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INVESTIGACIÓN

Design and Simulation of an e-Kart for racing

Diseño y Simulación de un e-Kart de Carreras

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Resumen

Objetivo: diseñar y simular un kart eléctrico que maximice la eficiencia energética para carreras.
Métodología: el proyecto se desarrolló bajo un enfoque cuantitativo, descriptivo y experimental de carácter virtual, pues se basa en la construcción de modelos matemáticos, el diseño asistido por computadora y la simulación en software especializado. Es un diseño de investigación aplicada que busca generar una solución técnica a un problema específico: el incremento de la eficiencia energética en karts eléctricos de competición. La investigación se apoya en métodos deductivos a partir de teorías de dinámica vehicular y eficiencia energética, hasta la validación de un modelo optimizado mediante simulaciones.
Resultados: los resultados validaron la viabilidad del diseño propuesto y proporcionaron información valiosa para realizar ajustes y mejoras. Se determinó que la integración del sistema de propulsión eléctrica en el kart no compromete sus características de rendimiento energético. En otras palabras, el sistema de propulsión eléctrica no aumenta el peso total del kart, lo que garantiza el cumplimiento del límite de 240 kg estipulado para la categoría SuperKart.
Conclusiones: mediante simulaciones numéricas realizadas en Matlab, se optimizó meticulosamente el rendimiento del eKart, medidos en la velocidad, la autonomía y la eficiencia energética. Los resultados revelan una mejora sustancial en la velocidad máxima alcanzada, la selección de la reducción óptima (NTF) y una mayor autonomía sin comprometer el consumo de energía. Las simulaciones por ordenador proporcionaron una visión completa del arranque y el funcionamiento de los componentes que conforman el sistema de propulsión del kart eléctrico durante las carreras, en las que el vehículo alcanza una velocidad de 248 km/h en tan solo 34 segundos.
Palabras clave: conducción autónoma, diseño cadena cinemática, kart eléctrico, simulación computacional.

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Abstract

Objective: To design and simulate an electric kart that maximizes energy efficiency for racing.
Methodology: The project entitled "Design and simulation of an electric kart that maximizes energy efficiency for racing" was developed using a quantitative, descriptive, and experimental virtual approach based on the construction of mathematical models, computer-aided design, and simulation using specialized software. The study is part of an applied research design, as it seeks to generate a technical solution to a specific problem: increasing energy efficiency in electric racing karts. Likewise, the research is based on a deductive method, starting from theories of vehicle dynamics and energy efficiency, to arrive at the validation of an optimized model through simulations.
Results: The results validated the feasibility of the proposed design and provided invaluable insights for adjustments and enhancements. So they found that putting the electric propulsion system into the kart is okay. The kart still works well with this system. The electric propulsion system does not make the kart too heavy. This is important because the SuperKart category stays that the kart cannot weigh more than 240 kg. The electric propulsion system helps with this rule. The kart with the electric propulsion system is still under the 240 kg limit, for the SuperKart category.
Conclusions: Through numerical simulations conducted in Matlab, the eKart performance was meticulously optimized, focusing on speed, autonomy, and energy efficiency. The outcomes reveal a substantial enhancement in the maximum speed attained, selection of the optimal reduction (Ntf), and increased autonomy without compromising energy consumption. The computer simulations provided comprehensive insights into the startup and operation of the components comprising the electric kart propulsion system during races, where the vehicle achieves a speed of 248 km/h in merely 34 seconds.
Keywords: Computational Simulation, Driving Autonomy, Electric Kart, Powertrain Design.

Introduction

In todays world of eco-transportation and the search for better alternative energy sources the car industry has seen a big shift toward electric vehicles[1][2] [3]. This change hasn't just impacted gasoline-powered cars; it has also greatly affected racing cars, where technology now plays a major role [4][5]. As a result, electric cars and racing car design have become areas of study combining ideas from mechanics, electrical engineering and computer science to create high-performance vehicles that are gentle on the environment [6][7]. The car industry is now focused on developing vehicles that are not only efficient but also environmentally friendly, and electric vehicles are leading the way in this new era of sustainable mobility, with electric vehicles being a key part of it [8][9].

