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A REVIEW PAPER ON FRONT AXLE FOR ELECTRIC VEHICLE

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Abstract: The emergence of electric vehicles has brought about changes to the loading and the designing of chassis elements, particularly front axles. Factors like battery packs weight, electric power drive units, high motor torque and regenerative braking have made changes in the static and dynamic loading of the front axles compared to those of the conventional internal combustion engine vehicles. This paper gives an insight into the current developments in design, materials and structural analysis of electric vehicle front axles. These include designs of the axle (beam axles, independent suspensions and e-axles), materials (forged steel, aluminum and composite materials) and the different analysis methods used (finite element analysis, topology optimization, fatigue life prediction, modal analysis and experimental validation). From this review, it is clear that design of lighter axles increase the driving range and the efficiency of the vehicle, but at the same time the factors like strength, stiffness, fatigue endurance, manufacturing cost should be considered. Currently there are few researches on electric vehicles and most of them are on conventional and heavy vehicles. There are very few researches done specifically on the front axles of the electric vehicles considering their loadings.

Keywords: front axle, electric vehicle, e-axle, structural analysis, finite element analysis, topology optimization, lightweight design, fatigue life, regenerative braking

I. INTRODUCTION

The increasing concerns about climate change, pollution in cities, and reliance on fossil fuel-powered engines have led to the move from internal combustion engine (ICE) cars to electric cars. Electric cars are more efficient in terms of power use, are less polluting and cost less to run, but there are additional challenges associated with their construction. The battery packs add significant mass, electric engines provide large amounts of torque at zero speed, and the use of regenerative braking affects the distribution of forces on the axles.

The front axle constitutes one of the vital components that take the load of a car. The axle bears part of the vehicle's weight, transfers braking and steering loads, and takes care of the shock loading of the road and cornering loads. For the electric vehicle, it also needs to withstand the high static loads due to the battery and torque reaction loads due to the drive unit in case of the front drive or integrated e-axle configuration. Fatigue failure, excessive deflection, and high stress concentrations may affect the handling and performance of the car. Weight reduction is essential for an extended driving range, hence the studies on steel, aluminum alloys, and composite materials.

Design analysis techniques including Finite Element Analysis (FEA), Topology Optimization, Fatigue Life Prediction, Modal Analysis, and experimental analyses have become a standard part of the process of developing axles. These techniques make it possible for designers to analyze stresses, deformations, natural frequencies, and fatigue life under actual loading conditions even before the first prototype is created. However, literature available at the moment is scattered across materials, design approaches, and analysis techniques, and focuses on traditional or heavy-duty commercial trucks as opposed to electric vehicles. This paper aims to review the current studies concerning the design and analysis of EV front axles and their comparison.

II. LITERATURE REVIEW

1. Martino et al. [1]
In this paper, an improved functionally integrated e-axle was developed for A-segment electric cars in the context of the FITGEN EU Project. The traction motor, power electronics and transmission system were all incorporated into a single modular unit. Packaging, thermal management, weight saving and manufacturability considerations have been taken into account in this study. This paper offers some valuable lessons in relation to the integration of the electric drive components and its effect on the axle design.

Janardhanan et al. [2]
The study analyzed single e-axle and multiple e-axles layouts of heavy electric vehicles. Various layouts using two electric motors with different gear ratios were studied in terms of their cruising and startability. Control algorithms were designed to reduce motor and brake losses while keeping acceptable axle loading. It was found out that single e-axle layout had a stronger dependency on friction braking and thus suffered from greater losses.

Yadagiri et al. [3]
The authors analyzed the design and optimization of a front axle of electric utility vehicles. The emphasis was put on the carrying ability, strength, lightening, and compatibility of the axle with the suspension system of the vehicle. The application of the finite element analysis and topology optimization methods was taken into consideration for enhancement of the axle geometry and material usage.

Liu et al. [4]
In this work, the authors provided a review of electric drive axle systems used in new energy vehicles. Specifically, they covered topics such as the combination of electric motors, gearboxes, and power electronics into small electric drive axles. Much emphasis was put on the areas of thermal management, cooling, control algorithms, and integration. This review shows how advancements in electric drive axles can lead to more efficient, lightweight and improved vehicle performance.

Huang et al. [5]
The authors considered the essential technologies utilized in the integrated electric drive axles applied to commercial vehicles. The paper focused on different e-axle architectures and the feasibility of their application for passenger cars, light commercial vehicles, and heavy-duty vehicles. The motor, inverter, and transmission were recognized as the major subsystems that affect the system performance.

Matsumori [6]
This paper focuses on studying the electric axle system that is installed in the electric vehicles with special consideration to the integration of electrical and mechanical aspects. E-axle comprises of an electric motor, inverter, and reduction gear integrated in one body. This integration decreases weight and size as well as the number of cables needed for the whole system. The study highlights the benefits of applying the e-axle system in FWD and RWD electric vehicles.

Ruiz Diez et al. [7]
The authors studied the problem of torque vectoring control of front-to-rear axle in electric cars with two electric engines. They have designed a torque vectoring strategy that distributes the torque between front and rear axles depending on certain vehicle operating conditions. Such an approach enhances vehicle dynamics and helps to minimize the effect of oversteer while turning.

