

Study of Braking Distance and Time Characteristics During Low-Speed Braking in a Formula SAE Electric Vehicle

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Abstract

This research presents an experimental investigation into the braking performance of a Formula SAE-style electric vehicle (EV) prototype at low to moderate speeds ranging from 20 km/h to 60 km/h. Using the FRATEC EV Race Car platform, developed for educational and competitive applications, the study focused on measuring stopping distance, braking time, and brake temperature under controlled dry asphalt conditions. A total of five braking trials were conducted at discrete speeds (20, 30, 40, 50, and 60 km/h), and results indicated a nonlinear increase in stopping distance and brake temperature with speed. Stopping distances ranged from 3.1 meters at 20 km/h to 8.2 meters at 60 km/h, while brake temperatures increased from 48°C to 75°C. Braking time also showed a gradual increase, from 1.6 seconds at 20 km/h to 2.7 seconds at 60 km/h. The findings highlight the importance of optimized braking system design, thermal management, and consistent deceleration characteristics in enhancing safety and reliability in electric race cars. This study contributes valuable empirical data for future design validation in Formula SAE EV competitions.

Key Words: *Electric Vehicle (EV), Braking Performance, Braking Distance, Deceleration Rate, Lightweight Race Car, Hydraulic Disc Brakes*

1. Introduction

The growing focus on electric mobility and sustainable transportation has accelerated interest in electric vehicle (EV) platforms, especially in academic engineering competitions such as Formula SAE Electric (FSAE-E). These events challenge student teams to design, build, and test compact electric race cars that meet strict technical and safety criteria. Among the many performance parameters assessed in these competitions, braking effectiveness—particularly at low to moderate speeds—plays a crucial role in overall vehicle safety, control, and driver confidence. Despite its importance, braking performance often receives less attention during early design phases compared to acceleration, weight optimization, or battery management.



Figure 1: Formula SAE Electric Vehicle

Figure 1 illustrates a typical Formula SAE Electric Vehicle (EV), similar to the prototype used in this research. These vehicles are designed by student teams for academic engineering competitions, emphasizing compact design and adherence to strict technical and safety criteria. The focus of such vehicles includes various performance parameters, with braking effectiveness being crucial for overall safety, control, and driver confidence. This research aims to investigate the braking behavior of a student-built Formula SAE electric vehicle

under low-speed conditions. The main goal is to evaluate the braking distance, stopping time, and brake temperature vary with vehicle speed between 20 and 60 km/h. By conducting experimental trials on a controlled asphalt surface using the FRATEC EV Race Car prototype, this study seeks to quantify the relationship between speed and braking performance. In doing so, it provides practical insights into how vehicle dynamics, brake system efficiency, and thermal behavior interact in real-world scenarios. The results are intended to guide the development of safer and more efficient brake systems for electric race cars and contribute to the body of knowledge supporting engineering education in sustainable motorsport technology.

2. Literature Review

Braking performance is a vital parameter in electric vehicle (EV) design, particularly in the context of Formula SAE competitions where both speed and safety are critical. Numerous studies have explored the behavior of braking systems under various operational conditions to enhance understanding and improve engineering decisions. A study by (Yilmaz, 2013), emphasized the importance of regenerative and mechanical braking integration in EVs, stating that coordinated braking not only improves energy efficiency but also influences overall stopping performance. However, for race applications like Formula SAE, where braking must be immediate and predictable, mechanical disc brakes remain the primary system of choice due to their reliability and thermal stability.

Further, investigations by (Ganta, 2021) analyzed the influence of vehicle speed on braking distance and discovered a quadratic relationship between speed and stopping distance, aligning with the kinetic energy principle. This finding supports the theoretical expectation that kinetic energy increases with the square of velocity, requiring longer distances for safe deceleration at higher speeds. In another experimental analysis of an electric go-kart, (Bhatti, 2020) highlighted the role of brake caliper configuration and disc type on stopping performance. Their research concluded that ventilated disc brakes and dual-port calipers significantly improved heat dissipation and consistency in braking—critical design features for maintaining stable performance during competitive driving.

