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The Effects of Different Type of Tires on The Power Consumption of an Electric Motor

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ABSTRACT

Electric cars are inevitably the future of transport, but they still share some key components with their gas guzzling counterpart which includes tires. Tires are an important part of our transport system that most tend to overlook. They are the contact points for our vehicles that directly interact with the road surface which can directly impact our vehicle's behaviour and performance during our daily commute. Other than grip level, tire manufacturers claim some of their models can offer better fuel mileage too. This study aims to compare different tire models on their power consumption on an electric motor. This study will provide vital information on whether the efficiency claims are true and what influences the differences in power consumption between different tire models. A rolling drum test bench in conjunction with a power monitoring software will be used to measure the power consumption of two tyre models.

Keywords: *Electric Motor; Tires; Power Monitoring; Efficiency*

Introduction/Background

Growing concern over our environment has brought nations and organizations to pursue a greener and more environmentally friendly approach for their business and operations. The automotive industry is often put in the spotlight when it comes to emissions and global warming. Nations and states such as Britain and the State of California, USA are on their way to ban the sale of internal combustion cars as early as 2030 and 2035 respectively [1], it is clear

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the automotive manufacturers need to move towards a greener path, a path paved with electricity. It is obvious, that electric is the future of transport. Tesla has made great progress in making electric vehicles mainstream and Volkswagen claim that they will follow suit by being an all-electric manufacturer by the year 2035[2]. However, where we are now, electric vehicles have a clear disadvantage when compared to their gas-guzzling counterparts, which is the range, or extra mileage. The Tesla Model S, the longest-range electric production car at the time of writing, has a range of 622 kilometres with a full charge [3]. That is a lot, but factor in the time taken to charge it which can reach up to 44-hours, it seems a bit inconvenient for everyday users. The range is the direct product of the electric motor's efficiency. This project aims to study the effect of tires on the power consumption of the electric motor.

Tire manufacturers such as Michelin and Bridgestone claim their tires can increase range up to 11 kilometres [5] and add 8% more to fuel efficiency [6]. Various other tire manufacturers also have similar claims, but is it really the case or just another marketing ploy to sell consumers more expensive 'Eco' tires? This project will study two different types of tires, a claimed 'fuel efficient' tire by Bridgestone, the Ecopia with Ologic which is the official tire used by teams in the Bridgestone World Solar Challenge and a regular off the shelf aftermarket tire by CMI Racing, the CMI72.

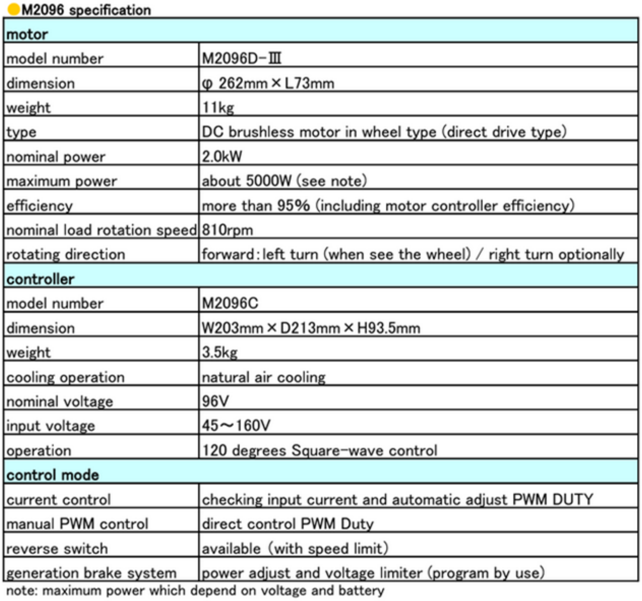
Figure 1: Tires used in this project

One of the main aspect of tires that affect range and fuel efficiency is rolling resistance. Bridgestone explains on their page:

"Tire rolling resistance is the energy that your vehicle needs to send to your tires to maintain movement at a consistent speed over a surface. In other words, it is the effort required to keep a tire rolling. The main contributor to rolling resistance is the process known as hysteresis. Hysteresis is essentially the energy loss that occurs as a tire roll through its footprint. The energy loss must be overcome by the vehicle's engine, which results in wasted fuel." [7]

Rolling resistance can be minimized but cannot be fully eliminated. It is influenced by several factors such as inertia, road quality and air drag. But by keeping the other components of the project as a constant, we can identify the rolling resistance caused by the tires. Tires can have different levels of rolling resistance depending on several characteristics such as their size, weight, and compound. To keep things as even as possible between the two tires, the size will be the same for both. Thus, that makes it easier to pinpoint the exact characteristics that directly affect the power consumption.

