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The significance of telemetric data collection in electric motorcycles

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Motorsport is a branch of the automotive industry that requires constant research and testing to gain a competitive edge. A small change in a vehicle's suspension settings or engine management can make the difference between winning and losing in a particular competition. In order to ensure success, the vehicle is often pushed to its limits, however, while maintaining the driver's safety, all with the option of using vehicle telemetry, which collects, transmits, and analyses vehicle data during and after driving. Operational parameters measured in real time are analyzed for future corrections and improvements. This paper presents an analysis of telemetry testing of an electric motorbike, related to energy consumption, power output, torque, and thermal conditions to improve the efficiency of the drivetrain on the Aragón circuit in Spain at the MotoStudent competition. The article also demonstrates how to validate the values of individual parameters obtained during calculations and simulations, as well as the impact of minor changes on these parameters. It also describes how telemetry helps in assessing the skills of drivers.

Key words: *motorcycle, rider behavior, telemetry system, vehicle performance, data acquisition system*

1. Introduction

Electric motorcycles are rapidly advancing in both consumer and competitive markets, driven by sustainable energy solutions and the demand for high-performance vehicles. While consumer models emphasize range and affordability, racing models prioritize torque delivery, battery efficiency, and thermal management to enhance track performance. In racing, these motorcycles present unique challenges and opportunities due to factors such as torque delivery, battery management, and thermal regulation. Effective data-driven approaches are critical for optimizing performance on and off the track.

As electric motorcycles face distinct challenges in energy efficiency, thermal regulation, and torque delivery, telemetric data collection has become a fundamental tool in motorsports, providing real-time insights into vehicle behaviour and environmental conditions to address these issues effectively. It enables engineers and riders to refine strategies, enhance technical adjustments, and improve overall performance. While telemetry is well established in traditional motorsports, its application in electric motorcycle racing remains an emerging field with significant potential for innovation [12].

This study examines the significance of telemetric data acquisition in optimizing electric motorcycle performance by analysing data collected during the MotoStudent competition at the Aragón racetrack in Spain, an event that provides a controlled yet highly competitive environment for evaluating real-world racing conditions. Using an advanced data logger and a custom-built data acquisition system, key performance metrics – such as acceleration, speed, cornering dynamics, and load distribution – were monitored. Based on that data optimization opportunities were identified, contributing to a deeper understanding of how telemetry can shape electric motorcycle racing.

Telemetry systems are essential for real-time data collection during races. Professional teams in MotoGP use telemetry to monitor parameters like tire temperature, brake pressure, and throttle input, allowing precise adjustments to engine settings and suspension dynamics. In electric motorcycles, telemetry focuses on battery state, motor efficiency, and energy consumption – critical metrics for optimizing energy use and extending vehicle range [5, 11]. Unique challenges such as thermal management and regenerative braking are addressed through telemetry insights, ensuring performance consistency under varying conditions [2, 5, 13, 19].

Effective vehicle control is essential for achieving optimal performance in motorcycle racing, influencing stability, handling, and rider confidence. Beyond energy management, telemetry plays a key role in monitoring suspension dynamics and tire grip, factors that significantly impact stability and cornering performance [8, 20]. Advanced systems track suspension travel, damping forces, and tire contact patches, allowing teams to fine-tune settings for improved handling. For electric motorcycles, telemetry optimizes traction control and regenerative braking, balancing energy recovery without compromising stability [6, 8, 9, 15, 20, 21].

Telemetry is also instrumental in analysing rider behaviour and refining training methodologies. By tracking throttle position, braking force, and lean angles, teams can identify areas for technique and strategy improvements. This is particularly relevant for electric motorcycles, where riders must adapt to instant torque delivery and the absence of engine braking [1, 10, 14, 17].

The integration of artificial intelligence has further transformed telemetry by enabling predictive analytics. AI models process vast datasets to forecast vehicle performance under different track conditions, optimize throttle maps, and enhance energy management in electric motorcycles [18, 21]. AI-driven telemetry supports strategic decision-making, leading to better race outcomes for both electric and combustion-engine motorcycles.

