Evaluation of an Electric Go-Kart with Lithium-ion and Nickel-Metal Hydride Batteries

Gustavo Alvarez-Coello
*ERGON - Automotive Engineering Research and Development Center
Universidad del Azuay
Cuenca, Ecuador
galvarezc@uazuay.edu.ec

Andrés Idrovo-Pauta*
andres110792@es.uazuay.edu.ec

Daniel Cordero-Moreno*
dacorderom@uazuay.edu.ec

Efrén Fernández-Palomeque*
efernandez@uazuay.edu.ec

Abstract

Within the transition towards the use of electricity as a power source in the automotive industry, this investigation aims to evaluate the acceleration capacity of a go-kart type vehicle equipped with an electric motor. Two types of battery were employed, Lithium-Ion and Nickel-Metal Hydride batteries, each one combined with two different gear ratios. Two methodologies were used to obtain the acceleration capacity, a mathematical model using Simulink and track tests. The best acceleration capacity was obtained with Lithium-Ion batteries and a gear ratio of 2:1. The difference between the model and on-track tests were 16.68%. The difference is higher with a 1:1 gear ratio. was attributed to the initial energy requirement of the batteries when starting the vehicle to overcome inertia.

Keywords: Vehicle dynamics, Nickel-Metal Hydride batteries, Lithium-Ion batteries, Go-kart, Acceleration capacity.

1. Introduction

The motivation for this article comes from the worldwide impulse for the development of electric vehicles. This study compares the go-kart acceleration capacity when its energy source is Nickel-Metal Hydride batteries and Lithium-Ion batteries, each combined with two fixed gear ratios. The importance of this research resides in quantifying the improvement that represents the application of one or the other battery technology, which is an important parameter to consider for future improvements of the vehicle in reference.

1.1. Objectives

- To evaluate the acceleration capacity of an electric go-kart with Nickel-Metal Hydride and Lithium-Ion batteries in an electric go-kart utilizing acceleration capacity tests.
- To determine acceleration capability of the go-kart by applying the SAE J1491 test protocol with a 1:1 and 2:1 gear ratio.
- To evaluate the results of the track tests concerning the vehicle dynamics model.

2. Literature Review

The use of non-conventional energy sources for transportation is a topic of global interest. Although since the beginning of the automobile era, in the dispute between vehicles with combustion engines and electric vehicles, the latter were left behind due to the limited autonomy of their batteries. This reality began to change with the appearance of current hybrid vehicles, which contribute to the arrival of electric vehicles based on the fact that the autonomy of batteries improved significantly and the price of these decreased by approximately 85% in the last decade (Castells, 2018).

As for go-kart type vehicles, in 2010, the project "The Cap Kart v2.0" of the Massachusetts Institute of Technology, developed a go-kart with a weight of 113 kg without considering the weight of the driver, which used a 7.5 kW motor powered by a 39.6 V Lithium-Ion battery, with 40Ah capacity connected in series to a 110F ultracapacitor at 16 V. This go-kart, with a fixed gear ratio of 3.2:1 reached a top speed of 64 km/h in 4.68 seconds (Starcher et al., 2010).

Even in motorsport, this transition to green energy has been notorious. This is the case of Formula E, which appeared in 2014. Another example is the use of a hybrid system for energy recovery called ERS in Formula 1. ERS generates approximately 160 additional HP during 33 seconds per lap through motor-generator units, which take advantage of both the kinetic energy of braking, MGU-K, and the thermal energy expelled by the turbocharger, MGU-H, storing it in batteries to then provide additional power to the vehicle, improving its efficiency (Madier, 2015) (Golebiowski & Kubiak, 2017).

In go-kart races, even though mainly these types of vehicles are equipped with combustion engines, in France for example, the IUTs French acronym for "Instituts Universitaires de Technologie", together with several engineering schools and vocational high schools specifically promote the use of an electric go-kart as an educational support (Lequeu et al., 2007). In 2018 Blue Shock Race, a European company dedicated to the construction of equipment for electric go-karts provided a complete kit for the French e-kart championship, which included a Motenergy ME1118 motor of 4.5 kW rated power, the 48 V SEVCON GEN4 controller, the Lithium-Ion battery, and the charger for all competitors (Stumps, 2019).

