

Module 1: Steering Systems in Electric Vehicles

1. Introduction to Steering Systems

Definition and Function

- The steering system allows the driver to control the vehicle's direction.
- Converts rotary motion of the steering wheel into angular movement of the front wheels.
- Provides stability and ease of maneuverability.
- Absorbs road shocks to minimize driver fatigue.

Components of Steering System

1. Steering Wheel
2. Steering Column
3. Rack and Pinion or Recirculating Ball Mechanism
4. Tie Rods
5. Steering Knuckle
6. Power Steering System (EPS or Hydraulic)

Requirements of a Good Steering System

- **Easy Operation:** Low effort required to turn the wheels.
- **Shock Absorption:** Minimizes shocks transmitted to the driver.
- **Self-Centering:** Returns to a straight-line position after a turn.
- **Directional Stability:** Prevents unwanted side movements.

2. Steering Geometry & Design Considerations

Steering Geometry Parameters

1. **Caster Angle (θ)**
 - Angle between the vertical axis and the steering axis.
 - Positive caster increases straight-line stability.
2. **Camber Angle (γ)**
 - Tilt of the wheel concerning the vertical axis.
 - Negative camber improves cornering performance.
3. **King Pin Inclination (KPI)**
 - Angle between the kingpin axis and vertical axis.
 - Improves steering stability.
4. **Scrub Radius**
 - Distance between the contact patch center and the projected steering axis.

- Affects steering effort and road feedback.
5. **Toe-in & Toe-out**
- Toe-in: Front edges of tires are closer than rear edges (improves stability).
 - Toe-out: Front edges are farther apart (improves cornering response).

Steering Ratio Formula

$$\text{Steering Ratio} = \frac{\text{Steering Wheel Angle}}{\text{Front Wheel Angle}}$$

- **Example Calculation:**
 - If the steering wheel turns 17.5° to achieve 1° of front wheel rotation:
 - $\text{Steering Ratio} = \frac{17.5}{1} = 17.5 : 1$

3. Steering System Configurations in EVs

Bicycle (Two-Wheel) Steering System

- Uses direct handlebar connection.
- Common in electric bicycles and motorcycles.

Dicycle, Tricycle, and Quadricycle Steering

1. **Dicycle (Two-Wheel)**
 - Handlebars directly connected to the front wheel.
2. **Tricycle (Three-Wheel)**
 - Delta (single front wheel steering) or Tadpole (two front wheels steering) configurations.
3. **Quadricycle (Four-Wheel)**
 - Similar to traditional car steering using a steering wheel.

4. Steering System Types in EVs

Rack and Pinion Steering

- Converts rotational motion into linear motion.
- Efficient and commonly used in electric vehicles.

Electric Power Steering (EPS)

- Uses an electric motor instead of hydraulic fluid.

- Provides variable assistance based on speed.
- Improves energy efficiency.

Variable Gear Ratio Steering

- Adjusts the steering response based on driving conditions.

Four-Wheel Steering (4WS)

- Rear wheels turn in the opposite direction at low speeds for better maneuverability.
- Rear wheels turn in the same direction at high speeds for stability.

5. Advanced Steering Technologies in EVs

Steer-by-Wire System (SBW)

- Eliminates mechanical linkages.
- Uses electronic sensors, actuators, and an ECU.
- Improves precision and integrates with autonomous driving.

Redundancy and Safety Features in SBW

- **Dual Sensor Configuration** for steering position.
- **Backup ECU and actuators** for fault tolerance.
- **Fail-safe modes** ensure manual control during failures.

Integration with ADAS & Autonomous Vehicles

- Works with lane-keeping assistance and adaptive cruise control.

Case Study: Tesla Model 3 Steering System

- Uses **Electric Power Steering (EPS)** with variable assist.
- Integrated with **Autopilot** for autonomous driving.
- Features **haptic feedback** for driver assistance.

Formulas from the PDF

Torque Calculation for Steering System

1. Force Calculation: $F = W \times g \times \mu$

- Where:
 - W = Vehicle Weight (kg)
 - g = Gravity (9.81 m/s²)
 - μ = Coefficient of Friction (0.7 - 0.9)

2. Torque Calculation: $T = F \times r$

- Where:
 - r = Wheel radius (m)
 - T = Torque (Nm)

Example Calculation:

- Vehicle Weight: 1800 kg
- Friction Coefficient: 0.8
- Wheelbase: 2.6 meters
- Steering Ratio: 15:1
- Wheel Radius Calculation: $r = \frac{2.6}{15} = 0.173\text{m}$
- Force Calculation: $F = 1800 \times 9.81 \times 0.8 = 14110.4\text{N}$
- Torque Calculation: $T = 14110.4 \times 0.173 = 2443.03\text{Nm}$
- Motor Torque Calculation: $T_{motor} = \frac{2443.03}{15} = 162.87\text{Nm}$

Conclusion

- Steering system design is **critical** for EV stability and maneuverability.
- Modern EVs use **EPS and Steer-by-Wire** for energy efficiency and autonomous integration.
- **Key parameters** like steering geometry, torque, and ratios impact performance.
- **Redundant safety mechanisms** ensure reliability in advanced EVs.