Finally, telemetry plays a crucial role in vehicle design and race strategy. Data-driven insights guide chassis development, energy-efficient cooling systems, and aerodynamic enhancements. In real-time race scenarios, telemetry informs pit stop planning, tire wear assessment, and energy conservation strategies – factors that can determine podium finishes [3, 4, 7, 16, 19].

In summary, telemetry has revolutionized motorcycle racing, offering data-driven solutions for performance optimization, strategic planning, and vehicle innovation. The integration of AI with telemetry further enhances its impact, allowing for predictive analytics that refine energy management, optimize real-time adjustments, and improve overall race strategies. As technology advances, future research should focus on improving telemetry accuracy, integrating new sensor technologies, and expanding AI applications to enhance electric motorcycle racing further.

2. Subject and research location

The research was conducted based on a data acquisition system designed and implemented for the prototype racing electric motorcycle LEM Tachyon. This motorcycle was built by a student team as part of their participation in the MotoStudent competition, the world championship of student motorcycle designs, with the final race taking place at the Aragón circuit in Spain.

The LEM Tachyon project was designed and built by the LEM Wrocław Motorsport student team from Wrocław University of Science and Technology. During its design, all elements, except for brakes tires and brakes which competition officials provided, were modeled and then subjected to theoretical loads that could occur on them within the framework of Finite Element Method (FEM) simulations. However, since this is a project built from scratch with custom parts, a comprehensive telemetric data acquisition system was also created to enable the assessment of the applied solutions and identify the weaknesses of various systems, allowing improvements for the design of future motorcycles.

The vehicle was built in accordance with the stringent requirements of the competition regulations, where the motorcycle's dimensions are based on the Moto3 class. The materials and manufacturing methods for individual components were optional but had to meet strength requirements that were tested during the competition. The frame was made of chromium-molybdenum steel tubes, while the subframe and fairings were made entirely of carbon fiber composite. The motorcycle's swingarm was milled and then welded from 7020 aluminum. The design features a reduction gear with a ratio of 1.83 to reduce the rotational speed on the active wheel of the chain drive. According to the datasheet, the motor has 48 kW maximum power and 22 kW nominal power with a maximum of 7500 rpm. The front tire is 87 mm wide and 576 mm in diameter. The rear tire is 113 mm wide and 602 mm in diameter. The maximum speed of the motorcycle, as planned for calculations, was 200 km/h, while the highest speed measured on the track was 193 km/h.

Different sensors were mounted, as shown in Fig. 1. These allowed us to measure acceleration values, rotational speeds of the engine shaft and individual wheels, GPS position, suspension travel, braking forces, throttle level, temperatures of the engine, gearbox, radiator, and battery. The entire system is based on the LG-μCAN11_Moto2-211 logger, which is typically used in Moto2 category races. It allows data acquisition at frequencies up to 800 Hz, which was used for suspension and break pressure analysis. Other sensors operated at frequencies between 12.5 Hz and 200 Hz. To ensure clarity regarding the sensors used and their respective measurements, Table 1 summarizes the key parameters captured during the study, including measurement ranges, units, and sampling frequencies.

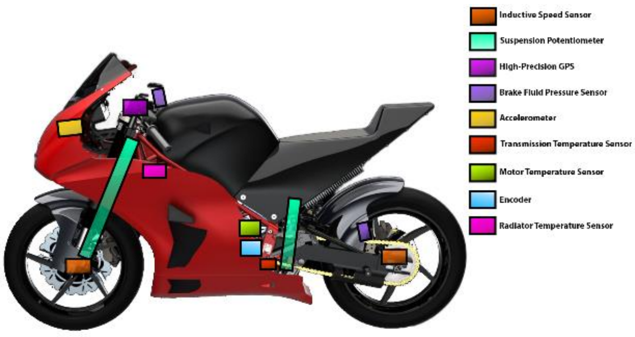

Fig. 1. Placement of sensors on the motorcycle

These sensors provided valuable insights into critical performance metrics such as braking forces, acceleration, and thermal behavior. All this data enabled us to improve the electric motor control to increase its efficiency, prevent failures of individual systems, and adapt the motorcycle to the specific rider. Thanks to this data and the changes applied based on their analysis, it was possible to prepare the motorcycle for the challenging conditions of the Aragón circuit.