Motion for the tires will be provided using Mitsuba's solar car electric motor, model M2096-3. Boasting an efficiency of more than 95% including the motor controller [8], it has proven to be the right choice for this experiment as proven by the number of teams running it in the Bridgestone World Solar Challenge. The motor specification can be seen in the following table:



● **M2096 specification**

motor	
model number	M2096D−Ⅲ
dimension	φ 262mm×L73mm
weight	11kg
type	DC brushless motor in wheel type (direct drive type)
nominal power	2.0kW
maximum power	about 5000W (see note)
efficiency	more than 95% (including motor controller efficiency)
nominal load rotation speed	810rpm
rotating direction	forward：left turn (when see the wheel) / right turn optionally
controller	
model number	M2096C
dimension	W203mm×D213mm×H93.5mm
weight	3.5kg
cooling operation	natural air cooling
nominal voltage	96V
input voltage	45～160V
operation	120 degrees Square−wave control
control mode	
current control	checking input current and automatic adjust PWM DUTY
manual PWM control	direct control PWM Duty
reverse switch	available（with speed limit)
generation brake system	power adjust and voltage limiter (program by use)

note: maximum power which depend on voltage and battery

Figure 2: Specifications for the MITSUBA M2096-III Solar Car Motor

With the key components available, the next step is to run the tests. The test bench is in the form of a rolling drum like the following figure:

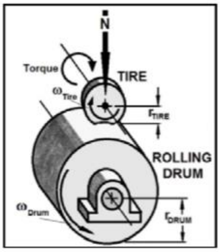


Figure 3: Schematics for the Rolling Drum Test Bench

The success of this experiment could contribute to the progress for UiTM's Solar Racing Team as well as the automotive industry.

Methodology

The flow chart below lists the procedures taken for this study. As previously mentioned, this project focuses on power consumption monitoring. Thus, it is necessary to produce a testbench and software that will allow such an experiment to be possible. The flowchart is as follows:

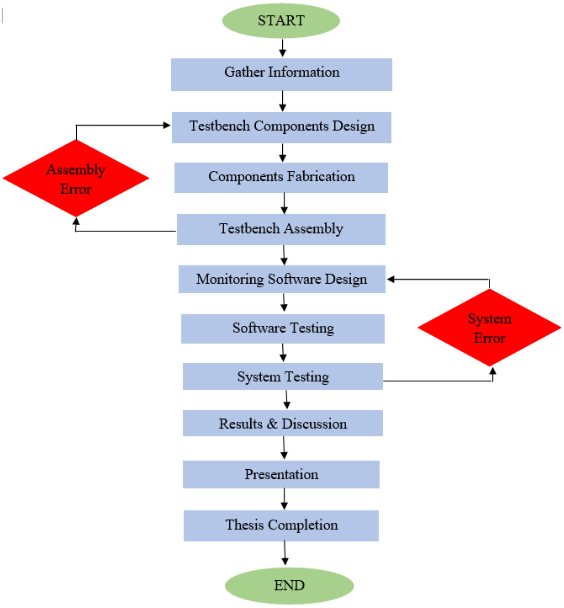


Figure 4: Research methodology flowchart

Gather Information

This phase focuses on gathering every necessary detail needed to do the project. These include components specifications, manufacturing process, pricing, and availability. This phase also includes the selection of monitoring software creation platform.

Testbench Components Design

The next phase will be dedicated to the design phase of the testbench. A suitable testbench is already available in UiTM, but a few modifications will need to be added for it to be suitable for the purpose of this project. In the case of it not being available for use, a backup plan is to fabricate the testbench from scratch. Thus, a design was conceptualised.

