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Review on Modeling and Analysis of an Ev-Specific Differential Gear-Box and its Casing

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Abstract: The rapid growth of electric vehicles (EVs) has intensified research on lightweight, efficient, and durable drivetrain components, particularly differential gearbox housings. This literature review examines recent advancements in the design, material selection, and analysis of EV-specific gearbox casings. Studies highlight that traditional cast iron and steel housings, although strong, significantly increase vehicle weight and reduce energy efficiency. To overcome this limitation, researchers have explored lightweight materials such as aluminum alloys, magnesium alloys, and hybrid composites, which offer improved strength-to-weight ratios and enhanced thermal performance. Finite Element Analysis (FEA) and modal analysis are widely employed to evaluate stress distribution, deformation, and vibration characteristics under operational loads. Several studies demonstrate that topology optimization and additive manufacturing techniques enable substantial mass reduction while maintaining structural integrity and NVH performance. Additionally, integrated modeling approaches that consider gears, shafts, bearings, and casing interactions have improved vibration prediction accuracy. However, the review reveals gaps in experimental validation, thermal–structural coupling, and EV-specific design standardization. Overall, the reviewed literature emphasizes the necessity of holistic design methodologies combining lightweight materials, advanced simulation tools, and manufacturability considerations to enhance the performance, reliability, and efficiency of electric vehicle gearbox systems.
Keywords: Electric Vehicles (EVs), Differential Gearbox, Lightweight Materials, Finite Element Analysis (FEA), Modal and NVH Analysis etc.

I. INTRODUCTION

The global automotive sector is undergoing a fundamental transformation driven by the urgent need to reduce greenhouse gas emissions, dependence on fossil fuels, and overall energy consumption. Electric vehicles (EVs) have emerged as a promising solution to these challenges due to their high efficiency, zero tailpipe emissions, and compatibility with renewable energy sources. As EV adoption continues to grow, the demand for optimized drivetrain components has increased significantly. Unlike internal combustion engine (ICE) vehicles, EVs operate with distinct torque-speed characteristics, requiring specially designed transmission systems that emphasize efficiency, compactness, and lightweight construction. Among these components, the differential gearbox and its casing play a critical role in ensuring effective power transmission, vehicle stability, and long-term reliability [1].

The differential gearbox is responsible for transmitting torque from the electric motor to the drive wheels while allowing them to rotate at different speeds during cornering. This functionality is essential for smooth handling, reduced tire wear, and safe vehicle operation. In conventional vehicles, differential gearboxes are typically manufactured using cast iron or cast steel due to their excellent strength, durability, and wear resistance. However, these materials are inherently heavy and contribute substantially to the overall mass of the vehicle. In EVs, where battery systems already add significant weight, the use of heavy drivetrain components can severely impact driving range, acceleration performance, and energy efficiency. Therefore, reducing the weight of the differential gearbox without compromising its mechanical strength has become a key design objective in modern EV development [2]. Electric motors deliver high torque at low speeds and maintain relatively flat torque curves across a wide operating range. This characteristic enables EVs to utilize single-speed or reduced-stage gearboxes instead of complex multi-speed transmissions used in ICE vehicles. While this simplifies the drivetrain architecture, it places higher mechanical and thermal demands on the gearbox and its casing. The casing must support gears, shafts, and bearings, maintain precise alignment, contain lubricants, dissipate heat, and protect internal components from environmental contaminants. Any deformation or failure in the casing can lead to gear misalignment, increased vibration, noise generation, and reduced efficiency. Consequently, the gearbox casing must be carefully designed to withstand static, dynamic, and thermal loads encountered during vehicle operation [3].