The transportation sector is a large consumer of energy, representing 19% of global final energy consumption in 2013; and the same sector will account for 97% of the increase in global oil consumption between 2013 and 2030 [10]. The consequent implications in terms of energy security and greenhouse gas emissions from an oil-dominated transport sector point to fuel reduction as one of the highest priorities for all countries. "And this influences the price of fuel to be a fundamental factor in the development of countries because it depends on the import and export of crude oil [11]. The rise in internal combustion engine performance—achieving more power from smaller engines—has played a major role in improving fuel efficiency, even as vehicles have grown larger and heavier. This trend is reflected in historical fuel economy data and economic reports compiled annually by CEPAL.

To understand eKart better [12], we detailed some of its main subsystems and its behavior [13][14]. An electric kart (eKart) is composed of different interconnected subsystems (Electric Propulsion System; Energy Management System; Control and Security System; Chassis System; and Aerodynamic System), which work together to power the vehicle, as shown in Figure 1. By integrating these systems, an e-Kart can achieve remarkable levels of performance, efficiency, and safety during races [15][16][17]. Dynamic models enable the prediction of its behavior under predefined racing conditions[17][18][19]. In this design, we employ the longitudinal dynamic model of a half-car, which not only predicts energy consumption but also facilitates the sizing of key powertrain components such as the electric motor and battery[20][21][22].

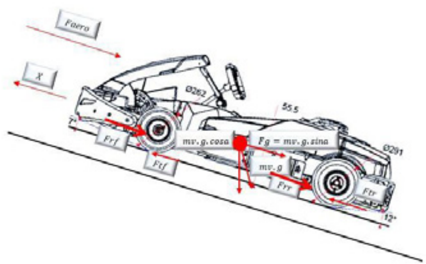


Figura 1. Half-car longitudinal model of an eKart

From the analysis of the free body diagram in Figure 2, the longitudinal Model can be determined from Equation (1):

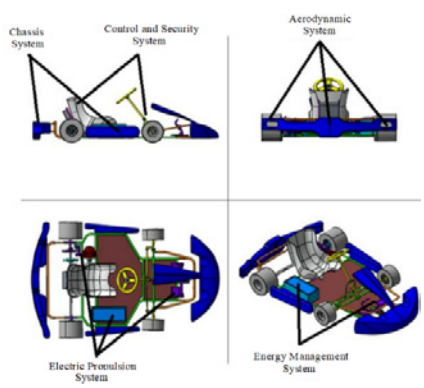


Figura 2. Subsystems of an eKart

$$F_x - R_x - D_a - F_g = m_{eq} a \qquad (1)$$

Where:

- Fx, is the traction force created by the electric motor. [N]
- Rx, is the rolling resistive force [N], in Equation (2).
- Da, is the drag force [N], in Equation (3)
- Fg, is the gravitational force [N], equation (4)

$$Rx = Fr * W \qquad (2)$$

$$D_a = \frac{1}{2} * Cd * p * A * V^2 \qquad (3)$$

$$F_g = m * g * Sen\theta \qquad (4)$$

Therefore, by employing the equations and evolving them into energy equations, it becomes feasible to design a powertrain for an eKart tailored for racing competitions. This manuscript is dedicated to elucidating the method used for selecting and optimizing key components of the e-Kart. Additionally it shows how to use simulation techniques to evaluate vehicle performance well.

Methodology

The following sections outline the steps required to advance the project. We will show you what to do one step, at a time. We will also explain how to go back and make changes if you need to. This way the project will keep moving and get done.

Karting

Karting is a motorsport discipline practiced using karts on circuits known as kartodromes[23][24], typically ranging from 600 to 1,700 meters in length and 8 to 15 meters in width. Because of its accessibility and strong focus on skill development, karting is widely regarded as the foundation for aspiring racing drivers, often serving as their first experience in competitive racing from a very young age—sometimes as early as five years old.

