structurally sound.

TABLE III: Swing Arm Design Parameters

Material	Value
Length	350 mm
Cross-Section	25.4 x 1.25 mm
Type	Hollow square pipe



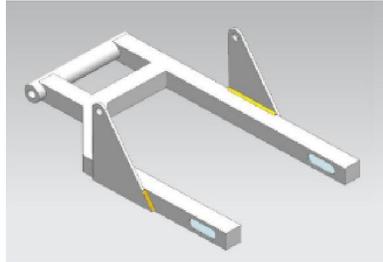


Fig. 3. Isometric view of swing arm (CAD model)

Damper Selection

The suspension system must absorb road shocks and maintain stability. For the design parameters of the work presented, the goal was to reduce the size of the dampers to optimize space and weight. By providing a large angle from the vertical, a very small component of force is transferred to the dampers, which facilitates the choice of smaller sized shock absorbers. The choice is based on the dampers available in the market and then testing it for calculated load values. Table 4 below represent the key parameters of the damper with values, and the Fig. 4 represent the CAD model of damper.

TABLE IVV: Key Parameter of Damper

Parameter	Value
Shear Modulus (G)	78,600 N/mm ²
Mean Diameter (D)	33.3 mm
Wire Diameter (d)	6.7 mm
Total Coils (N)	7

The Spring Constant is calculated from the use of below equation,

$$k = \frac{G \times d^4}{8 \times D^3 \times N} = \frac{78600 \times 6.7^4}{8 \times 33.3^3 \times 7} = 1230 \text{ N/mm}$$

The dampers were tested for compression loads on a Universal Testing Machine (UTM). For a load of 1200N, the compression achieved on the softest setting was 35 mm. Each damper can take up a load of 1200N, and hence, for a more 22 comfortable and reliable rides, a configuration of dual shock absorbers attached to the either side of the swing arm was chosen. Since, the maximum force on the rear wheel does not exceed 2400N, the selected configuration is safe. Also, the working force for regular conditions is within the range of 1200-1800N, hence, the dampers do not develop fatigue due to the working loads. This setup provides sufficient damping for a 180 kg load, ensuring a comfortable ride and stable handling. The dampers are arranged parallel to the swing arm (Fig. 5). They fulfil their purpose by saving space in the rear side of the vehicle which can be utilized for storage and utility purposes, and their combined weight does not exceed more than 500 grams for both the dampers. Due to this configuration, when compared to a regular dual damper setup, about 40% of weight reduction is achieved.



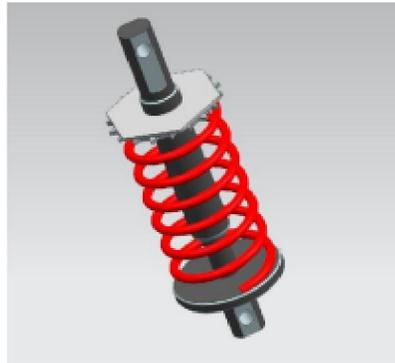


Fig.4. Damper CAD model

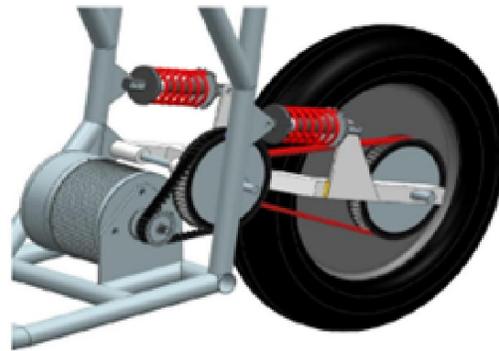


Fig. 5. CAD model meeting SAE clearances

FE Analysis of Swing Arm

Once the design of swing arm is completed then it is modelled in the SolidWorks software and then the file is imported into Ansys workbench. The type of analysis is structural analysis and different boundary conditions are applied to perform the analysis. The end attached to the tire was given free movement only in Y axis (vertical direction). The end attached to the chassis was allowed to rotate about X axis only (Fig. 6). A load of 1170 N is applied at the tyre axle end of the chassis. Mesh is generated and the element size of 5 mm is selected to perform the analysis and the element type chosen is Tetrahedral (quadratic). After generation of mesh and boundary condition application, it is solved to determine Max von Mises stress, permissible stress, maximum deflection and FOS. The values obtained after the analysis solution is 185 MPa, 276 MPa, 1.4 mm and 2.5 respectively. It is found from the analysis that the structural integrity is correctly maintained under the given load. The Fig. 7 -8 depicts the equivalent stress and total deformation results of the analysis.