Module 2: Suspension System in Electric Vehicles

1. Introduction to Suspension Systems in EVs

Purpose and Importance

- Provides **ride comfort, stability, and handling**.
- Maintains **traction** by ensuring tire contact with the road.
- Absorbs shocks from road irregularities.
- Minimizes **noise, vibration, and harshness (NVH)**, which is more noticeable in EVs.

Unique Challenges in EV Suspension

- **Battery Placement:** EVs have a **lower center of gravity** due to battery packs.
- **Increased Weight:** Heavy batteries affect load distribution.
- **Regenerative Braking Integration:** Impacts weight transfer and requires smooth suspension adjustments.

2. Types of Suspension Systems for EVs

1. Independent Suspension

- Each wheel moves independently, improving **ride quality and stability**.
- Common in **performance and luxury EVs**.

2. MacPherson Strut Suspension

- Single control arm with integrated **shock absorber and coil spring**.
- **Cost-effective and space-efficient**, used in **front-wheel-drive EVs**.

3. Double Wishbone Suspension

- Two wishbone-shaped control arms provide **better handling and comfort**.
- Used in **high-performance EVs**.

4. Multi-Link Suspension

- Multiple control arms allow **precise wheel movement control**.
- Balances **ride comfort and handling**, commonly found in **premium EVs and SUVs**.

5. Air Suspension

- Uses **air springs instead of coil springs**.

- Allows **adjustable ride height** for aerodynamics and better load handling.

6. Active Suspension

- Uses **electromechanical actuators** to adjust damping in **real-time**.
- Found in **luxury EVs with ADAS**.

3. Suspension Components and Design Considerations

Springs

- **Coil Springs:** Used in most passenger EVs.
- **Leaf Springs:** Common in heavy-duty EVs.
- **Air Springs:** Allow variable stiffness for load adjustments.

Shock Absorbers & Dampers

- **Hydraulic Dampers:** Traditional, cost-effective solution.
- **Gas-Charged Dampers:** Reduces cavitation and improves damping consistency.
- **Adaptive/Electronic Dampers:** Adjust damping force in **real-time**.

Damping and Vibration Control

- Ensures smooth ride quality by reducing oscillations.
- Minimizes **NVH (Noise, Vibration, Harshness)** issues in EVs.

Aerodynamic Optimization & Adjustable Ride Height

- Lowers ride height at **higher speeds** to improve aerodynamics.
- Increases height for **rough terrain** or **battery protection**.

4. Design Approach for EV Suspension System

Weight Distribution & Center of Gravity Considerations

- EVs have **low-mounted battery packs**, impacting suspension design.

Battery Pack Placement & Suspension Adaptation

- Suspension should **minimize vibrations to prevent battery damage**.
- Must **support additional weight** of the battery.

Spring and Damping Rate Calculations

Formula: Spring Rate (k)

$$k = \frac{W}{\Delta x} \text{ Where:}$$

- W = Load on the spring (N)
- Δx = Spring compression (m)

Example Calculation:

- Vehicle weight: 1800 kg
- Front weight distribution: 55% (990 kg)
- Rear weight distribution: 45% (810 kg)
- Spring compression: 100 mm (0.1 m)

$$k_{front} = \frac{9900}{0.1} = 9900 \text{ N/m} \quad k_{rear} = \frac{8100}{0.1} = 8100 \text{ N/m}$$

Integration with Regenerative Braking

- Suspension should handle weight shifts during braking.
- Smoothens transitions between **braking and acceleration**.

5. Case Studies on Suspension System Design in EVs

1. Independent Suspension Design for a Mid-Sized EV

- **Front Suspension:** Double Wishbone
- **Rear Suspension:** Multi-Link
- **Spring Rate Calculation:** Based on weight distribution
- **Damping Rate Optimization:** Determined through real-world testing

2. Tesla Model 3 Suspension System

- **Front Suspension:** Double Wishbone
- **Rear Suspension:** Multi-Link
- **Spring Rate:** 8870 N/m (Front), 9600 N/m (Rear)
- **Designed for performance and efficiency**
- **Adjustable damping for comfort and handling**

6. Advanced Concepts in EV Suspension Systems

Variable Geometry Suspension

- Adjusts **camber angles dynamically** to improve stability.

Energy Recovery from Suspension (eROT system in Audi)

- Uses **electromechanical dampers** to convert vibrations into usable energy.