The category selected for this study is SuperKart. This discipline stands out for its use of longer racetracks, where its unique characteristics can truly shine. With full bodywork and powerful 250 cc twin-cylinder engines producing close to 100 HP (75 kW), SuperKarts deliver remarkable speed and performance, making them one of the most impressive forms of karting. In Figures 3, 4 and 5, the dimensions of the kart under consideration are presented.

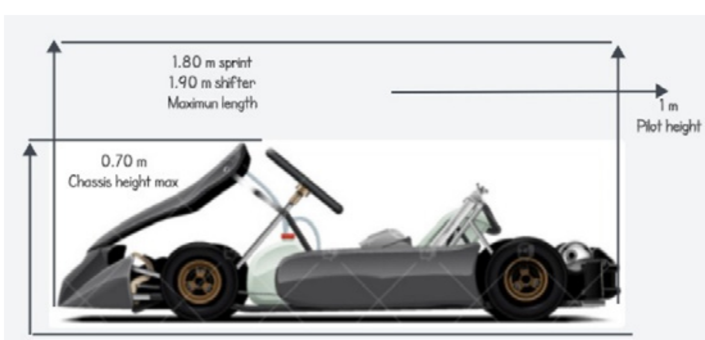


Figure 3. e-Kart Dimensions – Lateral

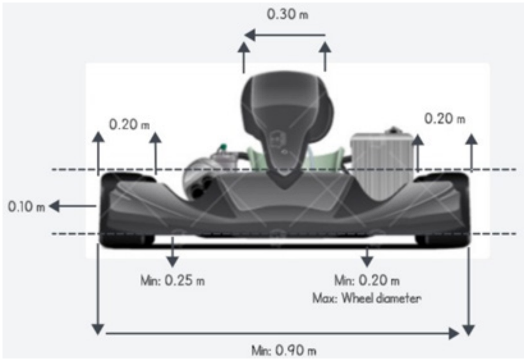


Figure 4. e-Kart Dimensions – Front

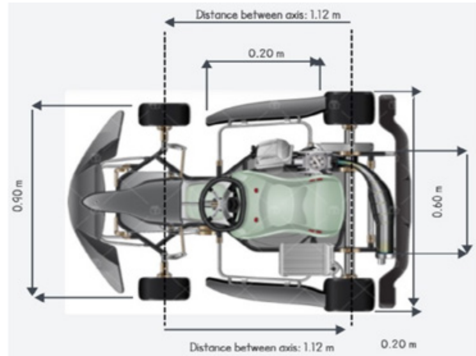


Figure 5. e-Kart Dimensions – Top View

On the other hand, Table 1 shows several variables and constants used in the e-Kart design.

Table 1. *Complementary variables*

Parameter	Symbol	Value	Unit
Mass - Kart	M	250	kg
Wheel Mass	msr-msf	3.3	kg
Area - Kart	A	0.45	m^2
Distance – Front Axle	L1	0.56	m
Distance – Rear Axle	L2	0.56	m
Distance between axles	Dee	1.12	m
Center of Mass	DZcm	0.125	m
Drag Coefficient	Cd	0.47	
Friction Coefficient	Us	0.03	
Air Density Coeficiente	Rho	1	kg/m^3
Aerodynamic Force	DZp	0.125	m
Wheel Radius	R	0.125	m
Wheel Inertia	Iw	0.0257	
Motor Inertia	Ie	0.18	
Transmission Efficiency	Ntf	0.9	

Selection of the electric motor

Once the parameters and technical characteristics have been established[26], the next step involves choosing an electric motor that aligns with the requirements of both the racing category and the driver's needs. Moreover, achieving maximum energy efficiency is paramount, achieved through parameter variations during simulations. Following this, the components of the traction system can be appropriately sized, including the battery, motor, reduction system, and wheel selection.

Figure 6 shows the simulation illustrating the product of the longitudinal speed achievable by the eKart and the traction force. This force serves as an estimate of the power required by the motor to withstand resistive forces, ensuring adequate autonomy during the competition in which the eKart will participate.

