

Design and Integration of a Compact Single-Stage Timing Belt Transmission Subsystem

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Abstract:

This project presents the design and development of a rear wheel subsystem for an electric vehicle (EV) scooter, focusing on power transmission and suspension components. With the increasing demand for sustainable urban mobility, EV scooters are emerging as viable alternatives to traditional two-wheelers due to their low emissions and operational efficiency. However, many current designs suffer from inefficiencies in power delivery and bulky packaging.

The methodology involved data collection from ISO standards and technical literature, followed by force analysis and belt drive calculations. CAD modeling was conducted using SolidWorks and Siemens NX, and the prototype was fabricated using materials like AISI 4130 alloy steel and mild steel reinforcements.

Key results include achieving a 6.875:1 gear reduction ratio with an estimated 91.3% transmission efficiency, and safe operation under a 180 kg load with satisfactory suspension performance. The final design meets the objectives of compactness, reliability, and manufacturability, making it suitable for both retrofit and production EV platforms.

Keywords — Electric Vehicle, Transmission, Power, Efficiency, Hub Drive, Two-wheeler, Performance

I. INTRODUCTION

The power transmission is the heart of any vehicle, responsible for converting electrical energy from the battery into mechanical motion of the motor and further, driving the wheels via a suitable transmission system, while the suspension system ensures stability, comfort, and control by managing the forces acting on the vehicle. For lightweight commuter vehicles like EV scooters, the integration of these systems must be both compact and efficient, balancing power delivery with ride comfort. Transmission designs often involve complex, bulky assemblies that increase weight, reduce efficiency, and limit design flexibility.

Given these challenges, there is a need for innovative subsystem designs that address these limitations without compromising on performance or durability. This project specifically targets the rear wheel assembly of an EV scooter, a critical component that influences power transmission, stability, and ride quality. This design aims to reduce overall weight, improve power efficiency, and enhance structural reliability. The choice of a single-stage timing belt drive is particularly advantageous for EVs, as it offers high efficiency, low maintenance, and smooth power delivery.

The transmission of power from the motor to the rear wheel is a critical subsystem in EV design. While hub motors eliminate mechanical transmission, they often increase unsprung mass, leading to reduced suspension efficiency and higher maintenance complexity during wheel replacement or

servicing. Conversely, mid-drive configurations utilize a centrally mounted motor to transfer power via belts or chains to the rear wheel. Chains are widely used due to their strength and ease of torque handling, but they require regular lubrication and generate noise. Whereas belts, particularly timing belts, offer quieter operation, lower maintenance, and better resistance to dirt and corrosion. Table 1 represent the comparison between hub and mid motor drive.

TABLE I
 COMPARISON BETWEEN HUB AND MID DRIVE MOTOR

Parameter	Hub Motor	Mid Drive Motor
Torque	Lower (direct drive)	Higher (gear reduction)
Handling	Slightly compromised (more unsprung mass)	Improved (centralized weight)
Cooling	Limited (inside wheel)	Better (exposed to circulation)
Maintenance	More difficult (wheel mounted)	Easier (frame mounted)
Customization (Gearing)	Not possible	Possible (change sprockets/pulleys)
Ride Comfort	Harsher (more unsprung mass)	Smother (less load on)

		swingarm)
Ideal for	Low-power, budget EVs	Performance-oriented EVs

This project adopts a mid-drive configuration using a single-stage timing belt reduction system for optimal performance and maintainability. Setup offers multiple benefits:

- Improved torque multiplication via customizable gear ratios.
- Lower unsprung mass, enhancing suspension performance.
- Centralized weight distribution, contributing to better handling.

II. PROJECT OBJECTIVES

The primary objective of this project is to design and develop a compact, lightweight, and efficient rear wheel assembly for an EV scooter. This subsystem aims to achieve the following:

- Mid-drive timing belt transmission to achieve high power transmission efficiency with reduced noise and maintenance compared to chain drives or hub motors.
- Space optimization by designing a compact layout that accommodates battery placement, improves ground clearance, and retains under-seat storage.
- Reduced unsprung mass by relocating the motor and drive elements away from the wheel hub, enhancing suspension performance and handling.
- Ease of assembly and maintenance, achieved through a single axle mounting system for the swing arm and intermediate pulleys, reducing part count and mechanical complexity.
- Integration of brake drum and rear wheel pulley into a single unit, minimizing misalignment, reducing weight, and simplifying rear wheel servicing.
- Modular and scalable design, adaptable to other EV platforms and configurations for retrofitting or new production vehicles.