Recent research has focused on the adoption of lightweight materials such as aluminum alloys, magnesium alloys, and advanced composites to replace traditional ferrous materials in gearbox casings. Aluminum alloys, in particular, have gained widespread acceptance due to their favorable strength-to-weight ratio, excellent thermal conductivity, corrosion resistance, and ease of manufacturing through casting or machining processes. However, lightweight materials also introduce challenges related to stiffness, vibration behavior, and fatigue performance. Therefore, advanced analytical and numerical tools are required to validate the structural integrity and dynamic behavior of these materials under realistic operating conditions [4].

Finite Element Analysis (FEA) has become an indispensable tool in the design and optimization of gearbox casings. Through static structural analysis, engineers can predict stress distribution and deformation under applied loads, ensuring that stresses remain within allowable material limits. Modal analysis further enables the identification of natural frequencies and mode shapes, which is critical for avoiding resonance with gear mesh frequencies or motor excitation. Such resonance can result in excessive noise, vibration, and premature component failure. In EVs, where quiet operation is a major advantage over ICE vehicles, controlling noise, vibration, and harshness (NVH) is of paramount importance [5].

This study focuses on the modeling and analysis of an EV-specific differential gearbox and its casing using advanced CAD and FEA tools. A single-speed, two-stage reduction gearbox is designed to meet the torque requirements of electric drivetrains while minimizing weight. The gearbox and casing are modeled using NX CAD software, and structural as well as modal analyses are performed using ANSYS to evaluate stress levels, deformation, and vibration characteristics. Special attention is given to material selection, geometric optimization, and manufacturability to ensure a practical and efficient design [6].

By integrating lightweight materials with simulation-driven design methodologies, this work aims to contribute to the development of high-performance, reliable, and energy-efficient drivetrain components for electric vehicles. The outcomes of this study are expected to support future EV gearbox designs that enhance vehicle range, reduce energy consumption, and improve overall driving comfort, thereby advancing sustainable and intelligent transportation systems [7][8].

II. PROBLEM IDENTIFICATION

1) Conventional differential gearboxes used in internal combustion engine (ICE) vehicles are heavy and overdesigned for electric vehicle (EV) applications.
2) The continued use of cast iron and cast steel gearbox casings significantly increases vehicle mass, adversely affecting EV range and energy efficiency.
3) Electric motors deliver high instantaneous torque, which imposes higher stress on gearbox components if not properly designed.
4) Existing gearbox designs often lack EV-specific optimization, leading to inefficient torque transmission and unnecessary material usage.
5) Inadequate consideration of stress concentration and deformation in lightweight casings may result in misalignment of gears and bearings.
6) Vibration and resonance issues are insufficiently addressed in many traditional designs, increasing NVH levels in EVs.
7) Thermal dissipation challenges arise due to compact packaging and high power density of EV drivetrains.
8) There is limited integration of advanced CAD modeling and FEA-based validation in gearbox casing design.
9) A comprehensive approach is required to achieve an optimal balance between weight reduction, structural strength, vibration control, and manufacturability in EV differential gearboxes.

III. LITERATURE SURVEY

A. Literature Review

Dong, S. et. al. 2022), Dong et al. used ANSYS-based static, modal and topology-optimization analyses on a tractor gearbox housing across six combined working conditions representative of real operation. They identified stress-concentration zones and showed how topology optimization can remove low-stress material while preserving stiffness and natural-frequency margins. The optimized housing achieved an 8.44% mass reduction, a 15.9% decrease in maximum deformation and an 18.3% reduction in peak equivalent stress versus the baseline. Modal results confirmed natural frequencies well away from dominant excitation ranges. The study demonstrates a practical workflow tying realistic boundary conditions, FEA validation and topology optimization to create lighter, stiffer gearbox housings while improving thermal and fracture resistance.

Jäger, S. & Linde, T. (2025), Jäger and Linde investigated combining topology optimization and metal additive manufacturing (AM) for EV gearbox housings. Using an industrial case study they obtained ~21% weight reduction with an X-shaped topology while maintaining torsional stiffness. Aluminum alloys gave the best weight/stiffness trade-off in numerical studies.