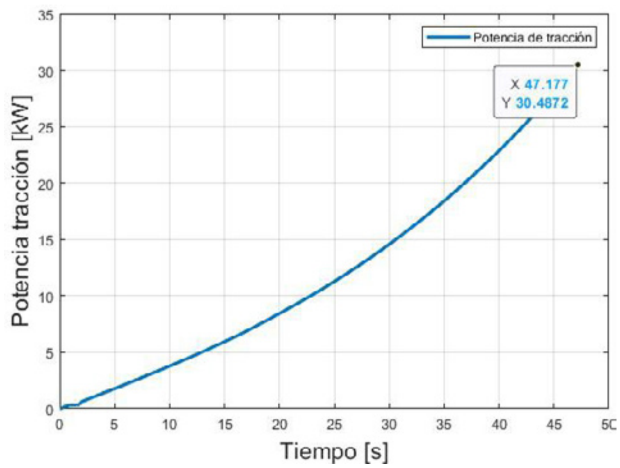
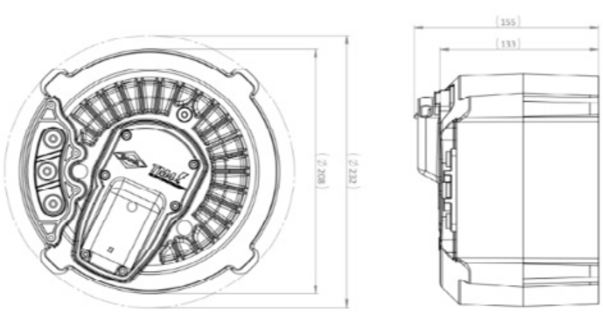
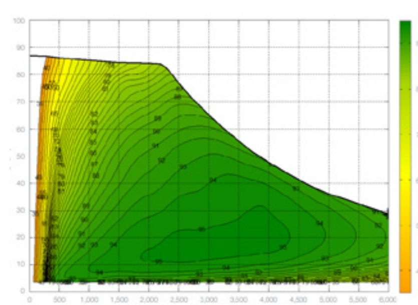


Figure 6. Tractive power generated by the electric motor.

For the electric motor selection, an axial motor was chosen for its strong torque and ability to reach high RPM. More importantly, it offers solid traction performance, with a peak power range of 10–35 kWp and a continuous output of 7–18 kW. It operates within a voltage range of 24–96 V, aligning with the specifications shown in Figure 7a. The chosen motor is the IPM 200-66, characterized as a low voltage motor, as depicted in the same figure. Figure 7b shows the torque versus RPM map, where in the green zone represents performance exceeding 85%. Furthermore, the constant power zone is noticeable, exhibiting a behavior similar to a decreasing exponential curve, spanning from 2500 to 6000 RPM.



(a) Mechanical Dimensions



(b) Efficiency map - torque vs RPM

Figure 7. Electric Motor IPM 200-66-BJ01 IP67

Battery size and selection

When picking the electric motor, we calculate the size of the battery needed in kilowatt-hours (kWh). This battery must hold enough energy for the competition, which involves a 1.2 km track. This track includes two qualifying rounds of 10 laps each and a final round of 20 laps. According to the SuperKart competition rules, no modifications to the vehicle are allowed during the elimination rounds. So, the battery needs to sustain performance for 20 laps. Each lap is done with an average speed of 90 km/h, which means it takes less than 1 minute (around 48 seconds) to complete a lap. Therefore, the total race time was calculated as 0.2666 hours. To accurately determine the energy requirement of the Kart, it is imperative to identify the maximum instantaneous traction power on the track, as depicted in Figure 6. This figure provides an insight into the mechanical energy necessary within the engine to overcome the inertia and resistive forces associated with the Kart, using the free-body diagram of the vehicle's longitudinal dynamics.

