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Mechanical Design of a Two-Wheeler Electric Vehicle

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***Abstract*: The mechanical design of a two-wheeler electric vehicle (EV) is a multidisciplinary exercise that must balance performance, efficiency, safety and cost-effectiveness. This paper presents the design considerations adopted for a two-wheeler EV, covering the chassis and frame, suspension, braking system, wheels and tyres, and the associated fabrication processes of welding and painting. A double-cradle chassis was selected and fabricated for the prototype, and its structural adequacy was verified through impact-load and factor-of-safety calculations for front, side, rear and torsional loading. Helical compression springs for the rear shock absorbers were sized from the static and dynamic load on the vehicle. The relative merits of drum and disc braking systems, and of the four common shock-absorber configurations used in two-wheelers, are compared to justify the choices made. The resulting design yields a lightweight, structurally sound and rider-comfortable platform suited to sustainable urban mobility.**

***Keywords*: chassis design, double-cradle frame, disc brake, drum brake, electric vehicle, shock absorber, two-wheeler, wheel, tyre.**

1. Introduction

The transport sector is among the largest contributors to global energy consumption and greenhouse-gas emissions. As urbanisation increases the demand for personal mobility, alternative fuels and electric power trains have become a key strategy for a sustainable transport system. Electric vehicles (EVs) are propelled by an electric motor drawing power from a rechargeable battery instead of petrol or diesel, and they produce zero tailpipe emissions [1].

A two-wheeler EV integrates mechanical, electrical and industrial design principles. Its mechanical design must meet performance, safety and regulatory requirements while remaining light enough to preserve range and agility. The frame, sub-chassis and swing arm form the core of the vehicle body; suspension, wheels and the braking system are integrated around this structure. The design of bodywork fuel-tank shell, fairings and seat is outside the scope of the present work.

The mechanical design aspects addressed in this paper are: (i) the frame and chassis, which form the structural foundation; (ii) the suspension system, which manages ride comfort and stability; (iii) the wheels and tyres; (iv) the braking system, including regenerative capability; (v) motor integration; and (vi) rider ergonomics and safety features. Sections 2–7 discuss each of these in turn for the prototype two-wheeler EV built for this project, and Section 8 summarises the advantages that motivate the shift to electric two-wheelers.

2. Chassis Design

A chassis is the load-bearing framework of the vehicle. It supports the battery, body and rider, distributes load evenly to prevent sagging or twisting, and provides mounting points for the suspension, brakes, motor and electrical components. The rigidity of the chassis governs handling, while its energy-absorbing capacity is central to occupant safety in a collision [2], [3].

A. Types of Two-Wheeler Chassis

Four chassis architectures are commonly used in two-wheelers, distinguished mainly by how the frame tube(s) route from the headstock to the swing-arm pivot.

Fig. 1. Backbone chassis - A single spine running along the centreline (e.g. Honda CD100)

1) Backbone chassis: A central spine carries all other components, giving a simple, light and easy-to-manufacture structure, though it is less stable in cornering and less adaptable to different engine/motor sizes.

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Fig. 2. Single cradle (single down-tube) chassis
(e.g. Honda CG125, TVS Victor)

2) Single cradle chassis: A single large tubular member curves from the headstock to the rear-wheel area, giving a more open structure that is more complex to build than a backbone frame but more stable in cornering.

Fig. 3. Double cradle (twin-downtube) chassis (e.g. Ather 450X, Royal Enfield Continental GT650)

3) Double cradle chassis: Two parallel tubes run from the headstock to the swing-arm pivot with the motor/engine mounted between them. The two cradles distribute the forces of acceleration, braking and cornering, making this the strongest and most rigid of the four layouts, at the cost of higher manufacturing complexity.

Fig. 4. Perimeter (twin-spar) chassis
(e.g. Yamaha R15, Bajaj Pulsar NS160)

4) Perimeter chassis: The steering head is joined to the swing arm by the shortest possible path, centralising mass and lowering the centre of gravity for sport applications, but it is the most complex design to manufacture.