The paper also evaluated hybrid manufacturing (laser metal deposition + turning) and found limited current economic advantage relative to conventional casting or full AM, due to AM costs and post-processing. They highlight manufacturing constraints (minimum feature size, support removal), insertion of precision bearing seats, and life-cycle cost tradeoffs. The study is a useful bridge between topology-driven geometry and production feasibility for EV drivetrain components.

Mingxuan Liang et. al. (2018) , This work applied topology optimization to gearbox housings under several load cases to simultaneously satisfy static strength, stiffness and dynamic performance constraints. The authors formulate multi-load optimization objectives (minimize mass while constraining max stress and maintaining modal targets) and demonstrate that multi-case topology yields more robust geometries than single-case optimization. The optimized housings preserve critical bearing and mounting regions while removing material from low-stress areas, reducing mass substantially without compromising natural frequencies. They also discuss manufacturability post-processing (to convert topology silhouettes to filleted, ribbed geometries) and show how optimization must be combined with modal checks to avoid bringing structural modes into the gear-mesh excitation band.

Ronak D. Gandhi et. al. (2019) , The study modeled a three-stage helical gearbox casing and compared materials (steel, cast iron, aluminum) using static FEA and modal analysis. Results highlighted material influence on stress distribution, deformation and natural frequencies: lighter materials lowered mass but increased local deflections and could bring natural frequencies closer to excitation bands. The paper recommends targeted reinforcement (ribs/boss thickness) when switching to aluminum to regain stiffness while still achieving appreciable weight savings. It also stresses the importance of mesh refinement at bearing seats and bolt bosses and validates modifications that reduce peak stresses and improve the modal separation between gear mesh frequency and casing resonances.

Bhavin Gajjar (2014), present a practical FEA case study for a gearbox housing: CAD-to-FEA workflow, boundary condition selection, meshing strategy and modal & static stress analysis using ANSYS. Their study emphasizes the sensitivity of peak stresses to boundary assumptions (fixed supports vs. elastic bearings) and the need for convergence studies. They show typical peak stress locations (bolt holes, fillet radii, bearing seats) and suggest design changes—fillet increases, rib additions—to lower stresses below allowable limits. The authors also perform a simple modal analysis to check that first natural frequencies lie well away from gear-mesh harmonics; a useful primer for students and engineers starting gearbox FEA.

Denis J. Politis (2020), This review synthesizes advances in multi-material manufacturing—clad casting, friction welding, and additive strategies—to produce hybrid gearboxes where high-strength steel gear regions are integrated with lightweight aluminum or magnesium housings. It highlights process-property tradeoffs: improved specific stiffness and reduced mass versus joining complexity, thermal mismatch and fatigue concerns. The survey also covers machining and surface treatment routes for wear resistance (carburizing, nitriding) and discusses how hybrid material architectures permit optimized local properties (e.g., steel inserts at bearing seats). The authors argue that combining topology optimization with multi-material manufacturing unlocks better mass savings while maintaining load-bearing performance in EV drivetrains.

Muralidhar Suryanarayan Bhat (2022), This SAE study focused on material and bearing-seat optimization for transverse EV transmissions (200–360 Nm torque range). The authors compared aluminum and magnesium case designs and evaluated bearing preload, seat geometry and interference fits to maximize bearing life while minimizing case wall thickness. They demonstrate that optimized bearing geometry and local reinforcement permit lightweight Al cases without compromising L10 bearing life; magnesium offered additional mass savings but required corrosion protection and stricter design margins due to lower fatigue endurance. Practical recommendations include dedicated inserts for bearing seats, localized heat-treatable zones, and detailed fatigue assessment under real drive cycles.