In Ecuador, the current impulse towards the use of hybrid and electric vehicles by the government, through the reduction of taxes on this technology (Castillo & Serrano, 2018), generates a wide expectation and drives the local development of knowledge in this field of mobility. Having as a background the modification work carried out on a kart from the University of Azuay in which the internal combustion gasoline engine was replaced by an electric one with the aim of comparing two energy sources such as Nickel-Metallic Hydride batteries in comparison with Lithium-Ion batteries (Luzuriaga, 2018). Lithium-Ion batteries have a higher energy density compared to Nickel-Metal Hydride batteries by approximately 30% (Mártil, 2019). A comparison between these two technologies is carried out for the present article by means of acceleration capacity tests of an electric go-kart.

One of the main parameters of vehicle performance is acceleration capacity, which is the time needed for a vehicle to reach a certain speed from another or from rest, for example, the time required for a vehicle to reach a speed of 50 km/h from rest (Cassani, 2010). When applying force equations on the vehicle in the longitudinal direction, resistive forces appear in the first place and in opposition to these resistive forces, there is the tractive effort provided by the engine. If the tractive effort exceeds the resistive forces, there will be a net force that will propel the vehicle with a uniformly accelerated motion (Mozota, 2011).

The objective of the present study is to evaluate the acceleration capacity of a go-kart using different vehicle configurations. Two different gear ratio and two types of batteries were employed in this work.

Finally, with the application of a mathematical model of vehicle dynamics adjusted to the characteristics of the components used in the acceleration capacity tests, such as the motor, the batteries, and the physical characteristics of the go-kart, it is intended to demonstrate in what proportion one battery technology is superior to the other in a theoretical way that supports the results of the physical tests.

3. Methods

3.1 Assembly of the battery set

For the Nickel-Metal Hydride batteries, 24 new battery cells were used. These cells are used in the battery pack of a Toyota Prius 2nd generation, whose configuration is shown in Figure 1, a final voltage of 57.6 V was obtained.

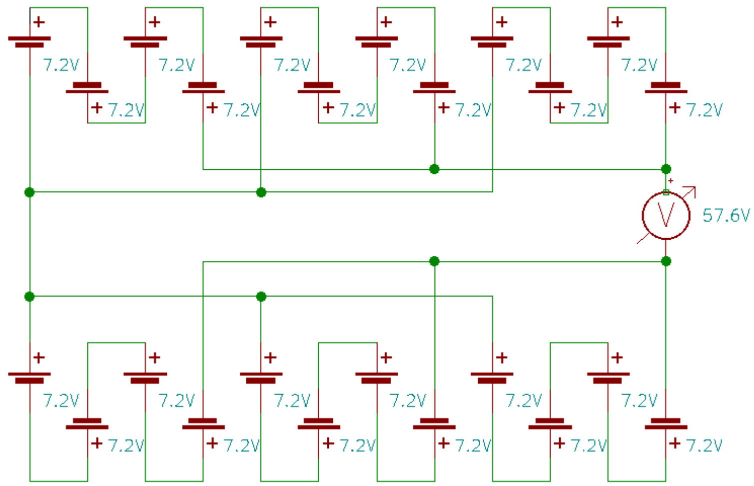

Figure 1. Nickel-Metal Hydride Cell Configuration

For the lithium-ion batteries, as they were sealed, only their state of charge was checked, and they were connected in series to obtain 58.4 V.

3.2 Chassis modifications

In order to make it possible to mount two types of batteries with different geometries, two aluminum plates were used, located on the chassis to the left and right of the driver.
Holes were drilled in these plates for fastening the batteries by means of bolts with lock nuts, as well as for their own fastening against the chassis. In the same way, the current controller was fixed to the left side of the go-kart, leaving on the right side the base for the motor with holes that allowed adjusting the distance between the motor axle and the rear axle where the driving wheels are located.

3.3 Assembly of transmission elements

In order to be able to use two gear ratio, two elements were mounted on the motor shaft carrying the 17 and 34 tooth drive sprockets respectively.
For mounting the 17-tooth pinion, the original central spline of the pinion was machined in such a way that it is possible to mount it on the smooth shaft with a single keyway of the motor, as well as to use its original key. For the mounting of the 34-tooth sprocket, the existing sprocket carrier element of the go-kart was used.
These transmission ratios were used because the difference between the installed 1:1 transmission ratio with two 34-tooth sprockets and the 2:1 transmission ratio with a commercially available 17-tooth sprocket was analyzed.