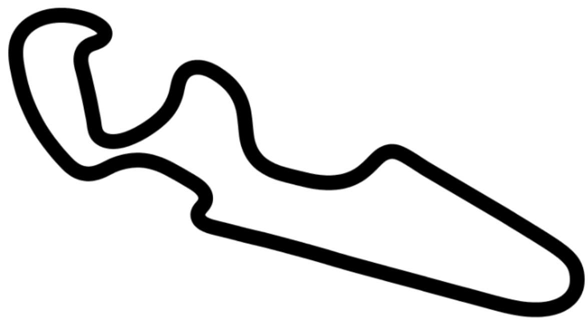

Fig. 2. Outline of the track shape of the Aragón Circuit

The Aragón circuit, shown in Fig. 2, is characterized by its complexity and presents many challenges for both riders and motorcycles during races. It features long straights, the longest being 1211 meters, as well as tight turns. Additionally, the total difference between the lowest and highest points of the track is 50 meters, with a maximum drop of 7.2%. The track length is 5.078 kilometers, and the width varies from 15 meters on the straights to 12 meters in other sections. Another aspect of this track is its heterogeneous surface throughout its length, resulting in changing traction conditions.

Table 1. Embedded sensors and data acquisition frequency

Name in data	Sensor	Measured parameter	Unit	Sampling frequency [Hz]	Notes
ACC_X, ACC_Y, ACC_Z	Accelerometer	Acceleration	m/s²	400	Used for analyzing vibrations and dynamics
BRAKE_F	Brake fluid pressure sensor (front)	Brake force of front system	Bar	800	Critical for managing high-speed braking stability
BRAKE_R	Brake fluid pressure sensor (rear)	Brake force of rear system	Bar	800	Used in sudden braking scenarios on straights
Latitude, Longitude	High-precision GPS	Geographic position	deg	12.5	
SV_Motor_Temperature	Motor tempera-ture sensor	Motor temperature	°C	400	Evaluates drivetrain thermal management
SUSP_F	Suspension potentiometer (front)	Front suspension travel	mm	800	Provides data for optimizing front suspension behavior
SUSP_R	Suspension potentiometer (rear)	Rear suspension travel	mm	800	Tracks rear suspension response to braking and acceleration
V_Front	Inductive speed sensor (front)	Front wheel speed measurement	m/s	200	Used to estimate slip ratio and track braking performance at the front wheel
V_Rear	Inductive speed sensor (rear)	Rear wheel speed measurement	m/s	200	Used to analyze speed, traction and braking performance
TEMP_Transmission	Transmission temperature sensor	Transmission system temperature	°C	12.5	Monitors gearbox thermal perfor-mance
SV_RPM	Encoder	Rotational position of the motor	deg	200	Tracks angular displacement for motor rotation
SV_Heatsink_temp	Radiator tem-perature sensor	Coolant temperature in radiator	°C	50	Ensures cooling system operates within optimal limits

That imposes a unique challenge for both the rider and the motorcycle. The rider must adapt seamlessly to a variety of riding conditions, while the motorcycle needs to be highly adjustable to achieve the best settings for any scenario. A specialized data acquisition system plays a critical role in bridging the gap between on-track performance and the decision-making process, ensuring precision and efficiency in adjustments.

3. Studies conducted and results

The measurement tests were carried out at the MotoStudent competition in Spain during the main race. Data collection included six full laps on the Aragón circuit. Initially, parameters such as engine speed and torque were analyzed to see how the driver loads the electric motor during each lap. The motor load parameter is important because it gives us the answer to how energy is consumed during each lap, what times the driver achieves each time, and how the motor load affects the heating process of the motor and battery. Each lap was analyzed separately, and in Fig. 3, the full range of engine speeds can be seen during the run. The average engine speed for all runs was 4052.42 rpm. The driver was fastest on the second lap with a time of 2:27:594 with an average engine speed of 4268.90 rpm and a torque of 28.38 Nm – Fig. 4.

In Figure 4, the engine's operating range can be seen with load range and the cumulations in the middle operating range.