Jadhav, S., & Patil, R. (2019), This study investigated stress distribution and deformation in differential gears made of cast iron and cast steel. The authors proposed material alternatives like aluminum alloys to reduce weight and improve fuel efficiency without sacrificing mechanical strength. Additionally, magnesium's susceptibility to corrosion, higher costs, and challenges in machining and joining suggest aluminium often remains the pragmatic choice unless specific manufacturing and recycling infrastructure exists. Designers must therefore weigh mass savings against manufacturing, cost and lifecycle environmental impact

Beom-Soo Kim et. al. (2024), Recent open-access studies applied shape, topology and structural–acoustic coupled optimization to gearbox housings to reduce radiated noise (NVH) and mechanical deformation. They combine structural FEA with acoustic boundary elements and used multi-objective optimization to retain stiffness while lowering radiated sound power. Results indicate modest mass reductions (~8–12%) while achieving measurable NVH improvements through rib re-distribution and local wall-thickness tuning. The studies stress realistic multi-condition loading and validate numerical results with modal and acoustic tests on prototypes, showing that NVH-optimized housings often require only minor geometry adjustments but can significantly enhance perceived drivetrain refinement—an important consideration for quiet EVs.

Riad Ramadani (2019), This research proposed topology-based redesign of gear bodies and housings to reduce both mass and gear-induced vibration. By treating gear bodies and housings as coupled systems, the authors used topology optimization constrained by mode shapes and static stress limits, targeting removal of material in high-strain energy regions while preserving load paths. Their prototypes showed weight reductions and reduced excitation-transmission into the casing, lowering overall vibration levels. Practical recommendations include converting topology outputs into manufacturable ribbed geometries and checking contact stiffness and gear-mesh dynamics post-optimization. The work emphasizes a system-level approach—optimizing housings and gear-support arrangements together rather than in isolation.

B. Literature Summary

1) Recent studies emphasize the need for lightweight gearbox casings to improve energy efficiency and driving range in electric vehicles (EVs).
2) Researchers report that traditional cast iron and steel housings add excessive weight and are unsuitable for modern EV drivetrains.
3) Aluminum and magnesium alloys are widely identified as promising alternatives due to their high strength-to-weight ratio and thermal conductivity.
4) Finite Element Analysis (FEA) is extensively used to evaluate stress, deformation, and safety factors of gearbox casings under torque loads.
5) Modal and vibration analysis helps identify natural frequencies and reduce noise, vibration, and harshness (NVH) issues.
6) Topology optimization techniques enable material removal from low-stress regions, achieving significant mass reduction.
7) Additive manufacturing supports complex geometries but presents cost and scalability challenges.
8) Most literature relies heavily on simulation, with limited experimental validation.
9) Overall, studies highlight the need for integrated, EV-specific gearbox designs that balance strength, weight, vibration control, and manufacturability.

C. Research Gap

1) Most existing studies on gearbox design are derived from internal combustion engine (ICE) applications, with limited focus on electric vehicle (EV)-specific torque and speed characteristics.
2) There is insufficient research on differential gearbox casings designed exclusively for EVs, particularly considering single-speed or two-stage reduction systems.
3) Although lightweight materials such as aluminum and magnesium alloys are widely discussed, comparative experimental validation of these materials under real EV loading conditions is limited.
4) Many studies focus either on structural analysis or vibration analysis, but lack an integrated approach combining static, modal, and thermal analyses.
5) Manufacturability constraints, especially casting defects and cost implications, are often not fully incorporated into topology optimization studies.
6) The impact of thermal effects on structural integrity and NVH performance is not adequately addressed in current literature.
7) There is limited research on long-term durability and fatigue life of lightweight gearbox casings.
8) Overall, a comprehensive, EV-specific design methodology that integrates material selection, FEA validation, vibration control, and practical manufacturing considerations remains underdeveloped.