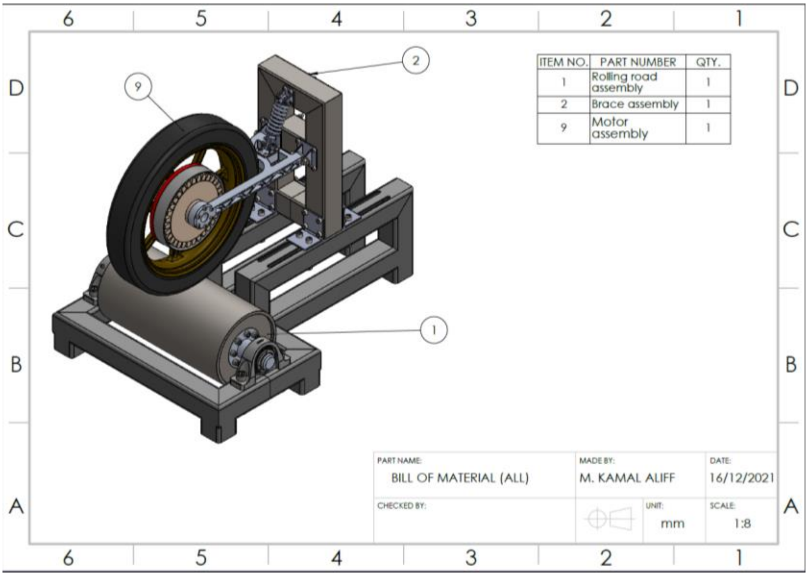


Figure 5: Concept design of testbench

Components Fabrication

Any components that are custom designed such as brackets and stands will be fabricated in this phase. It requires access to a workshop where necessary tools are available. Market ready components such as fasteners, bearings, and beams will be bought instead of fabricated.

Testbench Assembly

After all the components for the testbench is available, it will be time to assemble it. Components will be test fitted to check for errors and if any improvements or modifications will be needed. Any components that do not fit will be counted as an error and will be redesigned and fabricated. Luckily, the testbench at UiTM was available for use without modifications.

Figure 6: Testbench components assembly test

Figure 7: Testbench assembly hooked up to monitoring software

Monitoring Software Design

In this phase, the circuit diagram and programming will be made. Since the electric motor already has a microcontroller, it makes things a little bit easier. The main focus will be on the monitoring system of the voltage and current, in other words, the power consumption. Through discussion with UiTM's Ecophoton Solar Racing Team, it was decided that it would be more cost-effective to use Orion BMS to monitor the power usage as it utilises the already available battery management system in the battery pack. This eliminates the need to design a new software and is proven to be accurate.

Software Testing

After the monitoring software is chosen, it will be tested. This phase will see the motor being run for a set amount of time for multiple occasion to test out the accuracy and fluctuations of results, if any.

System Testing

The final phase will combine the monitoring software and the testbench. A test run will be conducted to ensure everything works as intended. If any problem arises, it will be categorised as an error and will be identified and eliminated. Improvements will then be made and implemented. The system will then be tested again until it is error free.

Result and Discussion

Table 1 explains the necessary information that is used in this research. The sizes are different due to availability issues where it is almost impossible to get another tire of the same size as the Bridgestone without spending a lot of money. Thus, the next best option was chosen where an almost similar size was chosen, with the CMI72 only having a difference of 10mm in diameter. This difference could be an advantage to the CMI72 as it needs less RPM for both speeds.