3.4 Instrumentation of the go-kart

The USB 2.0 port of the Alltrax 48400 current controller was used to obtain the current and voltage data from the batteries and motor with a data collection frequency of 1 Hz. A GPS was also used to obtain data on the speed and positioning of the go-kart with a data acquisition frequency of 20 Hz. Due to the limitation in terms of data acquisition frequency of the controller with respect to the GPS, it was necessary to use the GPS data with a frequency of 1 Hz limiting its capacity.
The connection diagram of the components used in the go-kart is shown in Figure 2 (Alltrax, 2017).

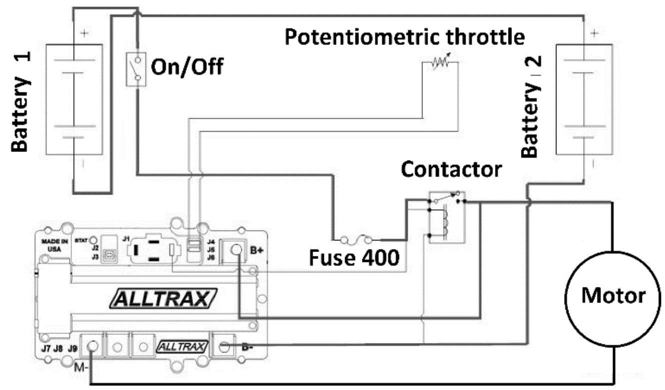

Figure 2. Component connection diagram.

3.5 Obtaining the frontal area

Through the Autodesk Inventor software, starting from a photograph taken perpendicular to the ground and parallel to the front of the vehicle, the determination of the frontal area was made by means of the projected area of the vehicle and taking as a reference measurement that the front wheelbase measures 1230 mm. The frontal area obtained is 0.907 m^2. The area is shown in Figure 3.

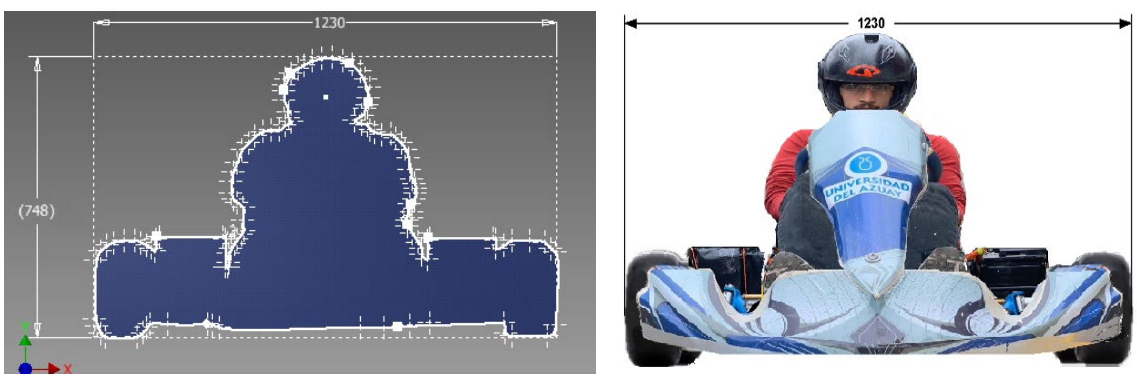

Figure 3. Front area drawn and photographed frontal area.

3.6 Vehicle and driver weighing

The weighing of the go-kart was performed as this value is required in the vehicle dynamics model. To the vehicle with a weight of 111.5 kg including batteries, the weight of 70 kg of the driver was added, bringing the total weight to 181.5 kg.

3.7 Determination of the acceleration capacity.

Through the application of numeral 9.1.4 of the SAE J1491:2006 test protocol "Acceleration Response Time¨ where the objective is to determine the time it takes for the vehicle to reach 30 mph (48.3 km/h), the acceleration capacity of each combination of batteries and transmission ratio was determined through GPS measurements.

3.8 Application of the vehicle dynamics model.

For the application of the vehicle dynamics model of acceleration capability, the physical constants describing both the vehicle and its environment were defined as shown in Table 1.

Table 1. Constants and symbols used

Constant	Symbol	Value	Unit
Frontal Area	A	0.907	m^2
Coefficient of rolling resistance	fr	0.025	[-]
Drag coefficient	Cd	0.8	[-]
Air density	ρa	0.93	kg/m^3
Transmission efficiency	ηtd	0.90	[-]
Gravity	g	9.81	m/s^2
Mass	M	181.5	Kg
Angle of slope	Θ	0	°
Dynamic radius	Rd	0.129	M
Motor constant torque according to current	Tc	0.15	Nm/A

On the other hand, the symbology used to define the variables is shown in Table 2.