The fifth lap was the slowest, with a time 13 seconds longer. The engine workload was completely in the other work ranges, as can be seen in Fig. 5. The average speed was 3851.94 rpm with an average torque of 21.13 Nm. The results from each lap of the race are illustrated in Table 2.

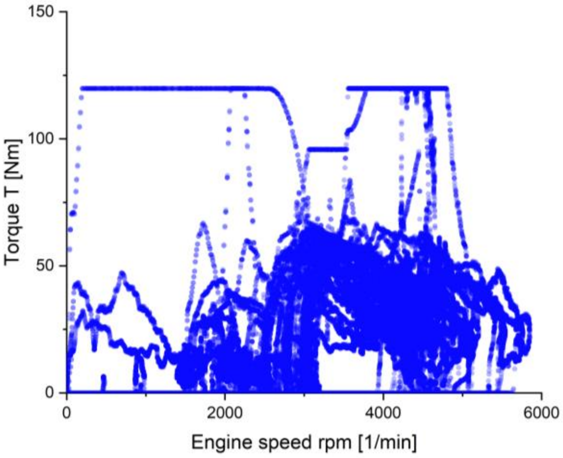

Fig. 3. Engine speed-to-torque graph for six laps

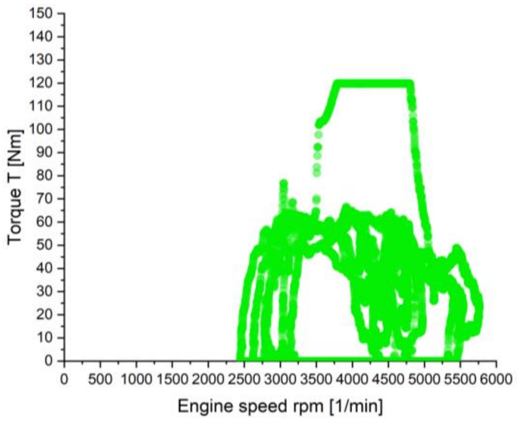

Fig. 4. Engine speed-to-torque graph for the fastest second lap

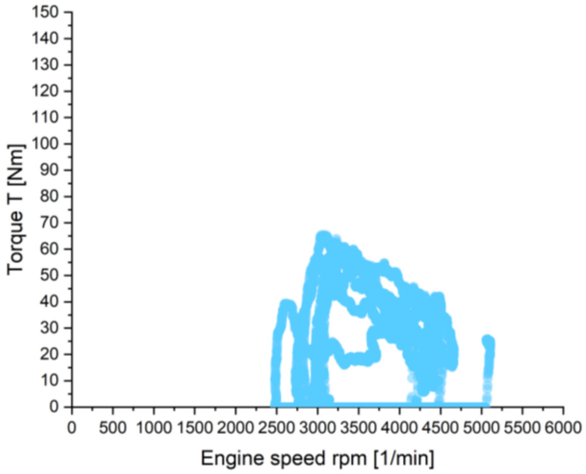

Fig. 5. Engine speed-to-torque graph for the slowest fifth lap

Table 2. Average engine parameters for each lap

Lap number	Average Torque T [Nm]	Average engine speed [rpm]	Lap time t [s]	Average speed V [m/s]
1	26,00	4183.34	2:29.911	33.35
2	28.38	4268.90	2:27.594	33.96
3	22.87	4037.05	2:34.474	32.42
4	23.03	4037.12	2:34.314	32.46
5	21.13	3851.94	2:40.715	31.31
6	26.91	3936.15	2:37.835	31.74

The important aspect that can be analyzed to improve performance and reduce lap times is the use of data from brake pressure sensors and throttle opening values. Analysis of these parameters allows for the development of more effective driver energy management tactics. Reducing the use of brakes in favor of driving using inertia enables a significant reduction in energy consumption, resulting in greater energy efficiency. In addition, less strain on the drivetrain leads to lower temperatures, preserving thermal reserves for moments requiring more power, for example, during dynamic acceleration on straight sections of the track.