III.LITERATURE REVIEW

Aniket et al. [1] discussed the design and analysis of an electric vehicle powertrain aimed at improving efficiency, reducing torque demand, and optimizing battery usage. They highlighted a timing belt drive as an optimal choice for lightweight EVs due to its high efficiency (~91.3%) and silent performance.

Gurumurthy et al. [2] provides a detailed methodology for selecting belt profiles, pulleys, and calculating load capacities—reinforcing the choice of an HTD S8M profile in this project.

Hashmi et al. [3] developed the design and analysis of an electric Formula Student vehicle’s drivetrain system, to meet Formula Bharat 2021 EV rules. Its focus is on maximizing the power-to-weight ratio while ensuring safety and cost-effectiveness, enabling the team to build a competitive yet feasible vehicle within budget constraints.

[4] explores the modeling and simulation of an electric vehicle powertrain using MATLAB/Simulink, covering components like the motor, transmission, and battery along with vehicle dynamics. Their study also highlights torque–speed compatibility, system performance under dynamic conditions, and confirms MATLAB/Simulink as an effective tool for analyzing and developing EV powertrains at the conceptual stage.

The study of [6] focuses on precise powertrain sizing for electric vehicles through detailed calculations of forces, energy, motor, and battery performance. By analyzing discharge rates and usage times, it determines optimal component capacities that enhance efficiency, extend range, and support improved vehicle design.

IV.METHODOLOGY

The following flow chart shows the methodology adapted in completing the project.

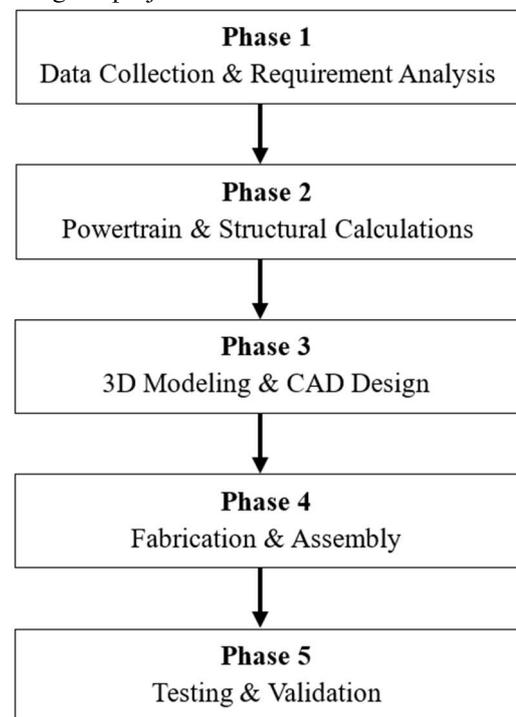


Fig.1. Methodology of project

V. POWER TRAIN SELECTION

The various component of the power train is discussed in this section and is one of the very important criteria. Following are the various components of the power train:

A. Battery

Choosing a suitable battery is also a crucial part of the powertrain. Lithium-ion batteries have high power density and for different cell chemistries, they offer different configurations. They are simply constructed by arranging cells in series and parallel to achieve desired power figures. For the application of current project, a Lithium Iron Phosphate

battery with 13S10P cell configuration, 48V and 24Ah capacity is selected.

B. Motor

For the current project, a 1000 W mid-drive motor have been selected to showcase the design of the power transmission. Since it allows for optimized torque multiplication, better weight distribution, and easier maintenances. Table 2 represents the motor specifications.