Hence, this value is taken as the basis to obtain the necessary kWh for the eKart operation, which is around 12.08 kW. Therefore, by combining the travel time of 48 seconds with the required motor power, it can determine that the energy required for the eKart operation is . This value is needed to run continuously for 20 laps based on the driving cycle, as shown in Figure 8. Since we assume the track is a straight line and do not factor in energy use during corners, we decided to go for a battery with more kWh capacity to cover any extra usage. Table 2 compares different battery types, showing their technical differences to help us choose the best one.

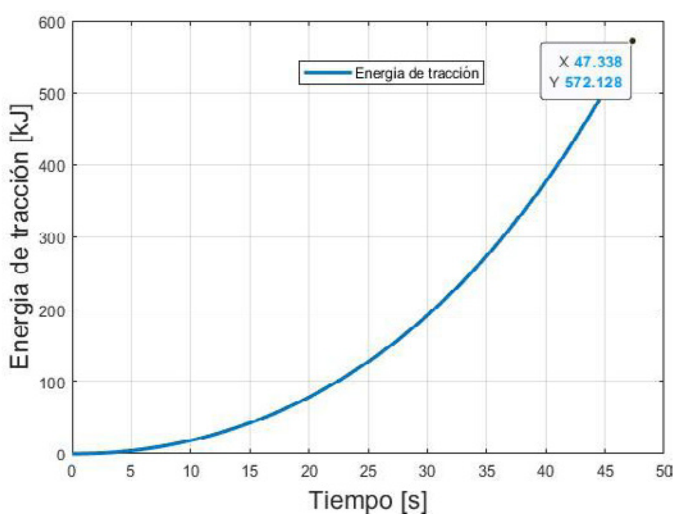


Figure. 8. Tractive Energy – Electric motor

Table 2. *Kind of batteries*

Voltage	Ah	Weight [kg]	kWh	Qty	Energy Density
24	100	22	2.4	2	0,11
24	150	35	3.6	2	0,1029
24	200	40	4.8	1	0,12
24	100	30	2.4	2	0,08
24	200	40	4.8	1	0,12
25.6	200	39	5.12	1	0,1313

It is evident that the LifePO4 battery with 25.6V@200Ah is an adequate choice for this project, weighing 39 kg and offering a power of 5.12 kWh, thus making it the preferred option. So, the chosen battery is the reference CNFLP200-25.6. Thus, with the materials now selected, we can proceed to develop the project. The findings are shown in Table 3.

Table 3. *Main components of e-Kart*

	Reference	Weight [kg]	Voltage [V]	kWh
CHASIS	-	45	-	-
ELECTRIC MOTOR	Dana TM4 IPM200 -66BJ01	18	24-96	7-18
BATTERY	LifePO	39	25.6	5.1

Results

Previous studies on electric kart modeling have primarily focused on efficiency, energy consumption, and component-level comparisons using MATLAB/Simulink. For example, [25] developed detailed traction drive models incorporating battery, power electronics, electric motors (including DC, induction, PMSM, BLDC, and SRM), and vehicle dynamics for a standard 48-second lap driving cycle, with emphasis on regenerative braking and overall system efficiency. Similar works by the same author compared different motor and battery combinations (e.g., favoring SRM with LMP batteries for higher performance). While these studies offered useful reference points for estimating energy use and modeling losses in recreational or junior electric karts [26], they generally focused on lower-speed scenarios and did not examine more demanding conditions, such as extreme acceleration or the optimization of a fixed transmission ratio for high-performance categories. In contrast, the longitudinal model developed here, together with a targeted NTF optimization approach, reaches much higher performance levels—achieving top speeds of up to 248 km/h in just 34 seconds—while still using a single fixed transmission ratio suited to the automatic category. This goes beyond the steady-state efficiency focus of earlier simulations, offering a more complete view of high-performance behavior.