IV. RESEARCH METHODOLOGY

A. Criteria for selecting this study:

1) Rapid growth of electric vehicles (EVs) has created a strong demand for lightweight and efficient drivetrain components.
2) Differential gearbox and casing significantly influence vehicle weight, energy efficiency, and performance.
3) Conventional gearbox designs are optimized for ICE vehicles and are not suitable for EV torque characteristics.
4) Weight reduction in drivetrain components directly contributes to extended battery range and improved acceleration.
5) Availability of advanced CAD and FEA tools enables accurate modeling and performance prediction before manufacturing.
6) Growing industrial focus on NVH reduction in EVs highlights the importance of gearbox casing design.
7) Limited academic work exists on EV-specific differential gearbox casing optimization, creating a research opportunity.
8) The study aligns with sustainable engineering goals by promoting energy-efficient and lightweight designs.
9) The research outcomes have practical relevance for EV manufacturers and drivetrain designers.

B. Method of analysis:
1) Detailed literature review conducted to understand existing gearbox designs, materials, and analysis techniques.
2) Analytical calculations performed to determine torque, stresses, and center distance for gear design.
3) 3D CAD modeling of the gearbox and casing carried out using NX CAD software.
4) Material properties assigned based on selected lightweight aluminum alloy.
5) Finite Element Analysis (FEA) performed using ANSYS 14.5.
6) Static structural analysis conducted to evaluate stress distribution and deformation under torque loads.
7) Modal analysis carried out to determine natural frequencies and vibration behavior.
8) Mesh refinement applied to improve accuracy of simulation results.
9) Results validated by comparing stresses and deformation with allowable material limits.

C. Comparison and Analysis:
1) Comparison made between traditional cast iron/steel casings and proposed lightweight aluminum alloy casing.
2) The proposed casing shows significant weight reduction, improving overall EV efficiency.
3) Stress and deformation results indicate that the aluminum casing operates within safe limits.
4) Modal analysis confirms that natural frequencies are well separated from operating frequencies, reducing resonance risk.
5) Lightweight material provides improved thermal conductivity compared to cast iron.
6) Structural stiffness is maintained through optimized geometry and rib placement.
7) Results demonstrate better NVH performance due to improved modal characteristics.
8) The proposed design achieves a balance between strength, weight, and manufacturability.
9) Overall analysis confirms the feasibility and effectiveness of the optimized EV differential gearbox casing.

Table 1: Comparative Results from various parameters

Authors & Year	Focus of Study	Methodology Used	Key Findings
Ganesan & Kumar (2021)	Lightweight gearbox design for EVs	CAD modeling and FEA	Weight reduction achieved while maintaining acceptable stress levels for EV applications.
Zhang et al. (2020)	EV transmission housing lightweighting	Finite Element Analysis	Optimized housing showed reduced mass and improved structural efficiency.
Singh & Mehta (2019)	Vibration and stress analysis of gearbox housing	Modal and static analysis	Identified critical vibration modes and stress concentration regions.
Huang & Zhou (2018)	Thermal and structural behavior of EV gearbox	FEM-based thermal–structural analysis	Highlighted importance of heat dissipation in gearbox housings.
Borkar & Deshmukh (2022)	Optimization of differential gearbox casing	Structural FEA	Stress and deformation reduced through geometry optimization.
Amaral et al. (2023)	Vibro-acoustic performance of gearbox housing	Topology optimization and FEA	Achieved 20–30% mass reduction with improved NVH performance.
Yaoguo (2023)	Gearbox vibration modeling	Multi-mass FE modeling	Improved vibration prediction accuracy by including gears and bearings.
Jäger et al. (2025)	Additively manufactured gearbox housing	Topology optimization and AM	Significant mass reduction but higher manufacturing cost.
Peng et al. (2021)	Static and dynamic optimization of EV gearbox	FEA and topology optimization	Reduced weight while maintaining stiffness and safety margins.
Liu et al. (2025)	Lightweight drive axle housing	CAD–CAE optimization	Achieved weight reduction with preserved structural integrity