Autonomous-Ready Suspension Technologies

- AI-controlled suspension adapting to road conditions.

Conclusion

- EV suspension systems need to handle **unique challenges** like **battery weight, aerodynamics, and regenerative braking**.
- **Advanced suspension designs** improve **comfort, stability, and performance**.
- **Future innovations** like **energy recovery and AI-driven suspensions** will further enhance EV ride quality.

Module 3: Wheels System in Electric Vehicles

1. Introduction to Wheels in Electric Vehicles

Importance of Wheels & Tyres in EVs

- **Performance Impact:**
 - Wheels influence acceleration, handling, and braking efficiency.
 - Lightweight wheels improve maneuverability and responsiveness.
- **Energy Efficiency & Range:**
 - Low rolling resistance tyres reduce energy consumption, improving range.
 - Aerodynamic wheel covers help decrease air drag, further enhancing efficiency.
- **Safety Considerations:**
 - Proper tyre selection ensures grip, stability, and braking performance.
 - Reinforced sidewalls are needed for high torque handling in EVs.

Material Considerations for EV Wheels

- **Steel Wheels:**
 - Heavy and less fuel-efficient but durable and cost-effective.
 - Used mainly in budget EVs.

- **Alloy Wheels (Aluminum, Magnesium):**
 - Lighter than steel, leading to better acceleration and handling.
 - Improves heat dissipation, enhancing braking performance.
- **Carbon Fiber Wheels:**
 - Ultra-lightweight, high strength-to-weight ratio, used in high-performance EVs.
 - Reduces rolling resistance and improves aerodynamics.

Comparison with ICE Vehicles

Factor	ICE Vehicles	Electric Vehicles
Weight Distribution	Engine weight in front	Battery weight low & centered
Torque Output	Gradual increase	Instant torque, requiring reinforced tyres
Efficiency Consideration	Fuel efficiency optimized via engine tuning	Rolling resistance & aerodynamics critical for battery range
Noise & Vibration	Engine noise masks tyre noise	Special tread patterns required for silent operation

2. Classification of Wheels in EVs

Based on Material

- **Steel Wheels:**
 - Cost-effective and durable but heavy, reducing energy efficiency.
 - Used in low-cost and commercial EVs.
- **Alloy Wheels:**
 - Lightweight, improving efficiency and heat dissipation.
 - Preferred for mid-range EVs.
- **Carbon Fiber Wheels:**
 - Extremely strong and lightweight, reducing vehicle weight.
 - Expensive, mainly found in luxury and high-performance EVs.

Based on Construction

- **One-Piece Wheels:**
 - Manufactured as a single unit, offering durability and simplicity.
 - Common in most passenger EVs.
- **Multi-Piece Wheels:**
 - Consist of separate components bolted together.
 - Offer customizability and easier repair but are heavier and costlier.

Based on Load Capacity & Purpose

- **Lightweight Wheels:**
 - Improve energy efficiency and reduce strain on motors.
 - Used in urban and economy EVs like Tesla Model 3.
- **Heavy-Duty Wheels:**
 - Designed for off-road and high-load conditions.
 - Found in SUVs and electric trucks like the Rivian R1T.

Special EV Wheel Technologies

- **Aero Wheels:** Found in Tesla models, reducing drag to increase range.
- **Regenerative Wheels:** Future innovation that captures kinetic energy.
- **Self-Adjusting Wheels:** Adapt to different speeds and terrains.

3. Classification of Tyres in EVs

Tubed vs. Tubeless Tyres

Type	Advantages	Disadvantages
Tubed	Cheap, easy to repair	Prone to punctures, increased rolling resistance
Tubeless	Less air loss, better efficiency	Slightly higher cost

Symmetric, Asymmetric, & Directional Tyres

Type	Features	Best Used For
Symmetric	Uniform tread pattern, long lifespan	Budget-friendly daily EVs
Asymmetric	Better grip & handling, optimized water dispersion	Performance EVs
Directional	Enhanced wet traction, hydroplaning resistance	High-speed EVs

Radial vs. Bias-Ply Tyres

Type	Advantages	Disadvantages
Radial	Low rolling resistance, longer lifespan	Slightly costlier
Bias-Ply	More durable on rough roads	Higher energy loss, less efficient for EVs

Special EV Tyres

- **Low Rolling Resistance:** Reduces energy consumption.
- **Reinforced Sidewalls:** Supports added EV weight.
- **Noise-Reducing Tread:** Minimizes tyre noise for a quieter ride.

4. Wheel Topology Design in EVs

Load Distribution & Battery Placement

- Battery placement lowers the center of gravity, improving handling.
- Even weight distribution prevents tyre wear and enhances stability.

