BIRMINGHAM CITY University

School of Engineering and Built Environment

Investigating the Role of Torque Vectoring in Enhancing Electric Vehicle Handling and Safety

This Proposal is submitted as part of the Master of Science in Automotive Engineering Degree requirements

Course: MSc Automotive Engineering

Module: Individual Master's Project (ENG7200)

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1. Introduction

1.1 Background and Preliminary Literature Review

Electric Vehicles (EVs) are not merely a part of the future of transportation; they're a significant portion of the present. Governments and manufacturers are ramping up EV adoption due to their environmental benefits and the decreasing cost of battery technologies. As these vehicles become a staple on the roads, their handling and safety characteristics under various conditions become even more paramount.

Torque vectoring is one such technology that promises enhanced control, especially in challenging conditions. Historically, torque vectoring was primarily a feature in high-performance vehicles, designed to improve cornering and agility. However, with the shift to electric drivetrains, the precision and control offered by electric motors present a unique opportunity to implement torque vectoring in a wider range of vehicles for both performance and safety benefits.

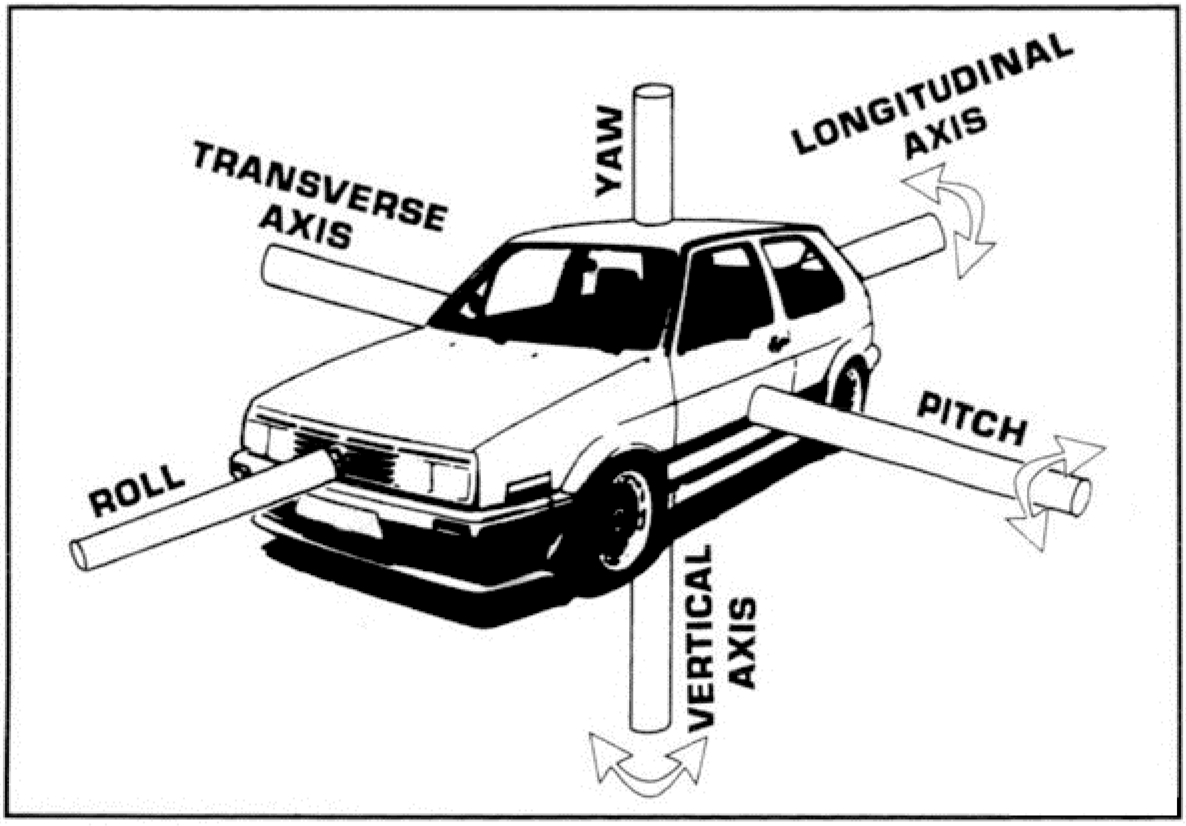

Figure 1 Translational moments acting on a car (Getty Images, 2020).