Li et al. [8]
The authors conducted an investigation on lightweighting of front suspension upright of an electric Formula race car by using topology optimization methods. Several load cases such as turning, braking, and emergency braking have been considered in their structural analysis. As a result, a considerable weight reduction in the design was obtained without losing its strength and stiffness. This work offers valuable knowledge about the design of lightweight front axle and suspension systems in electric vehicles.

Ucak and Cengiz [9]
In this paper, the research is conducted on the design of an independent front suspension lower control arm for electric light-duty vehicles via topology optimization. A double wishbone suspension design has been chosen, and the multibody dynamics analysis is carried out to identify the forces acting on the suspension elements. The considered cases are braking, cornering, bumping, and braking & cornering conditions.

Design, Prototype, and Testing of an Integrated E-Axle [10]
In this study, the design, development, prototyping, and testing of an integrated e-axle for third generation electric cars in the FITGEN project was provided. In this research, the authors concentrated on the integration of electric motor, inverter, and gearbox in a single drivetrain system. The aim was to provide a design that would offer high power density with a compact design.

Efficient Regenerative Braking Approach [11]
The authors put forward a novel approach to efficient regenerative braking of vehicles that have front-wheel drive, rear-wheel drive, and all-wheel drive designs. In particular, the braking control system was developed in such a way that the maximum amount of energy is regenerated without causing lock-up of wheels and ensuring the stability of the vehicle. The new technique incorporates both regenerative and hydraulic friction braking of a vehicle in case the electric motor fails to provide necessary torque.

Torque Control During Regenerative Braking using Tire Force Constraints [12]
This work discusses the issue of regenerative braking torque control for both front and rear-motor-driven electric vehicles. An approach to regenerative braking torque limitation based on tire forces was designed to ensure that wheel slip would not exceed certain limits while braking to ensure stability of the vehicle. The new control technique is based on tire forces distribution between the front and rear axles.

Analysis and Optimization of the Steering Axle Structure Through Finite Elements Method [13]
The paper analyzed the structural design and optimization of the steering axle of the new energy vehicles through finite element method. Various loadings were considered to study the stress distribution, deformations, and strength of the axle parts. The analysis and optimization of materials and structure were conducted for improving durability and eliminating the unnecessary mass of the part. The study is related to the front axle since the steering axle is an important part of the vehicle.

Review of the Lightweight and Intelligent McPherson Suspension for New Energy Vehicles [14]
In this paper, the authors presented a literature survey on the development of the lightweight and intelligent McPherson suspension for new energy vehicles. In their study, the influence of higher weight of the vehicle, battery placement, and noise-vibration behavior of the vehicle on the front suspension design was analyzed. Various optimization methods and lightweight materials for enhancing the suspension performance were covered.

Review on Intelligent Design of Chassis Structure for Electric Vehicles [15]
The authors examined the intelligent design of chassis structure for electric vehicles with centralized drive systems. This study covered issues concerning structural design, suspension system, steering system, and electronics control techniques. Special emphasis was put on lightweight structural design, vehicle stability, and collaboration among the chassis systems. The study gives a wider insight into the design of front axle structure along with chassis design of the contemporary electric vehicles.

Amine et al. [16]
The authors provided a design-focused review of electric vehicle gearbox technology, considering gearbox design, gear ratios, efficiency, noise, vibration, and reliability. Various gearbox configurations, such as single speed, dual speed, and multispeed transmissions, were analyzed. The benefits and drawbacks of different gearbox designs and their applicability to electric vehicles were explored. This information can be applied when choosing the correct gearbox for an electric vehicle front axle.

Huang et al. [17]
The authors provided an analysis of the key technologies that were involved in designing integrated electric drive axles. In particular, the authors have paid attention to electric motor choice, inverter design, transmission development, and axle design. Moreover, the authors have pointed out the problems associated with thermal management, power density, and reliability issues. The work is of practical value in designing front drive axles.

Variations in Manufacturing and Assembly of Electric Drivetrains [18]
In this research, the impacts of variations in manufacturing and assembly in terms of NVH properties of electric drivetrains were examined. Various sources of variation such as gear misalignment, bearing clearance, shaft eccentricity, and manufacturing tolerances were explored. The results of this research provide an insight into the impact of variations on drivetrain vibrations and acoustics. This is very relevant to front axle gearbox design since precise manufacturing and assembly is essential to lower noise and increase durability.

Electrical and Mechanical Integration in Electric Drive Axles [19]
In this study, the authors looked at the integration of the electrical and mechanical components of electric vehicles. In particular, the connection between the performance parameters of the electric motor, the transmission, the power electronics and the axle was described. Special emphasis was placed on issues related to packaging and the efficiency of the electric vehicle drivetrain.

Independent Front Suspension and Steering Systems Design for Electric Vehicles [20]
In this paper, the authors examined the design considerations of independent front suspensions and steering systems for electric vehicles. They analyzed various driving conditions such as braking, cornering, and road impact loading in order to assess the performance of front suspension components. The paper emphasizes the significance of suspension geometry, steering features, choice of materials, and structure in enhancing vehicle control and safety. All these elements play an important role in the design of the front axle system of an electric vehicle.

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