TABLE III
MOTOR SPECIFICATIONS

Rated Power	1000 W (Peak 1350 W)
Motor RPM (rated)	3000
Vehicle Speed	35 km/h (9.72 m/s)
Wheel Diameter	0.467 m (18.38 inches)

C. Transmission

In EVs, the choice of secondary transmission influences performance, efficiency, and maintenance. Timing Belt Drive uses toothed belts and pulleys for positive engagement. It has High efficiency (typically 90–98%), operates quietly and requires minimal maintenance. It is suitable for EVs with medium to high torque applications.

VI. DESIGN CALCULATIONS

The design of the rear wheel subsystem, including the suspension and power transmission, requires a series of precise engineering calculations to ensure optimal performance, reliability, and safety. These calculations cover power transmission, belt drive design, swing arm strength, and suspension parameters [7-10].

A. Powertrain Design and Calculations

Speed Ratio and Gear Reduction:

To determine the appropriate speed ratio, the desired wheel RPM is calculated by using the following formula.

$$\text{Wheel RPM} = \frac{\left(\text{Vehicle Speed} \left(\frac{\text{m}}{\text{s}}\right)\right)}{\text{Wheel Circumference (m)}} \times 60$$

$$\text{Wheel RPM} = \frac{9.72}{\pi \times 0.467} \times 60 = 397.6$$

The speed ratio is then given by:

$$\text{Speed Ratio} = \frac{\text{Motor RPM}}{\text{Wheel RPM}} = \frac{3000}{398} \approx 7.54$$

Effective reduction ratio is to be achieved by taking in account the efficiency of the transmission. There are some losses encountered due to use of ball bearings and the use of belt drive. The efficiency assumed to be 91.3%, as the wheel needs to be propelled at a higher RPM than calculated to account for the losses. The final Achieved Reduction Ratio is 6.875:1

This means the powertrain must reduce the motor's high-speed rotation by a factor of 6.875 to achieve the desired wheel speed.

B. Belt Drive Calculations

The following are the steps performed to calculate the belt drive:

Step 1: For 3000 RPM and peak motor power of 1000 W, belt type and tooth profile is selected by taking Factor of Safety of 2. So, for 2000W, the S8M belt is selected by referring to the chart of MISUMI Japan [6]. The High Torque Drive (HTD) S8M timing belt was selected for its strength, efficiency, and durability. The first pulley will transmit power from the motor to the intermediate pulley. This work selected 20 Teeth Pulley for the motor and 55 Teeth pulley for the intermediate pulley system. This gives gear ratio of 2.25

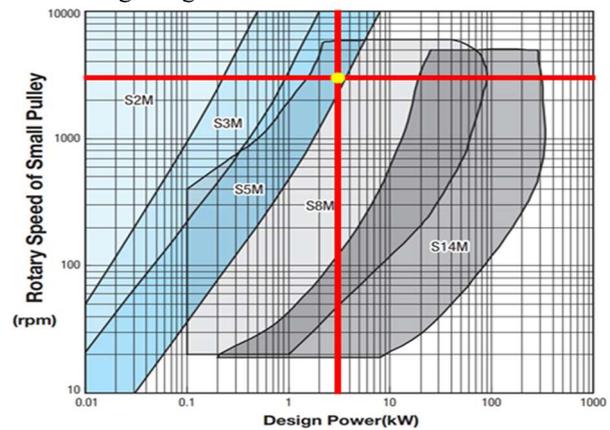


Fig. 2. Graph for selection of S_M Series Belt

Further, the power is transmitted from a co-axially attached intermediate pulley to the final drive pulley coupled to the rear wheel. The intermediate pulley has 24 Teeth, and the final pulley has 60 teeth. Therefore, the Gear ratio is 2.5. Hence, the final ratio comes out to be (2.25) (2.5) = 6.875 which is the desired value.

Step 2: Belt Length Calculation: It is done by making a 2D geometry on SolidWorks. For Initial pair of pulleys, the center-to-center distance is kept as 130 mm (Fig. 3) and for the next pair, the distance is kept the same as the swing arm length, i.e., 350 mm as shown in Fig. 4.