1.2 Preliminary Literature Review:

a. Fundamentals of Torque Vectoring

De Novellis et al. (2014) compared various feedback control techniques for torque-vectoring in fully electric vehicles. They introduced the concept as a method of distributing torque to individual wheels, thereby offering improved traction and steering. In another overview by De Novellis et al. (2012), the authors provided a comprehensive state-of-the-art exploration of torque vectoring in vehicles with individually controlled motors.

b. Torque Vectoring and Vehicle Performance

A significant contribution to understanding torque vectoring's impact on vehicle performance is by Vignati et al. (2018). Their study focused on the use of torque vectoring to enhance vehicle performance during drifting, a challenging driving condition. The results suggested enhanced stability and control, especially during high-speed maneuvers. Similarly, Lenzo et al. (2017) delved into torque distribution strategies, suggesting optimized distributions can result in energy-efficient operations without compromising performance

c. In-wheel Motor Systems and Torque Vectoring

One of the unique aspects of certain EV designs is the use of in-wheel motors. Studies such as Chae et al. (2019) emphasized the dynamic handling characteristics of in-wheel-motor driven EVs using torque vectoring, concluding significant improvements in handling. Furthermore, Kim & Kim (2023) showcased a model predictive control approach for yaw stabilization in EVs with four in-wheel motors, highlighting the energy efficiency benefits alongside improved handling.

d. Safety Enhancements through Torque Vectoring

Safety, being paramount in vehicular design, has been a focal point in several studies. Ren et al. (2019) discussed torque vectoring's role in assisting the turning of a narrow tilting electric vehicle. Their findings indicated that appropriately vectored torque can help prevent dangerous tilting behaviors in specific EV designs, enhancing safety. Moreover, Parra et al. (2018) proposed an intelligent torque vectoring approach that adapts to various driving conditions, further pushing the boundaries of safety and adaptability in EVs.

e. Challenges and Future Directions

Despite the noted advantages, challenges persist. While studies such as Mikle & Bat'a (2019) discussed the potentials of torque vectoring in all-wheel-drive EVs, they also highlighted the complexities in real-world implementations. The balance between energy efficiency, as discussed by Zhou et al. (2017), and dynamic performance remains a crucial area for further research.

1.3 Problem statement

With the surge in adoption of electric vehicles (EVs), ensuring their optimal performance, handling, and safety under varying conditions has become imperative. Traditional vehicular control systems, originally designed for internal combustion engine (ICE) vehicles, may not exploit the full potential of electric drivetrains. EVs, with their inherent characteristic of instant torque delivery and individual motor controls, present both challenges and opportunities in vehicular dynamics. While torque vectoring has been introduced as a solution in high-performance vehicles to enhance handling, its potential benefits in the broader spectrum of EVs remain understudied. There is a pressing need to understand and quantify the role of torque vectoring in enhancing the handling characteristics and safety protocols of EVs. This research aims to investigate how torque vectoring can be optimized for EVs to ensure safer, more efficient, and more responsive driving experiences across a wider range of scenarios and vehicle types.

1.4 Proposed Solution

a. Advanced Torque Vectoring Control System for EVs:

i. Dynamic Algorithm Development:

Develop a software-based control algorithm that caters specifically to the unique dynamics of EVs. Given the rapid and precise torque adjustments made possible by electric motors, the algorithm will ensure optimal torque distribution among individual wheels in real-time. Factors like wheel speed, steering angle, yaw rate, and lateral acceleration will be considered for real-time decisions.

ii. Integrated Safety Protocols:
Combine the torque vectoring mechanism with established vehicular safety systems, like the Anti-lock Braking System (ABS) and Electronic Stability Control (ESC). By coordinating these systems, the vehicle can be kept in a stable state even under challenging driving conditions, reducing risks of oversteer, understeer, and potential skidding.