More recent research has moved toward control-focused longitudinal dynamics and the integration of battery systems in electric go-karts. For example, [27] developed a first-principles model in MATLAB Simulink to describe longitudinal vehicle behavior and examined regenerative braking under different driving conditions. Their results showed that the model is well suited for real-time control and performance monitoring—an approach that closely aligns with the telemetry-driven framework used in this study. Likewise, [28] emphasized safety and energy density in chassis and battery design, recommending LiFePO4 (LFP) cells for their thermal stability, a choice reinforced here by the selection of a 5.12 kWh LiFePO4 pack (CNFLP200-25.6) that comfortably exceeds the simulated 3.213 kWh demand while keeping the total mass under the 240 kg SuperKart limit. Unlike many prior works that assumed ideal traction or focused on standard go-kart speeds (often below 70–100 km/h), the current simulations explicitly quantify wheel slip (up to 40% at launch with NTF=25), driver acceleration (±1 m/s^2), and the dominance of aerodynamic drag (13.6 kW), demonstrating superior high-speed capability and practical oversizing rationale tailored to competitive racing conditions [29][30].

We talked about this before so we decided to use the model to see what forces affect the eKart. This model looks at the forces that slow down the eKart and the forces that make it move. The Matlab code we made is really helpful, for controlling and keeping an eye on any kart in different competitions. We use telemetry and data mining to track the things that make the vehicle go faster. This helps us make the prototype we can. If you look at Figure 9 you can see what the simulation says about how the ekart can accelerate. The eKart simulation results are pretty interesting. The eKart is an important part of all this.

These simulations are built around the mechanical link between the motor's rotational speed and the wheels—similar to how gear ratios work in a conventional vehicle. To represent this relationship, the NTF (which defines the speed ratio between the motor and the wheels) is calculated for each simulation. Notably that for this type of vehicle, multiple gear changes are not necessary; a single change suffices, hence the vehicle falls under the automatic category. These NTFs represent the gear changes in electric cars, differing from those in conventional combustion cars.

Therefore, Figure 9 illustrates the acceleration of the electric kart, displaying the various gear changes and their impacts. It is observed that the reduction NTF = 25 enables higher speeds to be attained. Figure 10, shows the longitudinal speed of the eKart, where the gear change of 25 shows a speed of 248 km/h in 34s. Conversely, if an NTF = 50 were chosen, the vehicle would have a speed of 182 km/h in 47s as the race time.