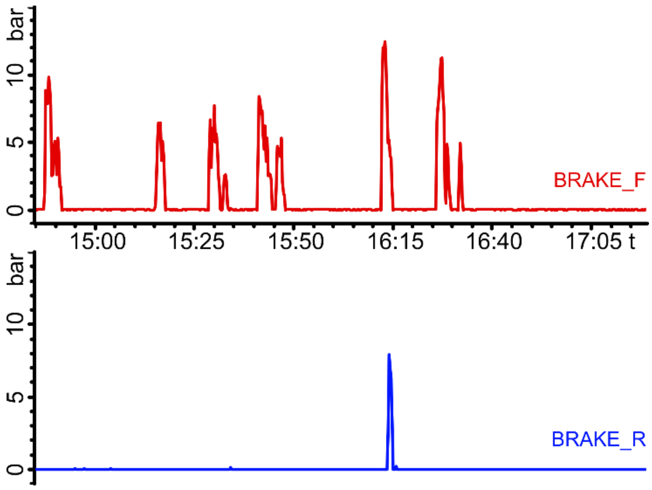

Fig. 6. Brake pressure plot for the fourth lap

In Figure 6, the brake pressure values are presented in correlation with the vehicle's position on the track. The inner curve, labelled BRAKE_R, represents the pressure in the rear brake system, while the outer curve, labelled BRAKE_F, illustrates the pressure in the front brake system at the same moments.

The analysis of the graph from Fig. 6 shows that the rear brake is rarely used, particularly during instances of sudden and intense braking. Conversely, the front brake is employed more frequently, indicating its critical role in managing speed and maintaining stability while navigating different sections of the track. The presented data reflects the expertise of an experienced rider who demonstrates a profound understanding of the dynamics of electric motorcycle handling.

Table 3. Min-max table for brake pressures for all laps

Lap ID	1	2	3	4	5	6
Total laps	1	2	3	4	5	6
Time [min]	2:29.9	2:27.6	2:34.5	2:34.3	2:40.7	2:37.8
Front brake pressure minimum brake_F [bar]	0	0	0	0	0	0
Front brake pressure maximum brake_F [bar]	14.8	13.5	14.2	13	14.2	11.9
Front brake pressure average brake_F [bar]	1.1	1.2	0.9	0.8	0.7	0.7
Rear brake pressure value minimum brake_R [bar]	0	0	0	0	0	0
Rear brake pressure value maximum brake_R [bar]	11	0	0	9	0	0
Rear brake pressure value average brake_R [bar]	0	0	0	0	0	0

Throughout all six laps, as Table 3 presents, brake pressure values range from 0 to 14.8 bars, highlighting a precise and deliberate approach to braking. Furthermore, Fig. 6 shows that the brakes are used almost exclusively before turns, underscoring a well-developed energy management strategy. This approach not only minimizes energy consumption but also optimizes the use of drivetrain reserves on straight segments of the track, constituting a fundamental aspect of efficient riding.

A crucial stage in the development and refinement of a motorbike lies in optimizing the suspension system, a fundamental component of any vehicle. The suspension must ensure optimal traction and stability throughout the lap, directly influencing performance and safety. By accurately acquiring suspension travel data, engineers can fine-tune the suspension settings with precision, enabling the motorbike to adapt seamlessly to both the rider's preferences and the specific conditions of the track.

Figure 7 shows suspension travel data overlaid over the Aragon track map. The inner curve represents front suspension travel values, while the outer curve represents rear suspension travel data. These values are highly correlated to braking data and acceleration data, as these are the main causes of changes in motorcycle dynamics.

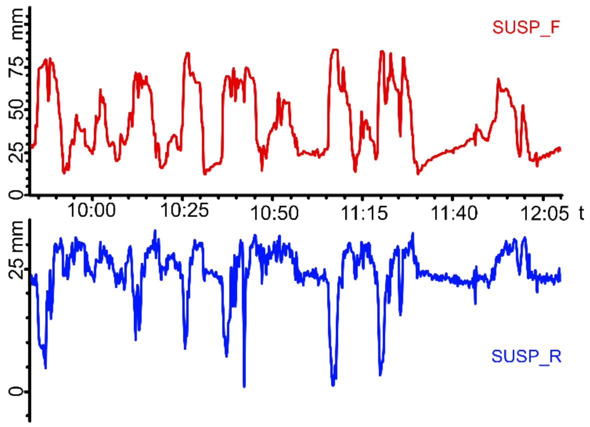

Fig. 7. Suspension plot, illustrating suspension behavior and dynamics across different sections of the circuit at second lap