b. Simulation and Real-world Testing:

i. Virtual Simulations:
Before real-world tests, deploy extensive computer-aided simulations to validate the efficacy of the developed torque vectoring system under varied simulated conditions—ranging from wet to dry roads, different temperatures, and various driving scenarios.

ii. Practical Field Tests:
Post-simulation, select a range of EV models and integrate them with the developed torque vectoring system. Subject these vehicles to rigorous field tests under diverse conditions to obtain a holistic understanding of system performance.

c. Feedback Loop for Continuous Refinement:

a. Data Collection:
Equip test vehicles with sensors and data loggers to gather exhaustive data during the testing phase. Parameters like torque distribution, wheel slip, vehicle speed, and steering angle should be logged in real-time.

b. Data Analysis:
Utilize advanced data analysis techniques, potentially including machine learning algorithms, to decipher patterns, anomalies, and areas of potential improvement from the gathered data.

c. Iterative Refinements:
Based on the insights from data analysis, make necessary adjustments and refinements to the torque vectoring algorithm to optimize performance further.

d. Collaboration and Integration:

Engage with prominent EV manufacturers and stakeholders to present the developed solution and its benefits. Work collaboratively to integrate the refined torque vectoring system into mainstream EV models, ensuring broader application and benefits to the end-users.

1.5 Research Question

How does torque vectoring influence the handling dynamics and safety measures of electric vehicles under various driving conditions

1.6 Research Aim

To comprehensively investigate and analyze the influence of torque vectoring on the handling dynamics and safety measures of electric vehicles, aiming to delineate its benefits, potential limitations, and integration challenges. Through this exploration, this research seeks to offer optimized strategies and actionable insights for the enhancement of electric vehicle performance, safety, and overall driving experience.

1.7 Research Objectives

- To dissect and understand the fundamental mechanics of torque vectoring systems
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- To evaluate the impact of torque vectoring on electric vehicle handling dynamics
- To ascertain the role of torque vectoring in elevating safety protocols
- To investigate any trade-offs between enhanced performance through torque vectoring and energy consumption
- To identify practical challenges and potential roadblocks in implementing torque vectoring systems in mainstream electric vehicles.
- To study how torque vectoring can augment the overall driving experience, focusing on driver feedback and comfort levels during various driving conditions.
- To provide actionable recommendations for electric vehicle manufacturers on the most effective strategies for integrating and optimizing torque vectoring systems in their vehicle models.

2. Research Methodology

2.1 Overview

Provide a succinct overview of the methodologies to be employed, focusing on the design, simulation, and validation of the torque vectoring system using MATLAB.

2.2 Design Process of the Torque Vectoring System

Objective Definition: Clearly state the goals, performance criteria, and constraints of the design.
Concept Generation and Selection: Outline the generation and selection process of different design concepts, detailing the chosen concepts for further development.
Detailed Design: Develop the selected concept into a detailed design, including specifications, calculations, and drawings

2.3 Simulation Process

Objective Definition: Clearly state the goals, performance criteria, and constraints of the design. Concept Generation and Selection: Outline the generation and selection process of different design concepts, detailing the chosen concepts for further development.
Detailed Design: Develop the selected concept into a detailed design, including specifications, calculations, and drawings

2.4 Validation with MATLAB

Objective Definition: Clearly state the goals, performance criteria, and constraints of the design. Concept Generation and Selection: Outline the generation and selection process of different design concepts, detailing the chosen concepts for further development.
Detailed Design: Develop the selected concept into a detailed design, including specifications, calculations, and drawings

Simulation Software Selection: Specify the software tools for simulation, explaining the choice and relevance. Model Development: Detail the development of a simulation model, discussing any simplifications and assumptions made.
Simulation Setup: Clearly define the setup, parameters, and conditions of the simulation.