Table 2. Variables and symbology used

Variable	Symbol	Unit
Acceleration	a	m/s^2
Wheel force	Fr	N
Drag force	Fd	N
Rolling resistance force	Rx	N
Slope resistance force	Rg	N
Inertia	Ri	N
Equivalent mass	me	Kg
Total transmission ratio	Ntd	[-]
Engine torque	τm	Nm

In the applied vehicle dynamics model, the velocity V [m/s], is obtained from the integral of the acceleration a, from the diagram of forces involved in the vehicle motion (Gillespie, 1992).

Thus, starting from the equation for the wheel force, Fx is expressed as:

$$Fx = Fd + Rx + Rg + Ri$$

Wheel force is also determined by:

$$Fx = \frac{\tau m * Ntd * \eta td}{Rd} - me * a$$

From equation (2), the equivalent mass of the rotating elements (me) is determined by:

$$me = M * mf - M$$

In turn the mass factor, mf, which is the combination of the effective mass and the equivalent mass is determined by:

$$mf = 1 * 0.04 * 0.0025Ntd^2$$

From equation (1), the drag force (Fd), rolling resistance force (Rx), slope resistance force (Rg), and inertia (Ri) are determined by:

$$Fd = \frac{1}{2}Cd * A * \rho a * V^2$$
$$Rx = M * g * fr * Cos\ \Theta$$
$$Rg = M * g * Sen\ \Theta$$

$$Ri = M * a$$

Replacing (3) in (2) gives:

$$Fx = \frac{\tau m * Ntd * \eta td}{Rd} - (M * mf * a) + (M * a)$$

Replacing (5), (6), (7), (8) and (9) in (1) we obtain the acceleration a remaining as final expression:

$$a = \frac{\frac{\tau m * Ntd}{Rd * \eta td^{-1}} - \left(\frac{A * V^2}{2(Cd * \rho a)^{-1}}\right) - \left(\frac{fr * Cos\ \Theta}{(M * g)^{-1}}\right) - \left(\frac{Sen\ \Theta}{(M * g)^{-1}}\right)}{(M * mf)}$$

Motor torque (τm) values were obtained from a table [ω,τm] in which each torque value has a corresponding angular velocity in RPM.

Angular velocity was obtained from the linear velocity of the vehicle (obtained from GPS) as a function of its dynamic radius. The value of ω is used to query its corresponding τm are obtained from:

$$\omega = \frac{1}{n}\sum_{i=1}^{n} \left(\left(\frac{60V}{2\pi Rd}\right) * Ntd\right)$$

Where V corresponds to each of the speed values obtained from the simulation.

The motor torque (τm) is obtained from:

$$\tau m = \frac{1}{n}\sum_{i=1}^{n} (C * Tc)$$

Where C corresponds to the measured values of motor current in amperes obtained in each test through the Alltrax Toolkit software of the current controller.

The Figure 4 illustrates the vehicle dynamics model applied in Simulink.

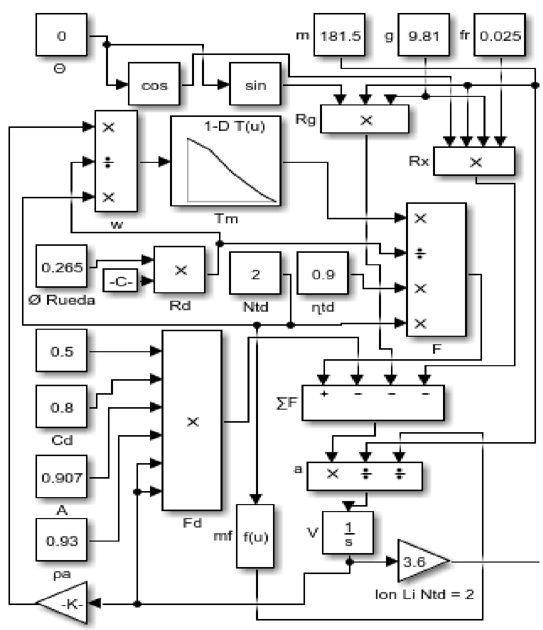

Figure 4. Vehicle dynamics model Simulink.