Table 4. Minimum and maximum values of front and rear suspension travel recorded across all six laps of the race at the Aragón Circuit

Lap ID	1	2	3	4	5	6
Time [min]	2:29.9	2:27.5	2:34.4	2:34.3	2:40.7	2:37.8
Front suspension displacement minimum Susp_F [mm]	10.3	9.95	9.98	10.74	13.5	16.56
Front suspension displacement maximum Susp_F [mm]	88.8	85.39	89.55	84.04	82.55	80.64
Rear suspension displacement minimum Susp_R [mm]	0.69	0.7	0.73	0.74	1.6	2.56
Rear suspension displacement maximum Susp_R [mm]	33.66	33.87	32.97	33.45	33.81	33.31

Based on the suspension settings, the front suspension travel ranges from 9 mm to 90 mm, while the rear suspension travel varies between 0 mm and 40 mm. Table 4 illustrates the minimum and maximum suspension travel values recorded across all six laps of the race at the Aragón Circuit, providing a comprehensive overview of suspension dynamics throughout the event.

Additional visualizations, such as histograms and XY plots, can be generated to conduct a more precise analysis of the suspension system's behavior, providing more detailed insights for the engineering team. By correlating data from the linear suspension potentiometer with accelerometer readings, a comprehensive understanding of suspension dynamics and its interaction with external forces can be achieved. This data can then be used to fine-tune the suspension setup, optimizing it for specific track conditions and rider preferences. Such adjustments help enhance traction, stability, and overall performance, ultimately leading to faster lap times and improved vehicle handling.

In racing motorcycles, virtually all components are pushed to their limits, significantly affecting their operating conditions. In this regard, electric motorcycles are not fundamentally different from their combustion-engine counterparts. Continuous monitoring of key parameters such as temperature, pressure, displacement, and forces acting on components provides valuable information. This enables the full potential of each motorcycle component to be utilized while ensuring the highest level of safety.

The drivetrain, which is a fundamental factor in motorbike performance, is not exempt from this. In the case of the LEM Tachyon, the electric motor's thermal management was the main limiting factor in the overall performance. By being able to always analyze the motorcycle's condition with precision during the test sessions, drivetrain engineers were able to make data-driven decisions about motor controller settings, resulting in an exceptional level of efficiency.

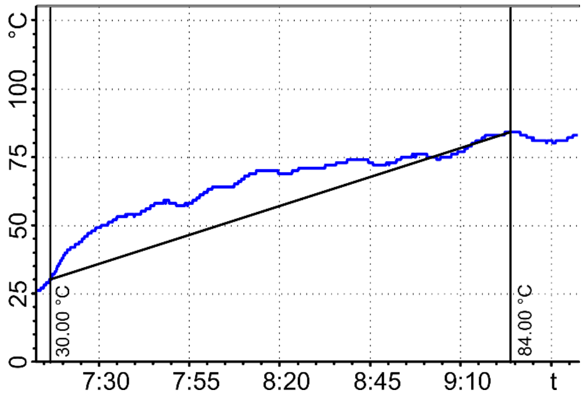

Fig. 8. Line plot of motor temperature over time in first lap

As illustrated in Fig. 8, despite the implementation of both on-board and external cooling systems to ensure the motor starts at the lowest possible temperature, the first lap sees a significant temperature increase of approximately 60 degrees Celsius. This rapid rise is attributed to the high current supplied by the motor controller to achieve the desired power output, which allows the vehicle to maintain a competitive edge. Furthermore, the motor's design limits the efficiency of heat transfer to the cooling system, thereby reducing its ability to regulate the drive unit's temperature effectively.