The MATLAB model of the torque vectoring system will be created by first identifying and translating the fundamental equations governing the system into MATLAB scripts or Simulink models. Each component of the system, such as motors and controllers, will be developed separately before being integrated into a cohesive model representing the entire system. Given the intricate nature of real-world systems, certain simplifications and assumptions will be made, which will be explicitly stated along with their justifications. Parameters will be meticulously defined, and sensitivity analysis will be conducted to assess their impact on the model. Where possible, real-world data will be utilized to validate the parameters and the overall model to ensure an accurate representation of the actual system behavior.

The following parameters related to safety and handling are considered and will be validated.

Safety:

i. **Braking:**

Definition: Braking refers to the deceleration of the vehicle, primarily to avoid obstacles, maintain safe distances, or slow down for turns.
Role of Torque Vectoring:
Distributes braking force variably to each wheel.
Helps in reducing the stopping distance.
Enhances stability during braking, especially in mixed traction conditions
(e.g., wet on one side, dry on the other).
Reduces the risk of skidding or spinning during sudden braking.
Measurement & Modelling:
Braking distance under various conditions.
Vehicle stability metrics during braking.

ii. **Understeer and Oversteer:**

Definition: Understeer: The front wheels don't turn enough, and the vehicle tends to go straight.
Oversteer: The rear wheels lose grip, and the vehicle tends to spin.
Role of Torque Vectoring:
Adjusts torque to individual wheels to counteract the onset of understeer or oversteer.
Enhances vehicle stability in slippery conditions or during aggressive maneuvers.
Measurement & Modelling:
Yaw rate or angular velocity.
Lateral acceleration.
Steering wheel angle vs. actual turn angle of the vehicle.

Handling:

i. **Enhanced Cornering:**

Definition: Refers to the vehicle's ability to navigate turns efficiently and comfortably.
Role of Torque Vectoring:
Distributes torque variably to inner and outer wheels during a turn.
Improves the vehicle's line-following ability in a curve.
Reduces the need for aggressive steering inputs.
Measurement & Modelling:
Cornering radius at different speeds.
Lateral force generation.
Steering effort and feedback.

ii. **Improved Agility and Responsiveness:**

Definition: Agility refers to the vehicle's ability to change direction swiftly. Responsiveness is about how quickly the vehicle reacts to driver inputs.
Role of Torque Vectoring:
Adjusts torque distribution rapidly based on driver inputs and vehicle conditions.
Enhances the immediacy of the vehicle's reaction to steering, acceleration, or braking inputs.
Measurement & Modelling:
Time taken for lane change maneuvers.
Transient response times.

3. Project Management

This project's project management component is organized according to a carefully considered procedure that takes into account the following elements.

3.1 Project Planning

The purpose of a Gantt chart is to list every project action together with its duration and dates. This enables the research team to monitor project planning and update the supervisor on project progress. (An additional file is submitted with the Gantt chart.)

3.2 Project Tracking

Weekly meetings with the supervisor will be held to monitor the project's progress and obtain input in order to make adjustments based on each week's project plan, in addition to using the Gantt chart. In order to ensure that the project progress is accurately documented, any notes regarding the plans and meeting materials are also recorded in a logbook.

3.3 Project supervision

This project will be supervised by Dr. David Ashman, Senior Lecturer in in Engineering and the Built Environment at Birmingham City University.

4. Conclusion

As the automotive industry accelerates its shift towards electrification, the importance of optimizing electric vehicle (EV) performance and safety becomes paramount. Torque vectoring, as evidenced by the literature, emerges as a central pillar in this optimization process. By directly influencing braking, mitigating risks of understeer and oversteer, enhancing cornering prowess, and amplifying vehicle agility, torque vectoring provides a multidimensional solution to the challenges faced by modern EVs. Its integration not only promises improved vehicular dynamics but also emphasizes the priority of passenger safety. Future research in this domain is poised to unlock further enhancements, solidifying torque vectoring's role in the next generation of electric mobility. As we stand on the cusp of automotive evolution, it is evident that innovations like torque vectoring will shape the future of safe, efficient, and dynamic transportation.

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