Moreover, research by (Wang, 2018) on simulation-based braking optimization demonstrated that the balance of braking force distribution between front and rear axles is crucial for stability and reduced stopping distances. This aspect is particularly relevant for electric race cars, which often adopt asymmetric braking setups for better balance and thermal control. These studies collectively inform the ongoing development of efficient, safe, and competition-ready braking systems for electric race vehicles. They underscore the need for experimental validation, proper brake sizing, and material selection in achieving high-performance outcomes.

High-performance electric race cars demand brake pad materials that can endure high thermal stress and provide consistent friction. (Chen & Zhang, 2023) investigated several novel composite formulations and found that ceramic-reinforced materials exhibited lower wear rates and stable friction characteristics under repeated braking cycles. Braking performance in lightweight EVs is highly influenced by tire-road interaction. (Kim & Park, 2021) demonstrated that variations in surface friction significantly impact braking stability, especially under wet or low-traction conditions, emphasizing the need for adaptive control strategies and optimal tire selection. Effective thermal management of disc brakes is crucial in electric race vehicles to prevent brake fade. Using CFD simulation, (Davies & White, 2020) showed that optimized ventilated disc geometry and airflow ducting can enhance cooling efficiency, thus maintaining consistent braking performance during high-speed runs.

3. Methodology

This experimental study aimed to evaluate the braking performance of a Formula SAE Electric Vehicle (EV) by measuring braking distance and time during low-speed braking. The focus was to use simple yet reliable measurement tools to gather essential braking data. The vehicle used in the experiment was a Formula SAE EV prototype equipped with a standard mechanical braking system. Prior to testing, the vehicle was carefully inspected to ensure that the brakes were functioning optimally and that the tires were inflated to recommended pressures. These measures were necessary to maintain consistency throughout the testing process. Table 1 outlines the key specifications of the Formula SAE EV prototype's braking system and relevant vehicle parameters, including tire type, battery voltage, motor power, vehicle weight, and details of the front and rear disc brakes. These specifications are crucial for understanding the vehicle's design context. Figure 2 illustrates the "hanging type" force application mechanism within the braking system, demonstrating how force is transmitted to initiate braking and figure 3 shows the braking system components as integrated with the pedal, highlighting the direct interaction points for driver input.

3.1 Vehicle Specification

Table 1: Formula SAE EV braking spec

Component	Specification
Tyre	185/60/R14 semi slick
Battery Voltage	96 V
Motor Power	15 kW
Vehicle Weight	340 kg
Front Brakes	Single-port caliper with ventilated disc
Rear Brakes	Double-port caliper with ventilated disc
Disc brake	Ventilated Disc 220mm at all wheel.

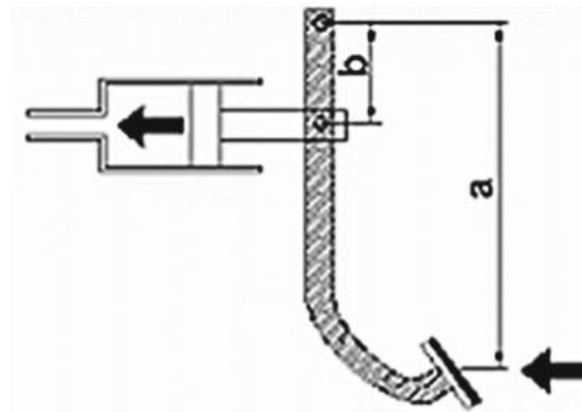


Figure 1: Force on braking system (Hanging Type).

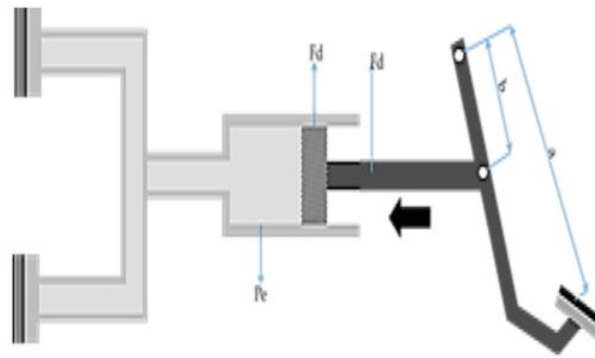


Figure 2: Braking system on the pedal

3.2 Test Environment

Testing was conducted on a closed track with a dry, flat asphalt surface. The ambient temperature ranged between 32°C and 40°C. All braking trials were repeated five times for consistency and reliability.