Table 1: Tire information

		
Tire make and model	Bridgestone, Ecopia with Ologic	CMI Racing, CMI72
Size	95/80R16	90/90R16
Diameter (mm)	558	568
Circumference (mm)	1754	1786
RPM (50km/h)	475.3	466.9
RPM (80km/h)	760.5	747.1

Results

The experiments consist of 3 runs for each tire at 2 different speeds. Orion BMS monitors the battery pack's voltage and current values and converts them into a format that can be used in Microsoft Excel (.csv file). The result from each run will then be combined according to the tire make and an average value will be calculated and tabulated. The gained power is instantaneous power gained by using the equation:

$$P = VA \tag{1}$$

In order to conduct a fair experiment for the two tires, some parameters were set to a constant as shown in Table 2:

Table 2: Experiment's constant parameter

Tire pressure (psi)	24
Test 1 speed (km/h)	50
Test 2 speed (km/h)	80

The graph for the test runs and average power consumption is as follows:

Test 1, 50km/h:
Bridgestone, Ecopia with Oologic:

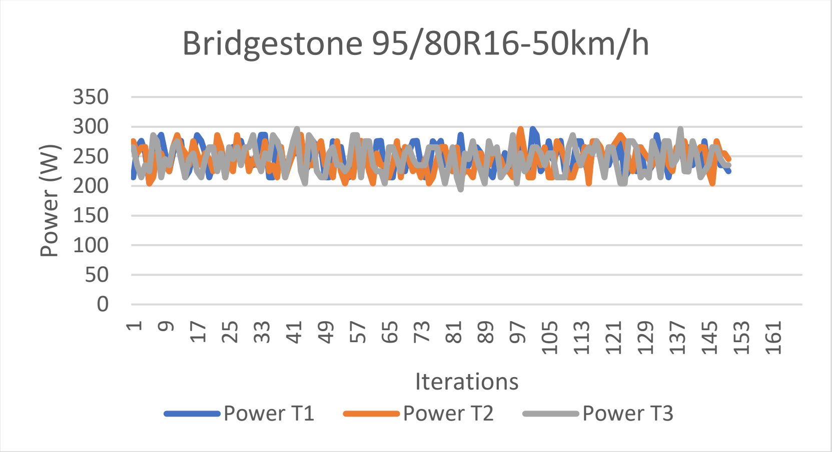


Figure 8: Bridgestone's power consumption comparison at 50km/h

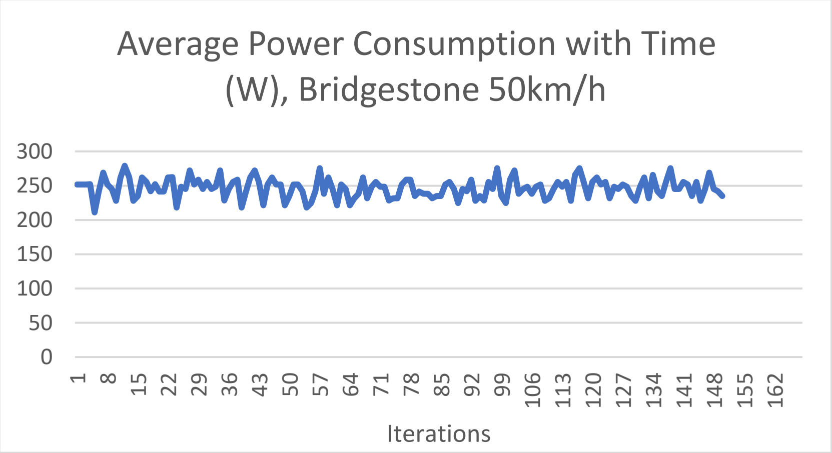


Figure 9: Average power consumption with time for Bridgestone tire at 50km/h

Table 3: Bridgestone’s tire power consumption data at 50km/h

Bridgestone 50km/h	Average Power (W)
Test 1	247.76
Test 2	245.37
Test 3	245.92
Average power of 3 tests	246.35