4. Data Collection

4.1 Chassis

The chassis used a FA Victory MA15 equivalent to an Original Tony Kart Racer 40 and in which the necessary adaptations were made so that it is possible to mount both, the Nickel-Metal Hydride batteries, and the Lithium-Ion batteries, in such a way that the control elements are located in a safe place for the driver and for the operation of the vehicle Figure 5.

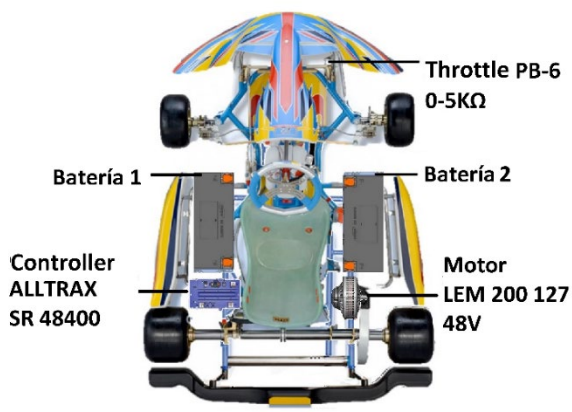

Figure 5. Arrangement of elements in the chassis.

4.2 Batteries

As represented in Figure 6, Lithium-Ion batteries have a higher energy density and specific energy with respect to Nickel-Metal Hydride batteries. These two types of batteries will be used in the acceleration capability tests of this paper.

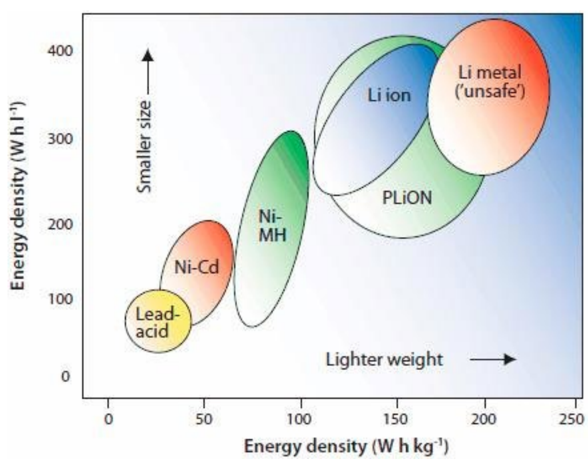

Figure 6. Volumetric energy density as a function of mass energy density of rechargeable batteries (Mártil, 2019)

4.2.1 Lithium-ion batteries

Nickel-manganese-cobalt (NMC) alloy positive terminal and natural graphite negative terminal. Obtained from "Samsung SDI ESS 192S1P Rack". This battery chemistry is the most applied in electric vehicles such as the Nissan Leaf, the Chevrolet Volt, and the BMW i3 and i8 (Vertiv, 2017) although with different configurations in terms of the number of cells. Specifically, the batteries used in the present project, Figure 7, have a capacity of 68 Ah, a nominal voltage of 58.4 V obtained from 2 modules of 8 cells each connected in series. Each cell provides 3.65 V nominal voltage and has a total weight of 44 kg (Samsung, 2015).

Figure 7. Nickel-Metal Hydride Battery Packs

4.2.2 Nickel-Metal Hydride Batteries:

The positive terminal of nickel oxide (NiOOH) and negative terminal of metal hydride alloy. Obtained from the third generation Toyota Prius and from which 24 cells of 7.2 V nominal voltage with a capacity of 6.5Ah and a weight of 1040 grams each were used (Primearth EV Energy Co Ltd, 2019). For the tests, each cell was charged individually obtaining 7.2V in each one, in order to assemble 2 sets of 12 cells each one adding up to a voltage of 57.6 V with a capacity of 19.5 Ah as shown in Figure 8.

Figure 8. Nickel-Metal Hydride Battery Packs

4.3 Motor

The motor used is a 48 V brushed LEM 200-127 which has a rated power of 8.55 kW and a rated torque of 31.5 Nm at 2592 RPM (Lynch Motor Company Ltd, 2016).

4.4 Transmission

Two fixed gear ratios using 34 and 17-tooth drive sprockets and a 34-tooth driven are used for testing to obtain ratios of 1:1 and 2:1 respectively. The application of these transmission ratios is justified by the need to compare the initial configuration of the go-kart, 1:1, versus the 2:1 ratio, the latter being a proposal for optimization in search of better acceleration, sacrificing the final speed of the vehicle since this is not the object of the present study.