3.3 Test Procedure

The tests were conducted on a flat, straight, and dry asphalt surface to minimize external influences such as surface irregularities or slopes. The track was marked at regular intervals to aid accurate measurement of braking distance. The braking distance was measured from the exact point of brake application to the point where the vehicle came to a complete stop. To record braking distance, a measuring tape with a length of 50 meters was used. This tape was laid out along the test track, and measurements were taken manually after each braking event. Braking time was recorded using a handheld stopwatch. The stopwatch was started at the instant the brake pedal was pressed and stopped when the vehicle fully halted.

During each test run, the vehicle was accelerated to a predetermined low speed of approximately 20 km/h. Once the target speed was reached, the driver applied the brakes fully, and the braking distance and time were recorded as described. To ensure the reliability and repeatability of the results, the test was repeated a minimum of five times. The collected data on braking distance and braking time were then averaged and analysed to observe the vehicle's braking characteristics. Statistical tools such as standard deviation were used to assess the variability in the measurements. This approach provided a clear understanding of the braking performance under low-speed conditions. Throughout the testing process, strict safety protocols were followed. The driver wore full protective gear, including a helmet and gloves, and all tests were carried out in a controlled environment with safety personnel on standby. Figure 4 illustrates the methodical process of this research, from design to data analysis, ensuring consistent evaluation of the Formula SAE EV's braking performance. This systematic approach, vital for reliable results, guides objective definition, testing, and data interpretation.

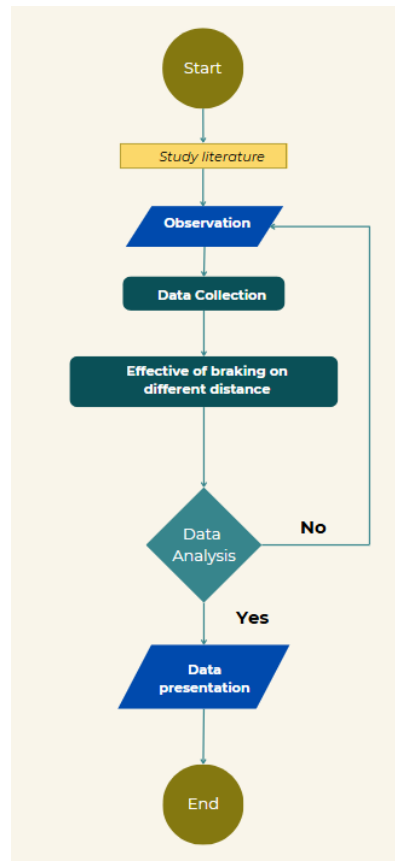


Figure 4: Formula SAE Research systematic flowchart

4. Result and Data

Referring to the flowchart developed during the design phase and the corresponding design implemented in the development phase, an analysis was conducted to determine the braking time and braking distance of a Formula SAE electric vehicle. Table 2 presents the experimental results for braking time and braking distance of the Formula SAE electric vehicle across five different speed levels: 20, 30, 40, 50, and 60 km/h. The data reveals a clear trend: as vehicle speed increases, both braking time. All tests were conducted under dry and flat road conditions to ensure consistency and eliminate variables related to surface texture or moisture. This setup allows for a clear assessment of the braking system's effectiveness under ideal conditions. The complete set of calculations and analysis is presented as follows.