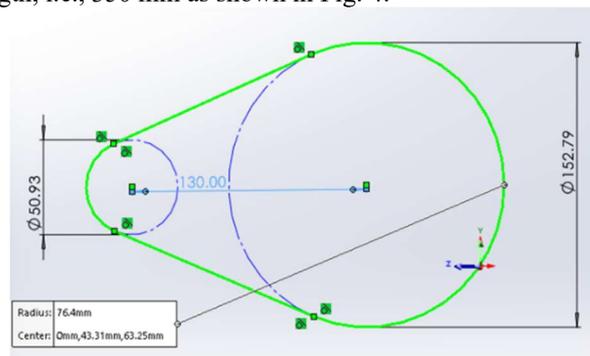


Fig. 3. Belt 1 Length Calculation by 2D Sketch

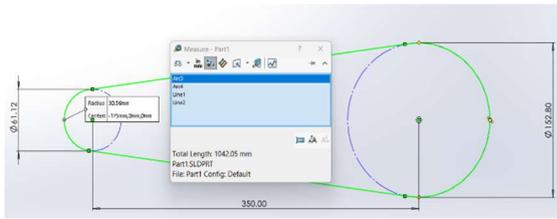


Fig. 4. Belt 2 Length Calculation by 2D Sketch

For the belt lengths, the chart for belt circumference length is referred and for the first belt, length is 600 mm and for the second belt, length is 1040 mm (Fig. 5-6)

Type: S8M (Pitch: 8mm)

Type	Part Number	Belt Nominal Width	Number of Teeth	Belt Circumference Length (mm)
	480 S8M		60	480
	520 S8M		65	520
	560 S8M		70	560
	594 S8M		73	594
	600 S8M		75	600
	632 S8M		79	632
	656 S8M		82	656
	710 S8M		89	710

Fig. 5. Charts representing Belt Teeth and Corresponding Length

976 S8M		120	976
1000 S8M		125	1000
1040 S8M	150	130	1040
1056 S8M	(15mm)	132	1056
1080 S8M	250	135	1080

Fig. 6. Charts representing Belt Teeth and Corresponding Length
Belt 1 Teeth = 75; Belt 2 Teeth = 130. Tolerance of ±10 mm can be assumed for tension.

Step 3: Belt Width Calculation: We take reference belt width and make the calculations accordingly and then verify the values.

Rotary Speed of Small Pulley (rpm)	No. of Teeth of Small Pulley													
	20	21	22	24	25	26	28	30	32	34				
	Diameter of the Pitch Circle (mm)													
	50.93	53.48	56.02	61.12	63.66	66.21	71.30	76.39	81.49	86.58				
870	6.38	6.70	7.02	7.66	7.98	8.29	8.93	9.56	10.20	10.83				
1160	8.51	8.93	9.35	10.20	10.62	11.05	11.89	12.73	13.58	14.42				
1750	12.81	13.44	14.07	15.34	15.97	16.61	17.86	19.12	20.37	21.62				
3500	25.33	26.56	27.78	30.20	31.40	32.59	34.96	37.29	39.60	41.86				
50	0.37	0.39	0.40	0.44	0.46	0.48	0.51	0.55	0.59	0.62				
100	0.73	0.77	0.81	0.88	0.92	0.95	1.03	1.10	1.18	1.25				
200	1.47	1.54	1.62	1.76	1.84	1.91	2.06	2.20	2.35	2.50				

Fig. 7. Reference Transmission Capacity of S8M Belt at 60 mm Reference Width

Ref width = 60 mm, assume belt width = 25mm Width correction constant $K_b = 0.37$ (Fig. 7-8) Therefore, the power tolerated by belt $P_s = K_b \times 21.8 = 0.37 \times 21.8 = 8.06$ kW (21.8 = correction factor at 3000 rpm).