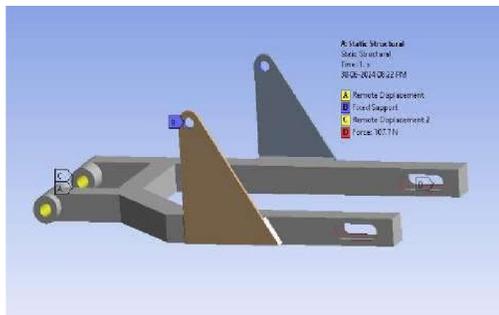


Fig. 6. Boundary conditions

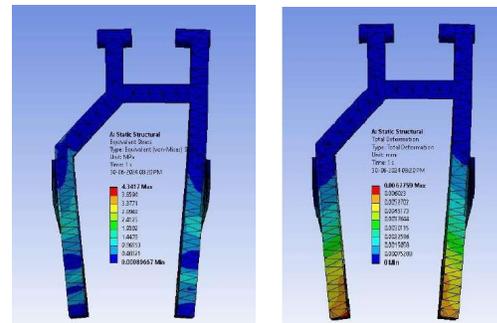


Fig. 7. (a) Equivalent Stress (b) Total Deformation

Rear Damper UTM Testing

For testing the rear dampers Universal Testing Machine (UTM) is used. UTM is an electromechanical system designed to assess the mechanical properties of materials and components through controlled application of tensile, compressive, or flexural loads, measuring parameters such as strength, deformation, yield stress, and modulus of elasticity. In this study on EV, two-wheeler rear shock absorber design, the rear damper was subjected to quasi-static testing on a UTM to evaluate its compressive strength and deformation characteristics under simulated service loads, providing essential baseline data for durability and performance optimization. The UTM setup involved securing the damper in compression fixtures, applying incremental forces via a screw-driven crosshead, and recording load-displacement curves using integrated load cells and extensometers. This approach yielded key metrics including maximum load capacity, deformation at failure, and elastic modulus, adhering to standards like ASTM for reproducible results in



automotive suspension validation. Such testing complements dynamic fatigue analysis, informing iterative design improvements for enhanced ride quality and structural integrity in EV two-wheelers. Damper load capacity is 1500 N and the load applied to the rear damper is 1200 N i.e. ~65% of total load and the deformation obtained is 35 mm. Fig. 8 shows the damper under testing phase. The result indicates that the energy absorption and rider comfort is effective under the load.



Fig. 8. UTM testing of rear shock damper

Validation and Final Adjustments

After testing swing arm and dampers, they are fitted/assembled on EV and the following validations and final adjustments procedures were done. Fig. 9 and 10 shows the suspension assembly in prototype and actual prototype of the EV scooter respectively.

Prototyping: The suspension subsystems were initially tested independently before being merged into a complete functional prototype. This modular approach helped in resolving any interfacing issues early in the process.

Integration and Vehicle Packaging: One of the major tasks was to integrate the design for an efficient assembly. Several iterations and alterations were made to the initial design according to the availability of components and their cost.

Suspension Response: The suspension system was evaluated under static and dynamic loads to ensure that the damper load capacities and swing arm reinforcements met design specifications, culminating in fine-tuning where necessary.

Iterative Improvements: Feedback from initial prototype testing was used to optimize the CAD design. Minor adjustments were made to increase component strength, reduce weight, and enhance overall performance.



Fig. 9. Suspension Assembly



Fig. 10. Actual Prototype of the EV Scooter



IV. CONCLUSION

This paper presented the design and validation of a reinforced swing arm suspension system with an integrated drivetrain and braking architecture for an electric scooter. The proposed single-axle configuration reduces assembly complexity while improving alignment accuracy, serviceability, and packaging efficiency. The swing arm, fabricated from AISI 4130 alloy steel, demonstrated adequate structural strength under critical loading conditions.

Suspension performance was experimentally validated through UTM of the damper and coil spring assembly. The system exhibited effective energy absorption with 35 mm of compression under a compressive load of 1200 N and operated safely within a maximum load capacity of 1500 N, resulting in a factor of safety of approximately 2.5. The use of rubber bushings at pivot locations further improved vibration isolation and ride comfort.

The integrated layout achieved a compact and modular rear assembly, with the intermediate axle serving both as the swing arm pivot and as the mounting shaft for the intermediate pulley, while the rear driving assembly was integrated with the brake drum and wheel rim. By relying on only two primary axles, the design simplifies assembly and disassembly. Overall, the proposed system demonstrates a viable solution for electric scooter applications requiring compact packaging, structural reliability, and reduced maintenance effort.

V. FUTURE SCOPE

The successful development and validation of the rear wheel subsystem for an EV scooter opened several avenues for enhancement, commercialization, and adaptation to broader applications. As the electric vehicle sector continues to evolve, the following future developments are proposed:

Commercial Product Development

The current prototype demonstrates proof of concept. With further refinement in ergonomics, aesthetics, and manufacturability, the system can be scaled into a production-ready module for commercial electric scooters. Potential exists for collaboration with EV start-ups to integrate this subsystem into low-cost urban mobility platforms.

Retrofit Applications

The design can be retrofitted into RTO-expired or old two-wheelers, offering a sustainable way to convert petrol scooters into electric ones.

Retrofit kits based on this subsystem could be standardized for widespread use, especially in developing markets.

Use in Student and Competitive Projects

This power transmission system is already in use by EV and E-BAJA teams at our institution, proving its suitability for performance-oriented applications.

Future design iterations can focus on high-performance use cases, such as endurance racing or rugged terrain competitions.

Integration with Advanced Technologies

Lightweight composites, such as carbon fibre-reinforced plastics, can be explored to reduce weight further without compromising strength.

The system can be adapted for regenerative braking integration, improving overall energy efficiency of the EV.

Modular Suspension Systems

A modular swing arm and suspension layout can be developed to fit a variety of two-wheeler geometries, supporting adaptability for different EV chassis.

Adjustable dampers or electronic suspension systems can be tested for future iterations aimed at premium models.

Long-Term Durability and Environmental Testing

Further testing over longer durations and varying environmental conditions (humidity, temperature, road conditions) is essential for full lifecycle validation.

Future versions can be subjected to automotive standard tests for vibration, fatigue, and corrosion resistance.



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