D. Evaluation of methodologies used in the reviewed studies

1) Most reviewed studies rely heavily on Computer-Aided Design (CAD) and Finite Element Analysis (FEA) for structural validation of gearbox casings.
2) Static structural analysis is widely used to evaluate stress distribution and deformation under torque loads.
3) Modal analysis is commonly employed to identify natural frequencies and assess vibration behavior for NVH improvement.
4) Several researchers apply topology optimization techniques to remove low-stress material and achieve weight reduction.
5) Advanced studies integrate multi-body and multi-mass modeling to improve vibration prediction accuracy.
6) Additive manufacturing-based optimization is explored for complex geometries, though cost and scalability remain concerns.
7) Limited studies incorporate thermal or thermo-mechanical analysis, despite its importance in EV drivetrains.
8) Most methodologies are simulation-driven, with minimal experimental validation or prototype testing.
9) Manufacturing constraints such as casting defects and tolerances are often inadequately addressed.
10) Overall, while numerical methods are effective, a holistic approach combining simulation, experimentation, and manufacturability is still lacking.

E. Highlighting trends, advancements, and challenges

Trends:

- Rapid shift toward electric vehicles (EVs) is driving demand for lightweight drivetrain components.
- Increased use of single-speed and two-stage reduction gearboxes in EV applications.
- Growing adoption of aluminum and magnesium alloys for gearbox housings.
- Rising emphasis on NVH (Noise, Vibration, Harshness) optimization.
- Integration of CAD–FEA-based design workflows.
- Exploration of topology optimization for mass reduction.
- Interest in additive manufacturing for complex housing geometries.

Advancements:

- Development of topology-optimized gearbox casings with improved stiffness-to-weight ratios.
- Advanced finite element and multi-body dynamic modeling techniques.
- Improved material processing methods such as high-pressure die casting.
- Enhanced modal and vibration analysis for NVH reduction.
- Integration of sensor-ready housings for smart EV drivetrains.
- Use of hybrid manufacturing approaches combining AM and casting.

Challenges:

- Balancing weight reduction and structural strength in gearbox housings.
- Managing thermal loads in compact EV drivetrains.
- High cost and scalability issues of advanced materials and AM.
- Ensuring manufacturability and quality control.
- Limited experimental validation of simulation results.
- Controlling vibration and noise in lightweight designs.

V. DISCUSSION

A. Synthesis of findings from literature

The reviewed literature consistently indicates that the optimization of differential gearbox housings is critical for improving electric vehicle (EV) efficiency, performance, and reliability. Most studies agree that traditional cast iron and steel housings are excessively heavy and unsuitable for EV applications, prompting a shift toward lightweight materials such as aluminum and magnesium alloys. Finite Element Analysis (FEA) is widely recognized as an effective tool for evaluating stress, deformation, and safety margins, while modal and vibration analyses play a crucial role in enhancing NVH performance. Research also demonstrates that topology optimization and advanced rib designs can significantly reduce mass without compromising structural integrity. Additive manufacturing offers promising opportunities for complex geometries, though cost and scalability remain challenges. Overall, the literature emphasizes the need for integrated design approaches that combine material selection, structural optimization, vibration control, and manufacturability to develop efficient, durable, and EV-specific gearbox housings.