<u>CMI Racing, CMI72:</u>

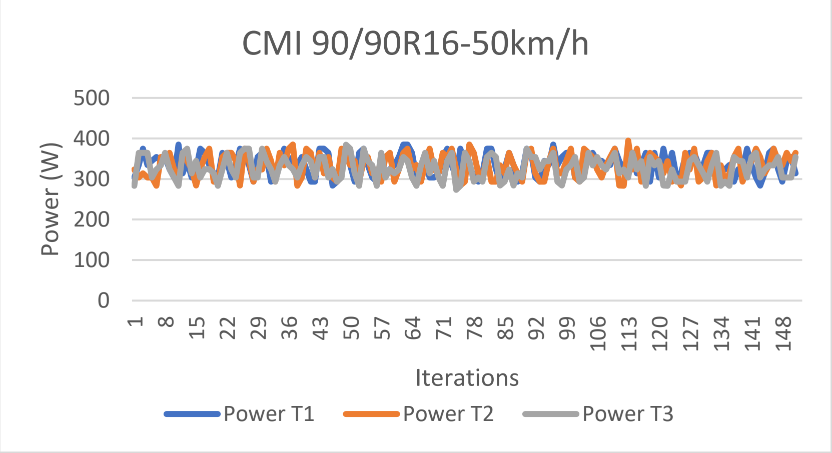


Figure 10: CMI’s tire power consumption comparison at 50km/h

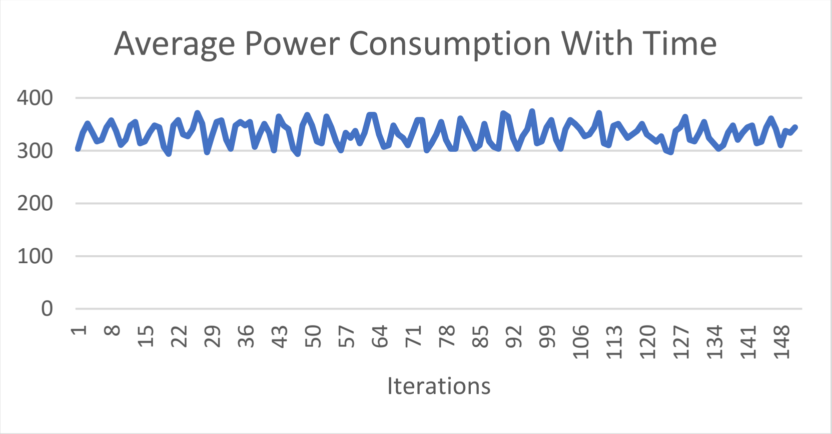


Figure 11: Average power consumption with time for CMI tire at 50km/h

Table 4: CMI's tire power consumption data at 50km/h

CMI 50km/h	Average Power (W)
Test 1	336.73
Test 2	333.27
Test 3	327.46
Average power of 3 tests	332.49

Test 2, 80km/h:

Bridgestone, Ecopia with Oologic:

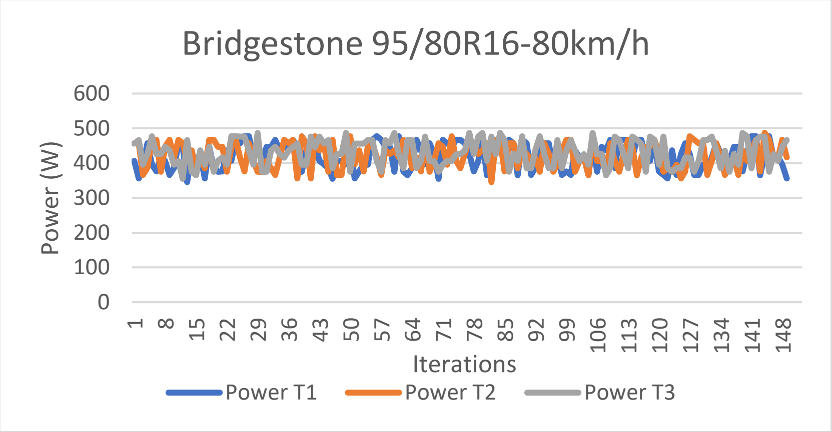


Figure 12: CMI's tire power consumption comparison at 50km/*h*

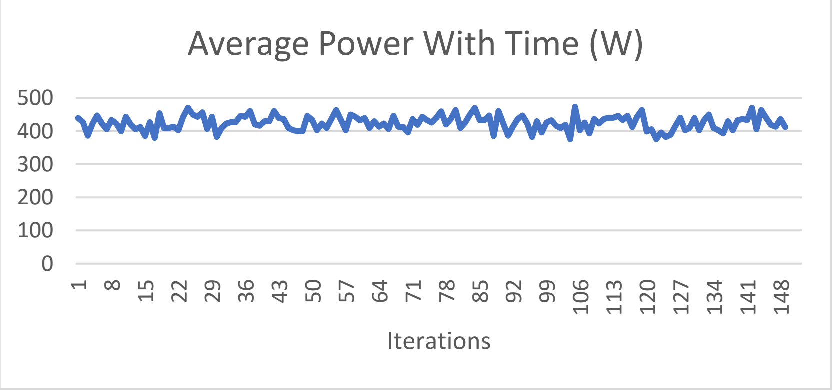


Figure 13: Average power consumption with time for Bridgestone tire at 80km/h

Table 5: Bridgestone's tire power consumption data at 80km/h

Bridgestone 80km/h	Average Power (W)
Test 1	421.18
Test 2	422.75
Test 3	430.15
Average power of 3 tests	424.69

<u>CMI Racing, CMI72:</u>

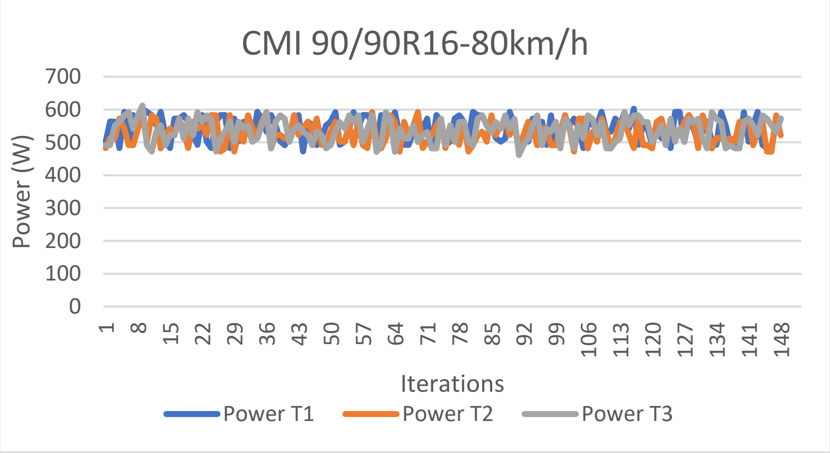


Figure 14: CMI's tire power consumption comparison at 80km/h

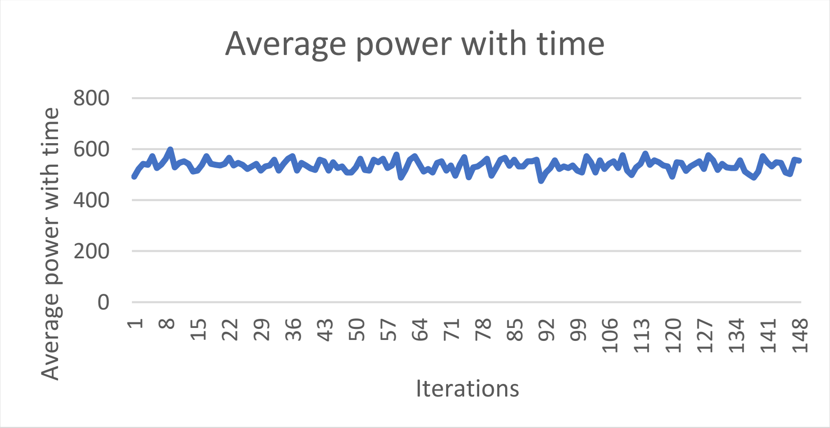


Figure 15: Average power consumption with time for CMI tire at 80km/h

Table 6: CMI's tire power consumption data at 80km/h

CMI 80km/h	Average Power (W)
Test 1	542.41
Test 2	529.62
Test 3	536.57
Average power of 3 tests	536.20

Head-to-head power consumption comparison

With the data acquired from the experiment, a direct comparison between the two tires at different speed can be made. The results are portraited in the following figure:

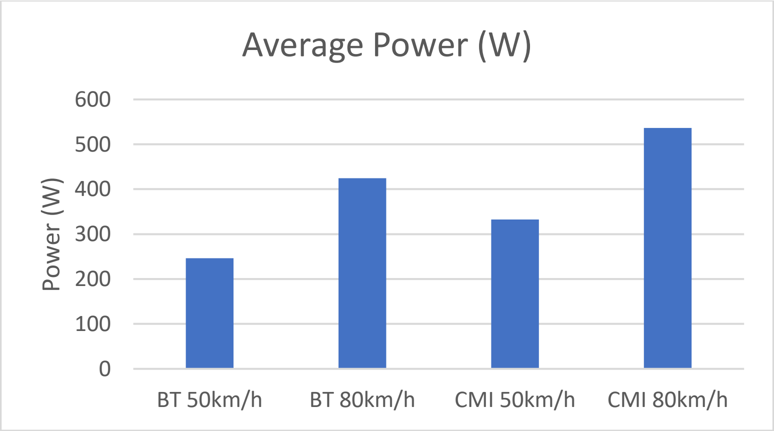


Figure 16: Average power consumption comparison between two tires at different speeds

Discussion

A fair and decisive experiment was conducted. Multiple tests were conducted to eliminate any doubts or errors that may have arisen. The Bridgestone's Ecopia with Ologic tire consumed an average of 246.35W and 424.69W at 50km/h and 80km/h, respectively. While CMI Racing's CMI72 tire consumed an average of 332.49W and 536.20W at 50km/h and 80km/h, respectively.

Through direct comparison the CMI72 consumed an average of 34.97% and 26.26% more power at 50km/h and 80km/h respectively. The power consumption difference between the two tires becomes smaller as the speed increases. But the more efficient tire is the Ecopia with Ologic by a big margin.

This difference can be narrowed down due to the constants set by the experiment where the only variable are the tires. Thus, for this experiment, we can conclude that the factor that contributed to the difference is the tire itself. More specifically the tire's mass and coefficient of rolling resistance. A higher mass needs more energy to overcome its inertia and sustain a certain speed. A higher coefficient of rolling resistance also contributes to the need of more power. Through measurement of the setup's mass, the only variable left missing is the coefficient of rolling resistance. It can be obtained through the use of the following equation:

$$P_{rr} = c_{rr}.m.g.v \tag{2}$$

where:

m = mass of the vehicle

g = gravitational force (m/s^2)

v = velocity of the vehicle

c_{rr}= rolling resistance coefficient (dimensionless)

Rearranging the equation gives:

$$c_{rr} = \frac{P_{rr}}{m.g.v} \tag{3}$$

The setup's mass was measured for both tires using a scale, the values are as follows:

Table 7: Setup's mass with different tires

Tire setup	Mass (kg)
Bridgestone	15.8
CMI Racing	18.1

Thus, the value of the coefficient of rolling resistance can be obtained. The values are as follows:

Table 8: Coefficient of rolling resistance values at different speeds

	Coefficient of Rolling Resistance, c_{rr}
Bridgestone (50km/h)	0.114434933
CMI (50km/h)	0.134822742
Bridgestone (80km/h)	0.123298811
CMI (80km/h)	0.135891463

The tire's coefficient of rolling resistance is not supposed to change at any speed, but due to more heat being produced at higher speed, it results in the motor having to use more power to work against the rolling resistance [9]. At 50km/h, Bridgestone's tire has a coefficient of rolling resistance value of 0.114434933 while CMI's tire coefficient of rolling resistance value is 17.82% higher at 0.134822742. While at 80km/h, Bridgestone's tire has a coefficient of rolling resistance value of 0.123298811 while CMI's tire coefficient of rolling resistance value is 10.21% higher at 0.135891463.

Conclusion

The power consumption of the electric motor has successfully been monitored and compared between two types of tires. It is concluded that different tires do indeed affect power consumption and the main factor is the tire's mass. A higher mass contributes to more power needed to overcome rolling resistance and in turn, results in a higher coefficient of rolling resistance. A recommendation when choosing a tire for our vehicles in the future would be to compare the masses between the tire choices and pick the one with the lowest mass if the main objective is lower power consumption or lower fuel consumption. Other than that, check the manufacturer's specifications sheet for the tire's coefficient of rolling resistance value and choose a tire with a smaller value.

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