B. Chassis Adopted for This Vehicle

A double-cradle chassis was selected for the prototype because it offers superior strength and rigidity for a given tube weight, is relatively straightforward to fabricate from mild-steel tubing, and provides convenient mounting points for the battery pack, motor and rear suspension. Fig. 5 shows the fabricated chassis prior to fitting of the bodywork.

Fig. 5. Fabricated double-cradle chassis of the prototype two-wheeler EV

C. Design Methodology

The chassis was developed through the sequence: definition of requirements → collection of data (availability, machinability, cost, reliability, feasibility and ergonomics, together with the target overall length, height and weight) → design → analysis → feasibility study → documentation and drafting. Table 1 summarises this workflow.

Table 1
Chassis design methodology

Stage	Purpose
Requirement definition	Fix load, rider count and target dimensions
Data collection	Material availability, machinability, cost, reliability
Design	Select frame type and lay out members
Analysis	Impact-load and factor-of-safety calculation
Feasibility study	Check manufacturability and cost
Documentation & drafting	Finalise drawings for fabrication

D. D. Material Selection

Material choice depends on load, function, operating environment, service life and cost. Steel alloys, aluminium alloys, titanium and carbon fibre were the candidate materials; a low-alloy structural steel was selected for the prototype frame on the basis of cost and weldability. Its composition and mechanical properties are given in Tables 2 and 3 [4].

Table 2
Chassis material composition

Element	Content (%)
Iron (Fe)	97.03 – 98.22
Chromium (Cr)	0.80 – 1.10
Manganese (Mn)	0.40 – 0.60
Carbon (C)	0.280 – 0.330
Silicon (Si)	0.15 – 0.30
Molybdenum (Mo)	0.15 – 0.25
Sulfur (S)	0.040 max
Phosphorus (P)	0.035 max

Table 3
Mechanical properties of the chassis material

Property	Value
Ultimate tensile strength	560 MPa
Yield tensile strength	460 MPa
Modulus of elasticity	190 – 210 GPa
Bulk modulus	140 GPa
Shear modulus	80 GPa
Poisson's ratio	0.27 – 0.30
Density	7.85 g/cm³
Melting point	1432 °C

E. Chassis Load and Factor-of-Safety Calculation

For a combined rider-plus-vehicle weight of 220 kg and an assumed 2g dynamic impact, the impact load and impact duration were estimated as:

Impact load, $F = 2 \times 9.81 \times 220 = 4316.4$ N

For a maximum speed of 58 km/h (16.11 m/s),
impact time $t = (m\cdot v)/F = (220 \times 16.11)/4316.4 \approx 0.82$ s

With a yield strength of 460 MPa, the factor of safety (FOS) obtained for four loading cases is given in Table 4 [2], [6].

Table 4
Factor of safety under different load cases

Load case	Working stress (MPa)	FOS
Front impact	220.37	2.09
Side impact	262.62	1.75
Rear impact	244.71	1.88
Torsion	180.92	2.54

Resistance forces during motion were also estimated for a 2.5° gradient, asphalt rolling resistance coefficient of 0.004 and frontal area of 0.7 m²: gradient resistance $F_h = Mg \sin\Phi \approx 42.79$ N; rolling resistance $F_r = C_r Mg \cos\Phi \approx 3.92$ N; and aerodynamic drag $F_d = 0.5\rho C_d A V^2 \approx 58.35$ N at 16.67 m/s. The propulsion power required, $P = F\cdot V$, works out to approximately 1752 W, which sets the minimum continuous rating for the drive motor.

3. Fabrication Processes

A. Welding

The chassis tubes were joined by arc welding, in which an electric arc between the electrode and the workpiece melts the base metal and filler to form a fused joint; a flux coating shields the weld pool from atmospheric contamination. Gas (oxy-fuel) welding, which uses heat from a burning gas mixture with an optional filler rod, was used for smaller brackets.