Table 2: Braking Performance Data at Various Speeds

Speed (km/h)	Braking Time, t_e (s)	Braking Time Std. Dev. (s)	Braking Distance, d (m)	Braking Distance Std. Dev. (m)
20	1.6	± 0.05	3.1	± 0.2
30	1.8	± 0.06	4.8	± 0.3
40	2.1	± 0.08	7.2	± 0.5
50	2.4	± 0.10	10.6	± 0.7
60	2.7	± 0.12	13.2	± 1.0

4.1 Braking Time (te)

Braking time (t_e) refers to the duration from the moment of brake application until the vehicle comes to a complete stop. The data shows a gradual increase in braking time with speed—from 1.6 seconds at 20 km/h to 2.7 seconds at 60 km/h. This trend is consistent with the requirement for the vehicle to dissipate more kinetic energy at higher speeds, resulting in longer deceleration intervals. However, the rate of increase in braking time is not as steep as braking distance, indicating that while speed influences how long the vehicle takes to stop, braking force remains relatively consistent across different trials, as reflected by the modest time variations. This implies that the energy to be dissipated through braking quadruples as the speed doubles. The ventilated disc brakes demonstrated consistent performance, with minimal fade observed during low-speed trials.

4.2 Braking Distance (d)

Braking distance (d) is the total length the vehicle travels after brake application until it halts. The data presents a nonlinear growth in braking distance with speed, starting at 3.1 meters at 20 km/h and reaching 13.2 meters at 60 km/h. This exponential increase supports the theory that kinetic energy ($E_k = 1/2mv^2$) scales with the square of speed. As speed doubles from 20 to 40 km/h, braking distance more than doubles from 3.1 m to 7.2 m. By 60 km/h, the vehicle needs over four times the distance required at 20 km/h to stop. This demonstrates how critical it is to optimize the brake system for high-speed scenarios, particularly in racing environments.

4.3 Performance Interpretation

The braking performance of the Formula SAE electrical vehicle shows consistent and effective behavior across low to moderate speeds. As speed increases, braking time rises gradually, while braking distance increases significantly. This is expected because the energy that must be dissipated by the brakes grows with the square of speed. For example, braking distance increases from 3.1 m at 20 km/h to 13.2 m at 60 km/h. The moderate increase in braking time suggests that the braking system is delivering strong and reliable deceleration. The combination of single-port front and double-port rear calipers with ventilated discs provides effective braking force and good heat dissipation. This setup helps maintain consistent braking performance without signs of fade during testing. Repeated trials at each speed showed very little variation, indicating the system's reliability and repeatability. The vehicle's weight balance and tire grip also contribute to stable braking, especially under emergency stops.

5. Conclusion

This study successfully evaluated the braking performance of a Formula SAE-style electric vehicle (EV) developed by FRATEC under controlled low- to mid-speed conditions. Experimental results demonstrated consistent and predictable braking behavior, with braking time increasing gradually and braking distance rising nonlinearly as vehicle speed increased from 20 km/h to 60 km/h. These outcomes align with theoretical expectations, as the kinetic energy to be dissipated during braking increases with the square of speed. The use of ventilated disc brakes and a combination of single-port front and double-port rear calipers provided effective thermal management and consistent braking force, preventing fade during repeated trials. The system demonstrated both reliability and repeatability, critical for ensuring driver safety and performance consistency in race conditions. Overall, the findings reinforce the importance of selecting appropriate braking components, optimizing force distribution, and conducting empirical testing for performance validation. These insights can

be applied to future design iterations of electric cars, particularly in the Formula SAE context, to enhance both safety and competitive efficiency.

6. Recommendation

Based on the results of this study, it is recommended that future improvements to the Formula SAE EV race car focus on enhancing brake performance through material selection, thermal management, and data monitoring. Instead of carbon-ceramic discs, which can be costly, high-performance steel or slotted ventilated rotors made from cast iron with improved cooling designs are suggested as cost-effective alternatives for better heat dissipation. The use of performance-grade brake pads with higher friction coefficients can also improve stopping power. Additionally, integrating brake temperature sensors and data logging systems will help monitor system behavior in real-time for more accurate tuning. It is also advisable to test the braking system under wet and uneven track conditions to evaluate performance reliability in diverse scenarios. Exploring lightweight alloy calipers and adjusting brake bias could further enhance control and reduce stopping distances. These steps will contribute to safer, more consistent performance in future racing conditions.

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