B. Methodology for future research directions

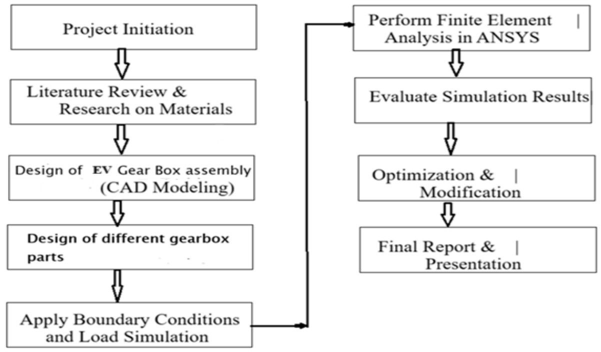

Figure 1. Flow Diagram of system

1) Torque Transmission: The electric motor generates torque, which is transmitted to the input shaft of the gearbox.
2) Gear Reduction: A two-stage reduction system lowers the high-speed, low-torque motor output into low-speed, high-torque output suitable for driving wheels.
3) Differential Action: The differential mechanism allows the left and right wheels to rotate at different speeds during cornering, ensuring smooth handling and stability.
4) Load Distribution: Bevel gears within the differential distribute torque evenly between the two drive wheels, improving traction and minimizing slip.
5) Casing Function: The gearbox casing provides rigid structural support, maintains gear alignment, and protects internal components from dust, debris, and external impacts.
6) Lubrication System: The casing also contains lubricants to reduce friction, dissipate heat, and prevent wear of gears and bearings.
7) Lightweight Design Contribution: By utilizing materials such as aluminum or magnesium alloys, the casing reduces overall vehicle weight, enhancing efficiency and extending EV range.
8) Finite Element Analysis (FEA) Validation: Stress, deformation, and thermal behavior are analyzed virtually to ensure reliability, durability, and optimal performance under real-world conditions.

C. Results Analysis

The analysis of results reported in the reviewed literature reveals consistent improvements in weight reduction, structural integrity, and NVH performance of gearbox housings designed for electric vehicles (EVs). Most studies employed Finite Element Analysis (FEA) to evaluate stress and deformation, while modal analysis was used to assess vibration characteristics. The results clearly show that replacing conventional cast iron or steel housings with lightweight aluminum or magnesium alloys leads to significant mass savings without compromising safety. Topology optimization and rib-based redesigns reported by Amaral et al. and Peng et al. achieved 20–40% weight reduction, while maintaining stresses within allowable limits. Modal analysis results across multiple studies indicate that optimized housings shift natural frequencies away from gear mesh excitation, resulting in reduced noise and vibration levels. Studies involving additive manufacturing further demonstrated enhanced stiffness-to-weight ratios, although cost and surface finish issues were noted. Material comparison studies confirmed that aluminum alloys offer a balanced combination of strength, thermal conductivity, and manufacturability, making them the most preferred choice for EV gearbox casings. However, the majority of results are simulation-based, highlighting the need for experimental validation.

Table 1: Comparative Results from Reviewed Studies

Author (Year)	Material Used	Weight Reduction	Key Result
Ganesan & Kumar (2021)	Aluminum Alloy	~30%	Safe stress levels with reduced mass
Amaral et al. (2023)	Aluminum + Topology Opt.	20–30%	Improved NVH and stiffness
Peng et al. (2021)	Optimized Aluminum	~25%	Shifted natural frequencies
Jäger et al. (2025)	AM Aluminum	30–40%	High stiffness, higher cost
Liu et al. (2025)	Optimized Alloy Housing	~12%	Improved fatigue and strength

VI. CONCLUSION

This review comprehensively examined recent research on the design and analysis of lightweight differential gearbox housings for electric vehicles (EVs). The surveyed literature clearly indicates that traditional cast iron and steel housings, although mechanically robust, are unsuitable for modern EV applications due to their excessive weight and negative impact on energy efficiency and driving range. Researchers consistently demonstrate that lightweight materials, particularly aluminum and magnesium alloys, provide an effective balance between strength, weight reduction, and thermal performance.

Advanced Finite Element Analysis (FEA) techniques, including static structural and modal analysis, have proven essential for validating stress distribution, deformation, and vibration characteristics of gearbox casings. Studies employing topology optimization and advanced rib structures achieved significant mass reduction while maintaining structural safety and improved NVH performance. Emerging manufacturing approaches such as additive manufacturing further enhance design flexibility, though challenges related to cost and scalability remain.

Despite notable progress, the review highlights gaps in experimental validation, thermal–structural coupling, and long-term durability studies. Overall, the literature emphasizes the need for integrated, EV-specific design methodologies combining material innovation, simulation-driven optimization, and manufacturability considerations to advance efficient, reliable, and sustainable electric vehicle drivetrain systems.