B. Painting

The finished frame was finished by spray (gas/airbrush) painting, in which compressed air or an air–gas mixture atomises the paint for an even, corrosion-resistant coating.

4. Suspension System

Shock absorbers (dampers) control the oscillation of the suspension springs, converting the kinetic energy of wheel motion into heat and keeping the tyres in contact with the road. Four configurations were reviewed for this vehicle.

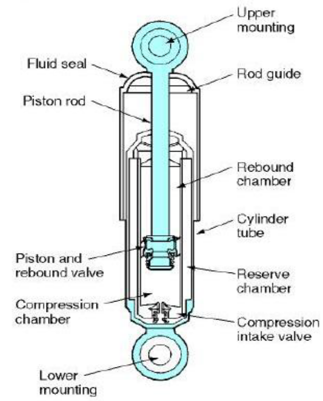

Fig. 6. Hydraulic-type shock absorber: Piston and cylinder with rebound/compression chambers

1) Hydraulic type: A piston moving inside an oil-filled cylinder forces fluid through small valves, generating a damping resistance that is proportional to piston velocity.

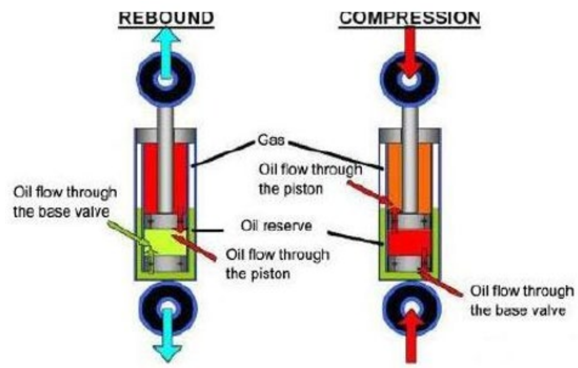

Fig. 7. Double-acting shock absorber - Damps both compression and rebound strokes

2) Double-acting type: Damps both the compression (bump) and extension (rebound) strokes, giving the best control of tyre contact and ride comfort; this type was adopted for the rear suspension of the prototype.

Fig. 8. Telescopic front fork — Outer fork tube and inner slider with internal spring and damper

3) Telescopic type: Used at the front, an inner tube (slider) travels inside an outer fork tube; an internal spring and damping valve absorb road irregularities while guiding the front wheel.

4) Single-acting type: Damps only the compression stroke and is lighter and simpler, but gives a bumpier ride on rebound; it was not used in this design.

A. Rear Spring Design

The helical compression spring for the rear shock absorber was sized from the static and dynamic load on the vehicle. For a kerb weight of 131 kg, two riders of 75 kg each, and 65% of the combined weight carried on the rear suspension, doubled to account for dynamic loading:

Total dynamic load on rear suspension, $w = 2 \times 0.65 \times (131 + 150)$ kg ≈ 342 kg $= 3355$ N; load per shock absorber, $W = w/2 = 1677$ N.

With modulus of rigidity $G = 78\ 600$ N/mm², mean coil diameter $D = 33.3$ mm, wire diameter $d = 6.7$ mm, spring index $C = D/d = 5$, and $N_1 = 17$ total coils, the solid length $L_s = N_1 d = 113.9$ mm and the free length L_f (solid length + maximum compression + 15% clearance) ≈ 167.8 mm. The resulting spring rate is $K = W/\delta \approx 35.7$ N/mm, with a pitch of about 10 mm per coil [5].

5. Braking System

The braking system converts the kinetic energy of the moving vehicle into heat through friction. Two configurations were compared for this two-wheeler.