S8M MTS8M	150	15	0.21
	250	25	0.37
	300	30	0.45
	400	40	0.63

Fig. 8. Corresponding Value of Width Correction Constant

K_m = Belt engagement factor

$$\text{No. of Teeth Engaged (Zm)} = \frac{Zd\theta}{360^\circ}$$

Where,

$$\theta = \text{Contact Angle} = 180^\circ - \frac{57.3 \times (D_p - d_p)}{C}$$

Zd = No. of teeth of small pulley

D_p = Pitch Diameter of Large Pulley (mm)

d_p = Pitch Diameter of Small Pulley (mm)

C = Inter-shaft distance (mm)

Z_m comes out to be 7.5 for the given values. So, $K_m = 1$ (Fig. 9)

No. of Teeth Engaged Z_m	More than 6	5	4	3	2
K_m	1.0	0.8	0.6	0.4	0.2

Fig. 9. Engagement Correction Coefficient (K_m)

Therefore,

Belt Width

$$= \frac{\text{Design Power} \times \text{Reference Width}}{K_m \times P_s} \times 60$$

$$= \frac{2 \times 60}{1 \times 8.06} \approx 15 \text{ mm}$$

Final belt width for both belts = 15 mm.

Step 4: Verification of Design: Now it can be verified if Design Power (P_d) satisfies the following formula. If not, then select the belt width of one size larger again. To verify, the following condition must be satisfied

$$P_d < P_s \cdot K_m \cdot K_b$$

Where,

P_d = Design Power

P_s = Reference Transmission Capacity

K_m = Engagement Correction Coefficient

K_b = Width Correction Coefficient

Therefore, $P_s \cdot K_m \cdot K_b = 8.06 \times 1 \times 0.37 = 2.98$ kW

Since, $P_d = 2$ kW, i.e., The condition is satisfied and the design is safe. Hence two selected belts are **600 S8M** and **1040 S8M** of 15 mm width each.

VII. MODELLING AND ANALYSIS

The following are the steps performed to model and analyze the drive:

A. Conceptualization and Sketching:

The project started with hand sketches and geometric layouts. Key design parameters such as the single-stage timing belt drive dimensions, gear ratios, and the suspension system's swing arm were determined.

B. Modeling the Transmission Components:

The timing belt drive, pulleys, and corresponding shafts were modelled in detail. Parameters like pulley diameter, tooth profiles (selecting the HTD S8M belt series based on preliminary calculations), and alignment were rigorously implemented in the CAD environment to ensure precision.

C. Modeling the Suspension Subsystem:

The suspension system was modelled focusing on the reinforced swing arm design. This model incorporated mounting points for dampers, reinforcements in the swing arm,

and rubber bushings to simulate realistic pivot behaviour (Fig. 10)

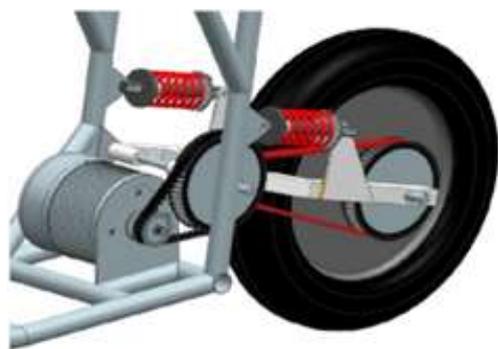


Fig. 10. Cad Model of Pulleys

D. Assembly and Interference Checks:

All individual components were assembled to form the integrated rear wheel assembly. The driving pulley of 20 teeth is coupled to the motor shaft via a slot and key coupling. The intermediate pulleys are connected to each other via 5mm bolts and lock nuts. As they constitute the moving parts, the pulleys have two 6201 deep groove ball bearings at both ends separated by a spacer of suitable length. The final pulley has a 6201 deep groove ball bearing at the 24 center and is directly fixed to the brake drum and the wheel rim via four 16 mm hardened steel bolts and lock nuts. The dampers are fixed to 6 mm thick plates welded to the swing arm on one end and to the frame of the vehicle via 4 mm thick plates. The dampers are assembled parallel to the swing arm.