4.5 Control equipment:

The energy provided by the batteries is managed through a DC Motor controller, Figure 9, model Alltrax SR - 48400, which distributes the current from the batteries to the motor according to the signal received from a potentiometric speed regulator "Pot Box PB6", which has an operating range of 0-5 k. The current to reach the motor flows through a 48 V electromechanical contactor at 400 A and a 400A DC fuse (Alltrax, 2017).

Figure 9. Alltrax SR – 48400

4.6 Data acquisition equipment

4.6.1 GPS

A GPS VBOX Sport, Figure 10, with an accuracy of 0.01 km/h and a data acquisition frequency of 20 Hz, was used to obtain the speed (Racelogic, 2014).

Figure 10. GPS VBOX Sport

4.6.2 Alltrax Toolkit

To obtain the motor and battery voltages and currents through the controller, the Alltrax Toolkit software is used, Figure 11, which is a software compatible with the Alltrax SR - 48400 current controller and allows exporting these values with a data collection frequency of 1 Hz (Alltrax, 2017).

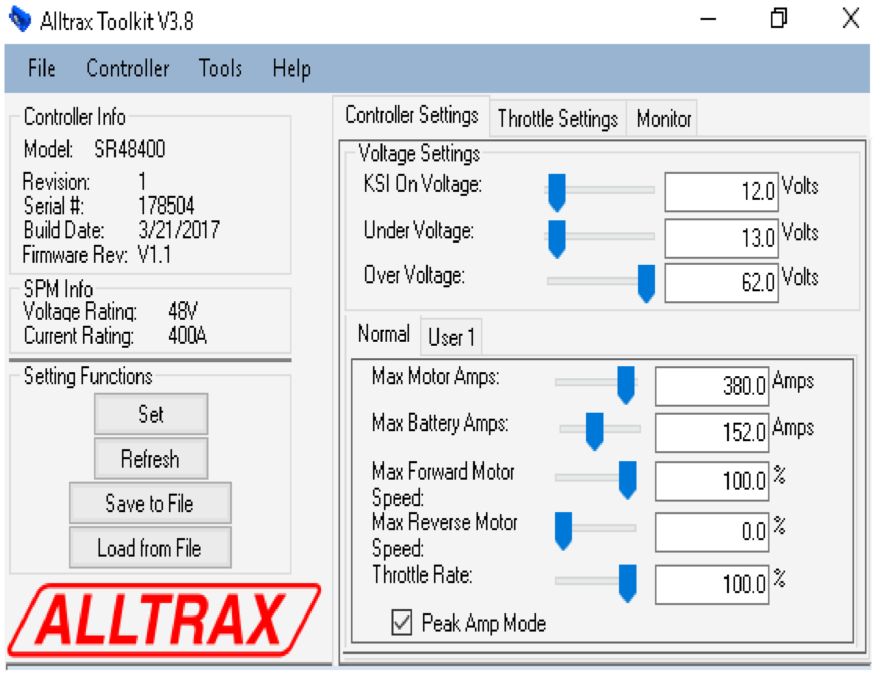

Figure 11. Software Alltrax Toolkit.

4.6.3 Digital multimeter

In order to control that the discharge of the batteries is not excessive, the go-kart was instrumented with a digital multimeter located just behind the steering wheel so that it is easy to see for the driver.

4. Results and Discussion

5.1 Numerical Results

The tests were performed on a 50 m long, flat, non-sloped asphalt section. Ten tests were performed with the Lithium-Ion batteries with each gear ratio and 4 tests with the Nickel-Metal Hydride batteries with each gear ratio. The acceleration capacities according to the battery type and gear ratio configuration achieved are presented in Table 3. The accuracy of obtaining speed data is ± 0.01 km/h.

Table 3. Results of acceleration capacity according to transmission ratio

	Lithium Ion		**Nickel - Metal Hydride**	
Ntd	**Speed** (km/h)	**Time.** (s)	**Speed** (km/h)	**Time.** (s)
2	45.64 ±0.37	4.92± 0.07	23.18 ±0.31	4.75 ±0.20
1	27.67 ±0.06	4.68± 0.15	15.59 ±0.27	4.50 ±0.29

Taking as a reference the combination of Lithium-Ion batteries with the 2:1 transmission ratio with which, the acceleration capacity obtained was 45.64 ±0.37 km/h in 4.92± 0.07 seconds, the other combinations used present, compared to the first one, a lower acceleration capacity in a similar time interval.
Thus, if instead of using the 2:1 gear ratio a 1:1 is used, the speed reached is reduced by 40%. If instead of replacing the gear ratio, the Lithium-Ion batteries are replaced by Nickel-Metal-Hydride batteries, the speed achieved is reduced by 49%. Finally, replacing both the transmission ratio from 2:1 to 1:1 and the Lithium-Ion batteries with Nickel-Metal-Hydride batteries reduces the achieved speed by 65%.