A. Drum Brake

Fig. 9. Exploded view of a drum-brake assembly: drum, shoes, springs, backplate and wheel cylinder

A cast-iron drum rotates with the wheel while curved brake shoes, lined with friction material, are forced outward against the drum by a wheel cylinder (hydraulic) or cable-operated cam. Being fully enclosed, the drum brake is protected from dirt and water and is inexpensive and simple to maintain, but it dissipates heat poorly, is heavier, and is more prone to brake fade under sustained use.

B. Disc Brake

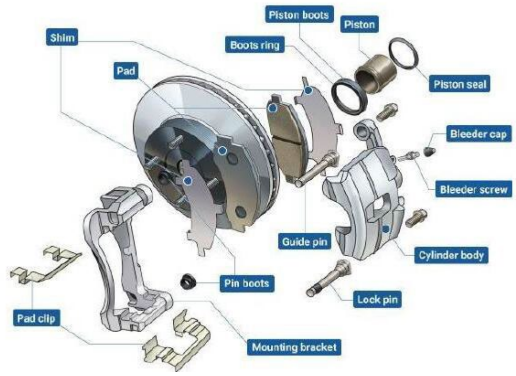

Fig. 10. Exploded view of a disc-brake assembly showing rotor, pads, calliper and mounting hardware

Fig. 11. Assembled disc-brake unit at the wheel hub

A rotor bolted to the wheel hub is clamped by friction pads housed in a calliper; hydraulic pressure from the master cylinder forces the pistons to squeeze the pads against the rotor. Because the rotor is exposed to air, disc brakes dissipate heat far more effectively than drum brakes, giving greater stopping power, less fade and easier maintenance, at a higher component cost [7], [8]. The prototype uses a disc brake on the front wheel and a drum brake on the rear the arrangement most common on Indian two-wheelers, balancing stopping power on the front wheel (which carries most of the weight transfer under braking) against the lower cost and self-enclosure of a rear drum.

6. Wheels and Tyres

The wheel supports the vehicle weight, provides the mounting for the tyre, and connects to the suspension through the hub bearings. Alloy (aluminium) wheels were used for their lower unsprung weight, better heat dissipation and corrosion resistance compared with steel wheels, at some cost in impact resistance.

A tubeless tyre was fitted, in which the tyre bead seats directly against the rim and a sealant layer closes small punctures, improving puncture resistance, lowering rolling resistance and reducing the risk of pinch flats compared with a tubed tyre.

Fig. 12. Rear wheel and hub assembly of the fabricated prototype


Fig. 13. Rear drum-brake assembly used on the prototype

7. Advantages of Electric Two-Wheelers

The shift toward electric two-wheelers is driven by several factors that reinforce the mechanical design choices above:

- Zero tailpipe emissions and improved urban air quality [1], [9].
- Higher drivetrain efficiency than an internal-combustion engine, since electric motors convert a larger share of input energy into motion [9], [10].
- Fewer moving parts than an IC-engine drivetrain, giving lower maintenance costs.
- Government incentives (tax credits/rebates) that improve the economics of ownership.
- Reduced dependence on imported fossil fuel.
- Quieter operation, which is particularly valuable in dense urban traffic.
- Regenerative braking, which recovers part of the kinetic energy lost during deceleration and complements the mechanical braking system described in Section 5.

8. Conclusion

This paper has presented the mechanical design of a two-wheeler electric vehicle prototype, covering chassis selection and verification, suspension, braking and wheel/tyre subsystems. A double-cradle steel chassis was chosen for its strength-to-weight ratio and was verified by impact-load and factor-of-safety analysis for front, side, rear and torsional loading, all of which exceeded a minimum factor of safety of 1.75. A double-acting rear shock absorber and telescopic front fork were selected for ride comfort, with the rear spring sized from the static and dynamic load on the vehicle. A front disc / rear drum brake combination was adopted to balance stopping power and cost. The resulting design gives a lightweight, structurally sound and comfortable platform for sustainable urban mobility. Future work will extend this study with finite-element validation of the chassis, thermal analysis of the disc brake, and optimisation of the suspension damping for varying payloads.

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