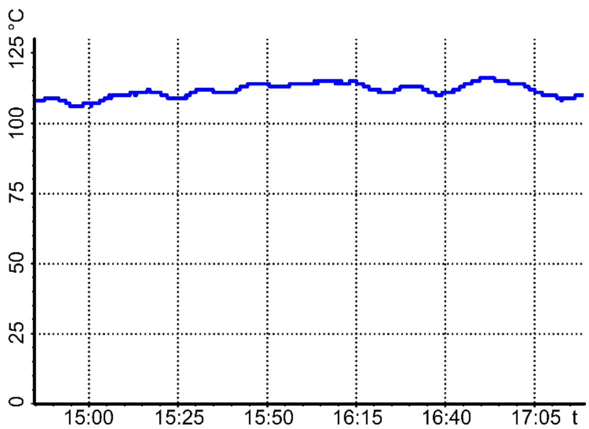

Fig. 9. Line plot of motor temperature over time in lap 4

In subsequent laps, as shown in Fig. 9, the temperature of the motor remains at a consistently elevated level. At this juncture, the onus shifts to the driver's ability to effectively manage the temperature through the utilization of available data, including motor temperature, coolant inlet and outlet temperatures, and other drivetrain performance metrics. This data provides a crucial foundation for the fine-tuning of the motor controller and the development of adaptive strategies. It offers evidence-based decision-making and immediate feedback on the efficacy of adjustments, thus enabling teams to optimize performance even under challenging thermal conditions.

4. Summary of results

The study underscores the significant role of telemetric data acquisition in enhancing the performance of electric motorcycles in competitive racing scenarios. Comprehensive telemetry data collected from the LEM Tachyon motorcycle during the MotoStudent competition at the Aragón circuit provided critical insights into various performance parameters, including engine speed, torque, suspension dynamics, braking forces, and thermal conditions. These data highlighted the intricate interplay between motor performance, energy efficiency, and thermal management.

The analysis revealed that optimal engine operation occurred at specific torque and rpm ranges, which varied across laps. The fastest lap was achieved at an average engine speed of 4268.90 rpm with a torque of 28.38 Nm, indicating the importance of precise load and energy management for competitive performance. Conversely, slower lap times were associated with higher drivetrain inefficiencies and suboptimal energy utilization. Data from brake pressure sensors and throttle usage demonstrated how strategic adjustments, such as reduced braking and inertia-based driving, contributed to improved energy efficiency and thermal control.

Suspension travel data emphasized the role of fine-tuning suspension settings to adapt to the track's unique characteristics. Front and rear suspension displacement patterns provided insights into load distribution and stability during braking and acceleration, enabling targeted improvements for handling and traction. Furthermore, drivetrain analysis highlighted thermal management as a limiting factor in maintaining consistent motor performance. The rapid rise in motor temperature during initial laps underscored the need for enhanced cooling systems and adaptive controller strategies.

The Aragón circuit's demanding conditions, characterized by its varying topography and traction levels, posed additional challenges for both the rider and the motorcycle. Telemetric data acquisition bridged the gap between on-track performance and decision-making processes, allowing engineers to apply data-driven refinements in real time.

5. Conclusion

The findings demonstrate that telemetric data acquisition is indispensable for the optimization of electric motorcycle performance in competitive settings. By capturing and analyzing data from a wide array of sensors, engineers and teams can identify performance bottlenecks, refine vehicle settings, and enhance energy efficiency. The study highlights several critical outcomes:

1. Energy and Thermal Management: Effective utilization of telemetric data enables the identification of optimal energy usage patterns and the mitigation of thermal inefficiencies, contributing to sustained motor performance during races.
2. Suspension Optimization: Detailed analysis of suspension dynamics facilitates precise adjustments to improve stability, traction, and rider comfort, enhancing overall vehicle handling.
3. Strategic Adjustments: Data-driven insights into braking and motorbike handle use support the development of adaptive strategies that optimize energy consumption and preserve drivetrain integrity.
4. Adaptability to Track Conditions: The ability to monitor and respond to the Aragón circuit's complex characteristics in real time showcases the versatility of telemetric systems in addressing diverse racing challenges.

The research confirms the potential of telemetric systems to drive innovation and efficiency in electric motorcycle racing. Future studies should focus on integrating advanced cooling technologies, refining sensor accuracy, and employing artificial intelligence for predictive analytics. These advancements will further unlock the capabilities of telemetric data, paving the way for more competitive, efficient, and sustainable racing solutions.

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