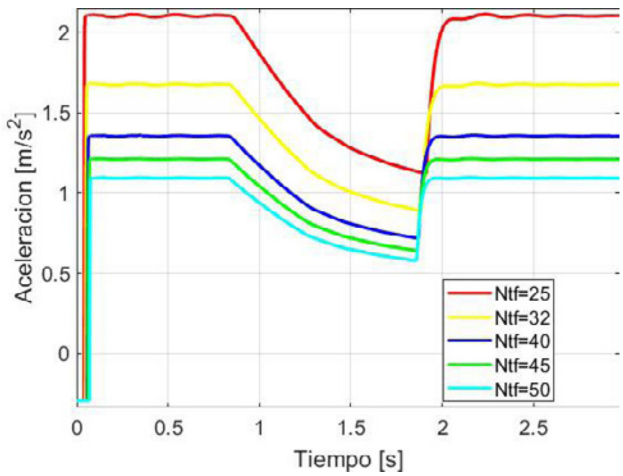


Figure 9. Acceleration of the eKart

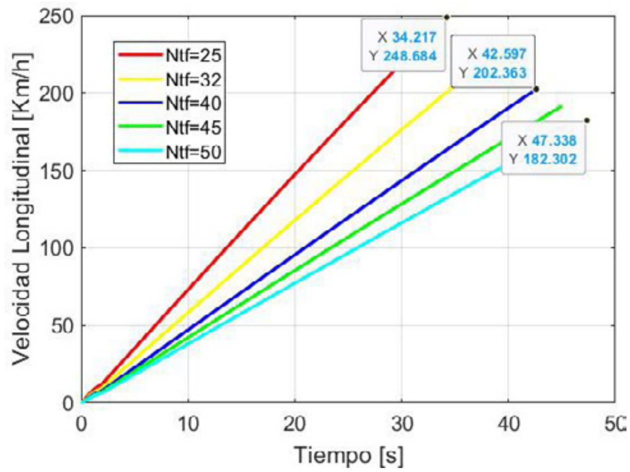
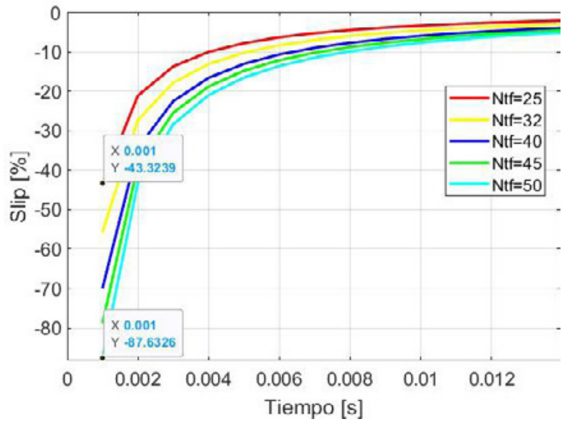


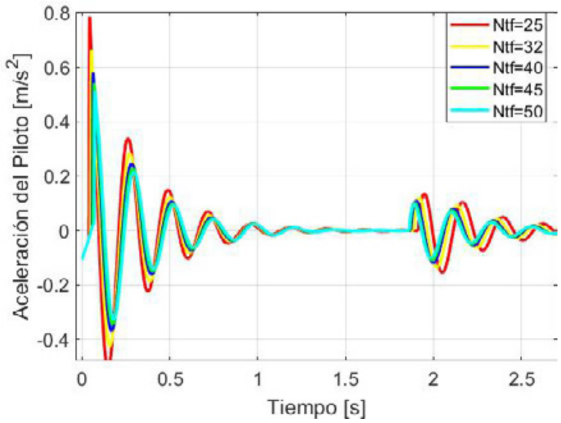
Figure 10. Longitudinal velocity of the eKart

The slip is the condition of wheel slippage that a car experiences when breaking the inertial force or during a start in a competition. In Figure 11a, a lower slip can be observed with lower reductions, but if the NTF is high, there will be greater wheel slippage during the start. For example, at NTF = 25, the Kart exhibits a slip of approximately 40%; compared to the gear change of 50, which is double that.

Therefore, the initial starts in competitions are very important, and that is why the driver's driving style and the effects of acceleration on their body are also critical. Therefore Figure 11b analyzes the driver's acceleration, establishing an average driver weight of 80 kg. Notably, for this competition and SuperKart category, drivers do not experience acceleration greater or less than ±1 m/s^2.



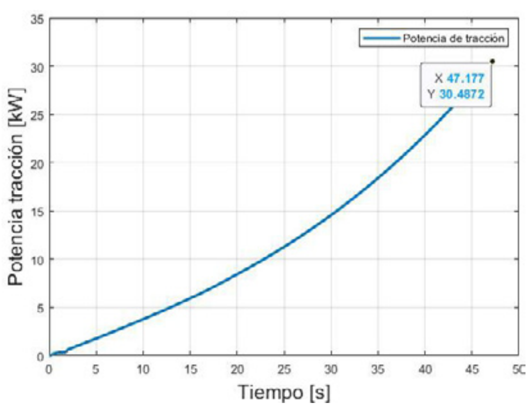
(a) Slip of the traction wheel



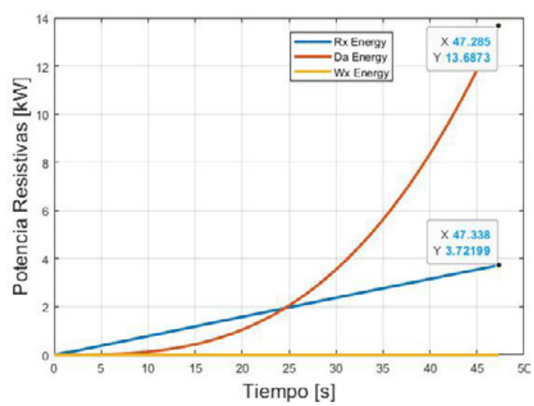
(b) Acceleration of the kart driver

Figure 11. Analysis of Slip and Acceleration

As explained earlier, traction power is relevant because it permits the overcome the initial inertia force of the vehicle. This traction power amounts to 30.4 kW, as shown in Figure 12a. In contrast, the power of resistive forces are lower. In Figure 12b, it is observed that the power of drag force is 13.6 kW, the power of rolling resistance is 3.72 W, and Wx is neglected as damping was not considered in the electric kart.