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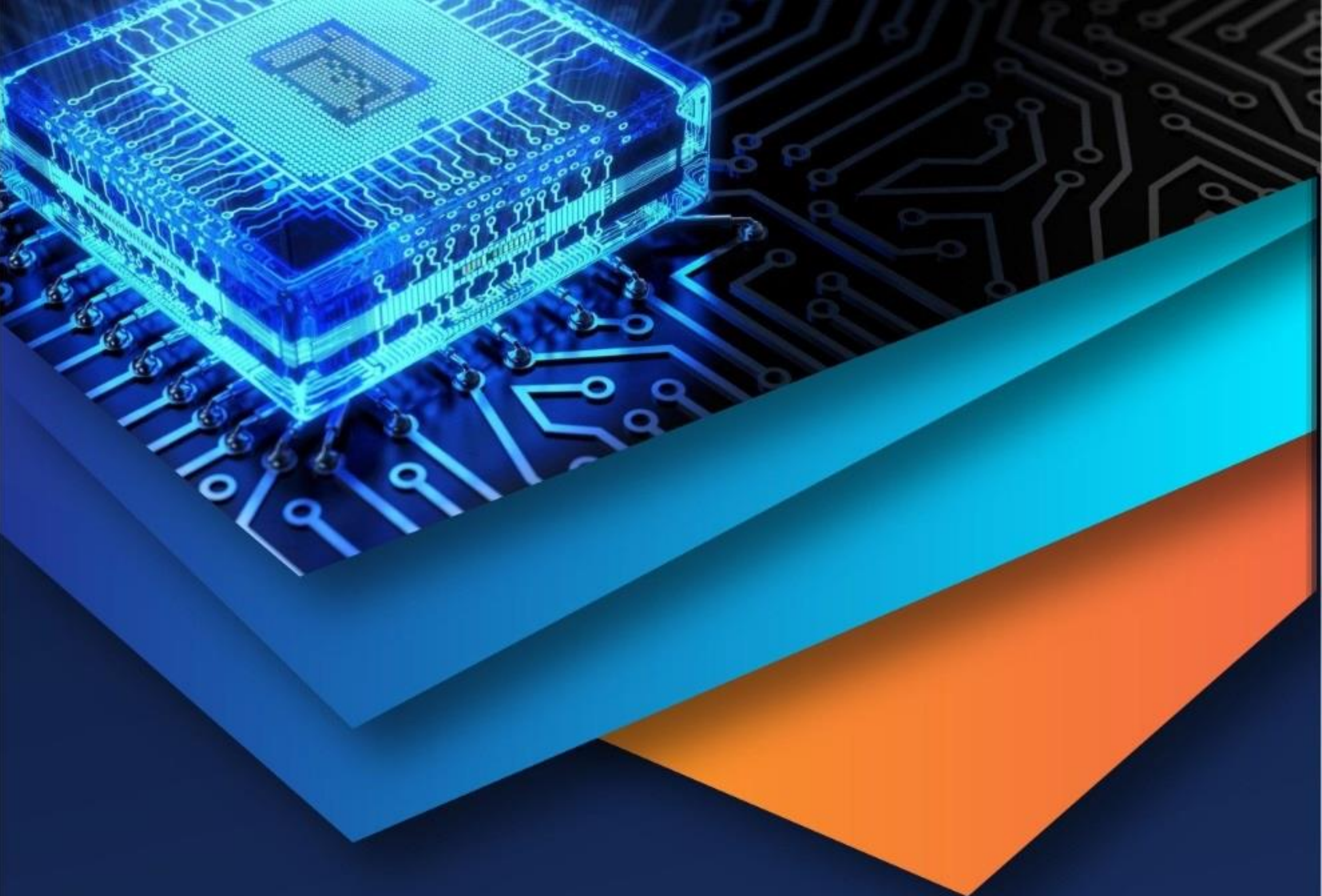

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