With respect to the vehicle dynamics model, the speed curves are simulated for a time of 5 seconds, in which the time in seconds is on the abscissa axis and the speed in km/h on the ordinate axis.
The differences between the measured results with respect to those obtained in 5 seconds both in the simulation and in the practical tests are expressed as a percentage in Table 4.

Table 4. Percentage difference between measured speed and calculated speed according to model

	Lithium Ion			Nickel - Metal Hydride		
Ntd	V. Calculated (km/h)	V. Measured (km/h)	Δ%	V. Calculated (km/h)	V. Measured (km/h)	Δ%
2	50.28	45.64	9.23%	24.16	23.18	4.06%
1	33.21	27.67	16.68%	18.05	15.59	13.63%

5.2 Graphical Results
Graphical results are presented in figure 12 and figure 13 below.

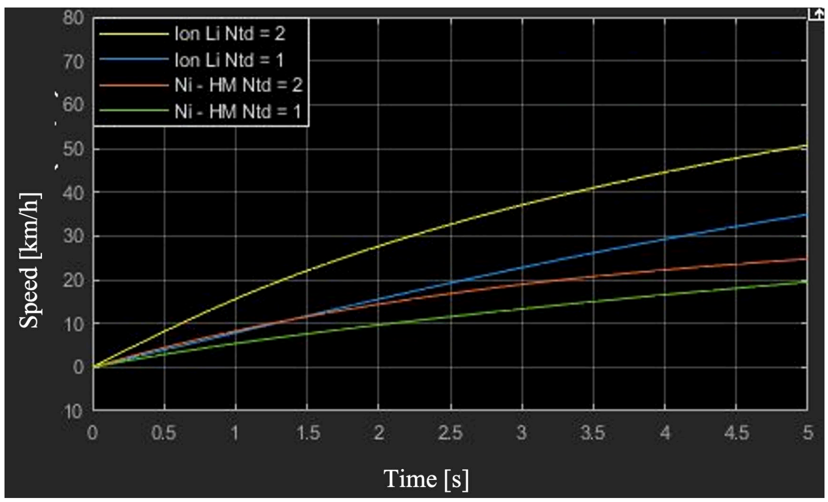

Figure 12. Curves of vehicle dynamics model in 5 seconds

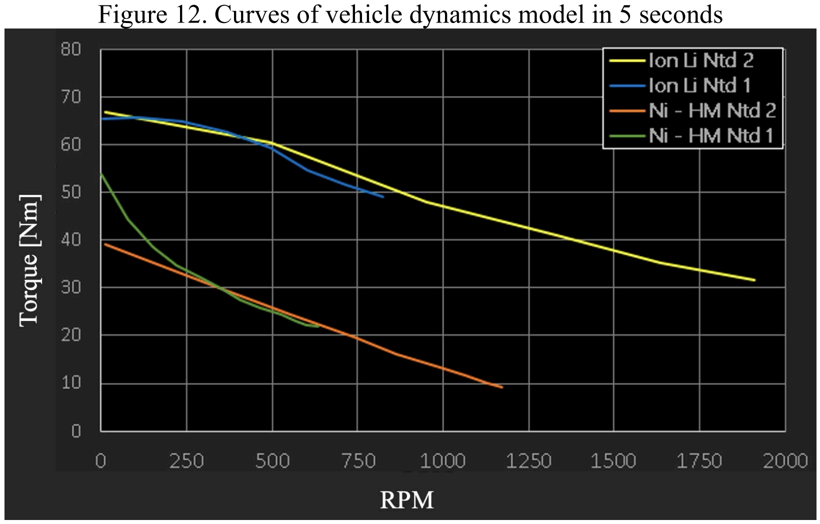

Figure 13. Torque - Angular velocity curves for the driven pinion gear.