(a) Simulation of the eKart traction power



(b) Simulation of the eKart resistive powers

Figure 12. e-Kart Simulation

So, it was seen how the necessary battery was previously selected to ensure that the eKart had sufficient autonomy for 20 complete laps and thus complete them without any issues. That's why a 5.1 kWh battery was chosen so that the kart has enough energy to overcome both traction and resistive forces as seen in Figures 13 and 14.

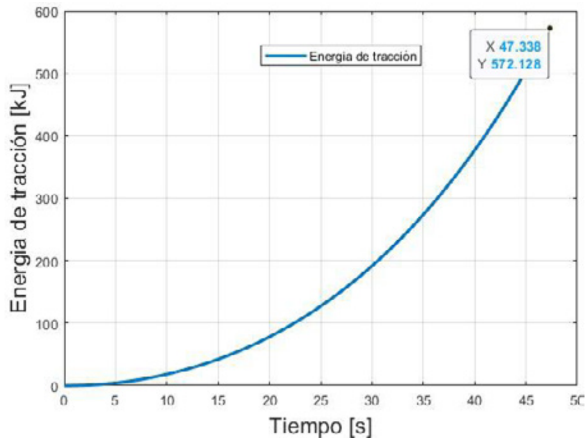


Figure 13. Simulation of the eKart Tractive energy

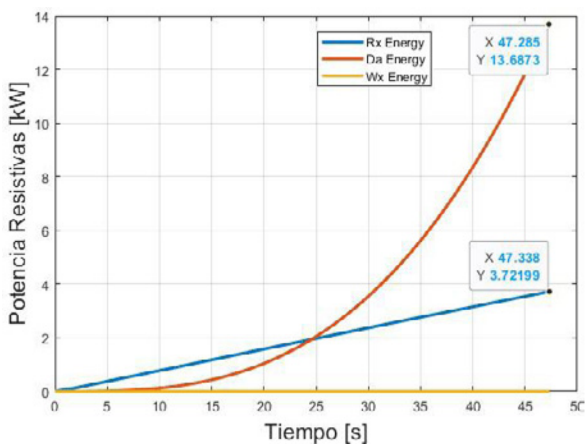


Figure 14. Simulation of the eKart resistive powers

Conclusions

Through numerical simulations conducted in MATLAB, the eKart's performance was carefully optimized with a focus on speed, range, and energy efficiency. The results show a clear improvement in the top speed, the identification of an optimal reduction ratio (NTF), and greater driving range without increasing energy consumption. These findings highlight the effectiveness of the proposed design, making it competitive with karts powered by conventional engines and opening up promising possibilities for the electrification of racing vehicles.

The computer simulations provided comprehensive insights into the startup and operation of the components comprising the electric kart propulsion system during races, where the vehicle achieves a speed of 248 km/h in merely 34 seconds. This phase was pivotal for evaluating the vehicle's performance.

The results validated the feasibility of the proposed design and provided invaluable insights for adjustments and enhancements. Furthermore, it was established that integrating the electric propulsion system into the kart does not compromise its energy performance characteristics. In other words, the electric propulsion system does not augment the total weight of the kart, ensuring compliance with the 240 kg limit stipulated for the SuperKart category.

This tool gives engineers quick access to key parameters during races, helping them make timely decisions that improve the vehicle's performance and competitiveness. It also provides valuable feedback, supporting the ongoing refinement and development of electric kart design and operation.

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