Detailed interference and clearance analyses were performed to validate that the compact layout met design criteria and allowed for ease of assembly as well as maintenance. (Fig. 11)

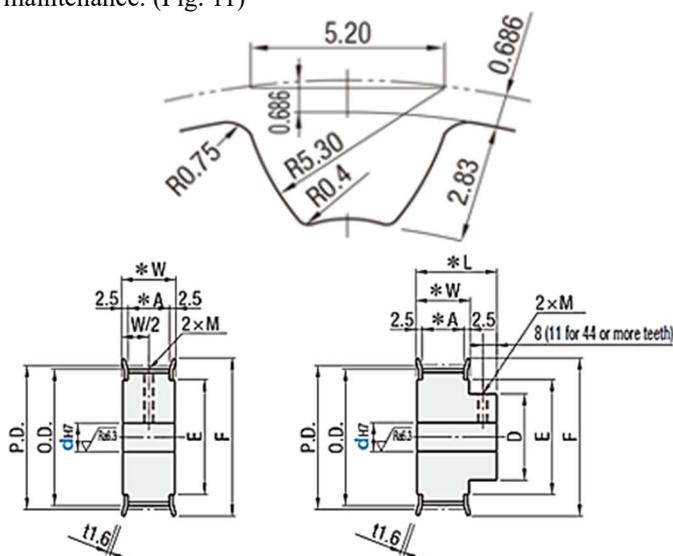


Fig. 11. Tooth profile of S8M Pulleys

VIII. TESTING OF THE PROTOTYPE

- Dimensional inspections were performed using callipers and coordinate measuring machines (CMM) to ensure parts matched the CAD designs.
- The assembled prototype underwent trial runs to validate the alignment, belt tension, and overall structural integrity before commencing full load testing.

IX. INTEGRATION AND FINAL ADJUSTMENTS:

- Operational Check: The belt drive mechanism was tested at operational speeds to verify the calculated final reduction ratio (approximately 6.875:1) and power transmission efficiency (~91.3%). (Table 3-4)
- 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.

TABLE III
TRANSMISSION SYSTEM TESTING BELT DRIVE

Parameter	Value
Type	HTD S8M Timing Belt
Reduction Ratio	2.75:1 (1st stage)
	2.5:1 (2nd stage)
Belt width	15 mm
Belt lengths	600 mm and 1040 mm
Pulley teeth	Small (20, 24)
	Large (60, 60)

TABLE IV
TEST RESULTS

Observed Speed	35 kmph
Wheel RPM	~400
Transmission efficiency	~91.3%
Remark	Smooth, quite power delivery, minimal belt slip

X. CONCLUSIONS

This project successfully achieved the design and development of a rear wheel subsystem for an electric vehicle (EV) scooter, focusing on optimizing power transmission and suspension performance while maintaining a compact and lightweight design. The integration of a single-stage timing belt drive with a reinforced swing arm suspension resulted in a subsystem that meets the demands of urban commuting providing smooth power delivery, improved ride comfort, and structural reliability. CAD-based modeling, supported by analytical calculations and finite element analysis (FEA), guided the design process and ensured accuracy in fabrication. Key achievements of the project include:

- 91.3% transmission efficiency achieved using an HTD S8M timing belt system with a gear reduction of 6.875:1.
- Durable swing arm construction using AISI 4130 alloy steel with effective load distribution.

- Suspension system withstood up to 1200 N in UTM testing, maintaining a safety factor of 2.5.
- Maximum stress and deflection values were within safe material limits under full load conditions.

The final prototype successfully supported a 180 kg load at 35 kmph and passed real-world operational tests, validating the design objectives. The modular nature of the subsystem also allows for ease of manufacturing and potential adaptability to other EV formats. In conclusion, the project demonstrates how thoughtful mechanical design, combined with simulation and practical testing, can lead to the development of efficient and sustainable EV components. The resulting subsystem is not only functional but also manufacturable, scalable, and aligned with the future of electric mobility.

XI. LIMITATIONS AND LEARNINGS

While the project was largely successful, a few limitations and observations emerged:

- Thermal expansion of belts under long-term operation needs further study.
- The rubber bushings, while effective, may degrade under prolonged UV or oil exposure.
- Precision in pulley alignment is critical minor deviations can reduce efficiency.

XII. SCOPE FOR FUTURE WORK

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:

A. 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.

B. 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.

C. 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.

D. 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.

E. 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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