Traction & Stability Considerations

Drive Type	Traction Benefits	Best Used In
FWD	Good for city driving, better wet traction	Economy EVs (Hyundai Kona Electric)
RWD	Better acceleration, dynamic handling	Performance EVs (BMW i4)
AWD	Superior stability, ideal for rough conditions	High-performance/off-road EVs (Rivian R1T)
In-Wheel Motors	Precise torque control, instant response	Future EVs with advanced mobility

Maneuverability & Steering Enhancements

- **Rear-Wheel Steering:** Enhances turning radius.
- **4-Wheel Steering:** Found in premium EVs (Mercedes EQS) for better agility.

5. Integration of Wheels with Traction Motor

Concept of In-Wheel Motors (Hub Motors)

- Direct torque delivery for higher efficiency.
- Eliminates traditional drivetrain components.

Challenges & Solutions in Wheel-Mounted Motors

Challenge	Solution
Heat Management	Liquid cooling, heat-resistant materials
Increased Unsprung Weight	Lightweight alloys, active suspension
Durability	Waterproof enclosures, corrosion-resistant materials

6. Influence of Wheel Size on Braking Performance

Effect of Larger Wheels

Pros	Cons
Bigger brake rotors for better stopping power	Increases overall vehicle weight
Improved heat dissipation	Higher rolling resistance

Case Study: Tesla Model S Plaid (21-inch vs. 19-inch wheels)

Feature	21-inch Wheels	19-inch Wheels
Braking Power	Higher due to larger rotors	Moderate
Energy Efficiency	Lower range due to rolling resistance	Better efficiency
Comfort	Stiffer ride	Smoother ride

Conclusion

- EV wheels & tyres **impact efficiency, safety, and performance.**
- **Wheel topology affects handling, traction, and stability.**
- **Integration with traction motors** enhances performance.
- **Optimized wheel size balances braking power & range.**

1. Rolling Resistance Force (F_r)

Rolling resistance affects energy efficiency and driving range.

$$F_r = C_r \times W$$

Where:

- F_r = Rolling resistance force (N)
- C_r = Rolling resistance coefficient (typically 0.005 to 0.015 for EV tyres)
- W = Normal load on the tyre (N)

✔ Example Calculation:

For an EV with mass = 1500 kg, and assuming a rolling resistance coefficient of 0.01,

$$F_r = 0.01 \times (1500 \times 9.81) = 147.15 \text{ N}$$

2. Wheel Rotational Inertia (Moment of Inertia, I)

The moment of inertia of a wheel affects acceleration and energy consumption.

For a **solid disc wheel**:

$$I = \frac{1}{2}mr^2$$

For a **thin hoop (idealized lightweight alloy wheel)**:

$$I = mr^2$$

Where:

- I = Moment of inertia ($\text{kg}\cdot\text{m}^2$)
- m = Mass of the wheel (kg)
- r = Radius of the wheel (m)

✓ Example Calculation:

For a **wheel mass of 10 kg** and **radius of 0.3 m**,

$$I = \frac{1}{2} \times 10 \times (0.3)^2 = \frac{10 \times 0.09}{2} = 0.45 \text{ kg} \cdot \text{m}^2$$

3. Braking Force (F_b)

Braking force depends on the applied torque and brake rotor radius.

$$F_b = \frac{T}{r}$$

Where:

- F_b = Braking force (N)
- T = Braking torque (Nm)
- r = Effective radius of the brake rotor (m)

✓ Example Calculation:

If a **braking torque of 400 Nm** is applied on a **0.3 m brake rotor**,

$$F_b = \frac{400}{0.3} = 1333.3 \text{ N}$$

4. Kinetic Energy of a Rotating Wheel (E_k)

The kinetic energy stored in a rotating wheel contributes to overall vehicle motion.

$$E_k = \frac{1}{2} I \omega^2$$

Where:

- E_k = Rotational kinetic energy (J)
- I = Moment of inertia ($\text{kg} \cdot \text{m}^2$)
- ω = Angular velocity (rad/s)

✅ **Example Calculation:**

If a wheel with inertia $0.45 \text{ kg} \cdot \text{m}^2$ rotates at **50 rad/s**,

$$E_k = \frac{1}{2} \times 0.45 \times (50)^2 = 562.5 \text{ J}$$

5. Power Loss Due to Rolling Resistance (P_r)

Power loss due to rolling resistance affects energy efficiency.

$$P_r = F_r \times v$$

Where:

- P_r = Power loss (W)
- F_r = Rolling resistance force (N)
- v = Vehicle speed (m/s)

✅ **Example Calculation:**

For a rolling resistance force of **147.15 N** at **20 m/s**,

$$P_r = 147.15 \times 20 = 2943 \text{ W (or 2.94 kW)}$$