6. Conclusion

The results of acceleration capacity tests obtained on track compared with those obtained from the vehicle dynamics model show that the model predicts the speed reached with a percentage variation of up to 16.68%. Therefore, corroborating that the most effective of the combinations is the one that uses Lithium-Ion batteries and a transmission ratio of 2:1.

According to the bibliography consulted, the total transmission efficiency was 90%, assuming that this efficiency represents possible faults in the optimal alignment and assembly of the drive shaft sprocket concerning the driven shaft sprocket and generating undesired resistive stresses in the transmission chain.

The results obtained in the tests and the simulation are higher in the 1:1 transmission ratio concerning the 2:1 transmission ratio because it is attributed to the initial energy required to move the vehicle and overcome the inertia.

Acknowledgements

To the Universidad de Cuenca and Dr. Luis González, who contributed to the project with the loan of the lithium-ion batteries.

References

Alltrax. *Operators Manual Alltrax SR 48-400*, 2017
Cassani, M., *Marcelo Cassani ' s Blog*. 8–11, 2010
Castells, J. *Los precios de las baterías llegan a mínimos históricos en, 2018*.
Castillo, M. A., & Serrano, D, 240 Vehículos Eléctricos Circulan En El País. *Diario El Comercio*, 2018
Gillespie, T. D. , *Fundamentals of vehicle dynamics Analysis, 1992*.
Golebiowski, W., & Kubiak, P. law, *Analysis of Vehicle Dynamics Parameters for Electric Go-Kart (eKart) Design*. *21*(3), 2013
Lequeu, T., Bidoggia, B., Derrien, Y., & Godefroy, N., *Two Examples of Pedagogical Applications of Electrical Go-Karts Keywords*. https://doi.org/10.1109 / EPE.2007.4417441, 2017
Luzuriaga, A., *Adecuación de un tren motriz de un go kart de combustión interna a una de propulsión eléctrica provista de baterías de Ni MH*, 2018
Lynch Motor Company Ltd., *MOTORS LEM-200 Overview Data, 2017*.
Madier, D., THE FORMULA 1 HYBRID POWER UNITS 2014-2015. In *F1-Forecast* (pp. 10–15), 2015
Mártil, I., *Baterías de ion-litio: pros y contras*, 2019
Mozota, A. *EL MOVIMIENTO DE LOS VEHÍCULOS*, 2011
Primearth EV Energy Co Ltd., *Módulo de batería NP2*, 2019
Racelogic., *Vbox Sport*. *10*., 2014
Samsung, *Energy Storage System for Home, 2015*.
Starcher, J., Moriarty, E., Colton, K., & Banzaert, S. *The Cap Kart (v2.0)*, 2010
Stumps, K. ,*Primer lugar para Harald en un kart eléctrico, 2019.*
Vertiv., *El Surgimiento De Las Baterías De Iones De Litio En Los Centros De Datos*, 2019.

Biographies

Gustavo Alvarez-Coello Automotive engineer from Universidad del Azuay, Ecuador (2012). Master's in automotive engineering at "Tecnológico de Monterrey, Mexico" (2014). Currently, associate professor at Universidad del Azuay and works as a researcher of the ERGON - Automotive Engineering Research and Development Center. Has worked in projects related to energy evaluation, air pollution and sustainable transport and mobility with private companies and governmental institutions.

Andres Idrovo-Pauta Automotive engineer from Universidad del Azuay, Ecuador (2020). Has worked in projects related to electric vehicles. His research interests include vehicle dynamics and energy consumption. wants to study a Master's degree in Automotive Mechatronics and Management to broaden his knowledge.

Daniel Cordero-Moreno is a full-time Professor at Universidad del Azuay. He currently teaches undergraduate and postgraduate students. Mr. Cordero-Moreno holds a Bachelor of Science degree in automotive engineering from

Universidad del Azuay and a PhD in Engineering from "Tecnológico de Monterrey". He has published journal and conference papers. Dr. Cordero-Moreno is a member of Ergon, Center for Research and Development in Automotive Engineering and has completed research projects for private and public institutions. His research interests include powertrain configuration, energy consumption, vehicle emissions and vehicle testing.

Efrén Fernández-Palomeque received the M.S. degree in Control Industrial University Polytechnic ESPOL from Guayaquil Ecuador, in 2010. He is a PhD electronic engineer of the University Polytechnic of Catalonia in Spain. His research interests include power-electronic system design, electrical motor drive, fault tolerant converters and their applications in hybrid and electrical vehicles.