Design, Construction and Research of an Electric Unicycle with Rechargeable Flow Batteries

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Abstract — *People walk through cities in order to conduct several activities of their interest such as working, studying, going shopping and visiting their friends. This movement can be done by walking or using motor vehicles (busses, automobiles and motorcycles). Said circulation is reflected in the used space, time, energy, and economic resources, bringing negative consequences like accidents, atmospheric and acoustic contamination, and vehicular traffic congestion, which are the reason to worry that has motivated the automobile industry to develop new prototype designs based on alternative energy. The next research has like objective to design, construct and investigate the electric mobility for the development of an electric unicycle with rechargeable flow batteries. The prototype consists on an aluminium structure with a low gravity center for its balance, it has a three-phase synchronous Brushless motor with permanent magnet rotor, two lateral platforms where the user's feet are put on to move, its ergonomic seat, its battery and the gyroscopicsystem that permits self-balancing, what means the natural body´s movement is used to move. This new alternative mobility will help us to fight the environmental, acoustic contamination and in especial to not cause vehicular traffic congestion, reducing in this way the impact that it has in the nature, giving a novel and technological contribution for the society.*

Keywords — *Design, Construction, Batteries, Motor, Efficiency, Energy, Ecuador.*

I. INTRODUCTION

This Every day takes more importance to the development of the electric mobility, due to the necessity of having a system that uses sustainable energy's, allowing us to improve the displacement in relation to transportation costs, reduction of time from origin to destination, decreasing the traffic accident rate, having an appropriate personal urban transportation service, reducing vehicular traffic accident rate and the environmental contamination by reducing the usage of individual and commercial vehicles, providing a better urban image of the city taking into account important aspects like integrity level, security and the accessibility to road users.

Currently, the necessity of improving the mobility systems by the use of alternative energies like electric unicycles, requires of a long and exhaustive research process, because the availability of information about the design and the characteristics of the electric propulsion system are very limited. This restriction is presented due to its development is made by private companies through closed innovation methods and its difficult to generate a process of technological vigilance [1].

The next research has like objective to design, construct and investigate the electric mobility that is at its peak. It is well known that fundamental concepts of the electric mobility are proven technologies and in some sense mature. The topic about the batteries and KERS systems are currently matter of investigation and continuous development, because these provide competitive advantages in the market and even it can provoke a future dominant position, in a short-term panorama the electric mobility be discerned like the most appropriate option for a sustainable development.

II. METODOLOGY

A It is developed an electric mobility prototype for educational purposes given as a result “know-how” acquired by hard work after going step by step planning, analyzing and solving each one of the turned-up difficulties during the development of this Project [2].

The methodology applied beginning with the mechanical considerations for the structure and the implementation of the electric unicycle. The next process in the methodology is the calculus over a free body diagram for selecting a motor for the required necessities, taking as reference the locomotion systems that comply with classical mechanical principles, being fundamental Newton´s second law in matters of acceleration and vehicle´s displacement.

The process is the application of a three-phase synchronous “Brushless” motor with a rotor of permanent magnets, iron-silicon core and an aluminium shell. The use of this type of motors is typical for the application of electric mobility, because it shows a good torque and power curve with a reduced weight.

In the analysis of different technologies of batteries, it was selected the lithium battery due to the superior capacity of specific energy vs. mass and volume.

Finally, it was shown the results and the conclusions we got once we realized the research process.

The results of the different tests realized aim to determine the capacity of this mean of transportation in comparison to conventional means of transportation.

The different test allowed implementing feedback processes in order to perfect the design and correct mistakes.

III. DEVELOPMENT

In this part is presented each one of the shown processes in the methodology.

A. *Mechanical Considerations*

Electric Unicycle´s Structure

The design was realized in accord to the motor, because as a great advantage we have it on the same wheel (see Fig. 1)

Fig. 1 Three-phase synchronous "Brushless" motor with a rotor of permanent magnets.

The motor is an integral part of the wheel because they share the rotation axis, so the motor´s thrust is applied directly on the wheel without passing through mechanical reducers, chains or transmissions; this traction system presents an advantage of efficiency, but it creates additional stress at the specific fastening point.

This simple solution avoids the material´s fatigue and provide´s structural security to ours electric unicycle.

After defining the requirements, it was designed the structure in a way it was aesthetically pleasant, it was decided a futuristic style to the unicycle.

The design was realized by using the software SolidWorks. The design can be seen in the Fig. 2.

Final Implementation

After the specification and selection of the components more important for the development of the electric unicycle, the process of assembly was started, in which it is integrated common usage components that are necessary for conserving the basic principle of this mean of transport.

Based on this first indication, it is integrated glass fiver, a simple seat but ergonomic with its reinforced aluminium structure, adding its wheel with its electric Brushless motor, handle, and its road security headlights.

Fig. 2 Electric Unicycle´s Design by Computer (Solidworks)

B. *Mechanical Principle*

Locomotion systems comply with classic mechanical principles, being fundamental Newton´s second law in matter of acceleration and vehicle´s displacement. It was made a calculus over a free body diagram to select a motor in accord with the required necessities (see Fig. 3).

According to the manufacturer´s graphics the "Brushless" motor of 500 W with the system controller that have the gyroscopic sensors has a maximum torque of 13,38 N/m, however, in case of going up a slope, the speed is typically between 15 and 20 Km/h and the torque that comes from the motor to that operation moment is between 3 and 4,5 N/m, highlighting that at that operation moment is presented the greater energy efficiency; around 82% (Golden Motor Technology Co. Ltd., 2012).

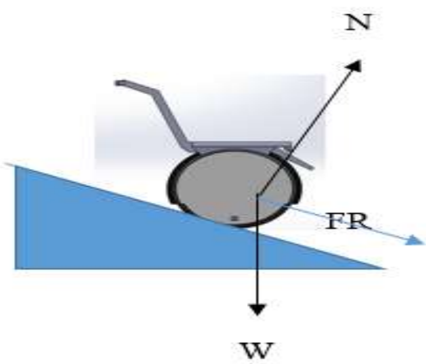

Fig. 3. Electric Unicycle´s Free Body Diagram

For the previous data, averaging the combined weight of the vehicle and the passenger of 90 Kg, an equivalent radius of the wheel of 38 cm and an approximated friction force to 10% of the thrust force produced by the engine, the unicycle can face slopes up to 7,5% without necessity of some force.

This value for the slope was chosen due to in Riobamba city there are slopes between 6 and 9%, being 7,5% a reasonable value. Besides, it must always be considered that in comparison with an electric automobile or an electric scooter; the electric unicycle is a human-machine ensemble.

C. *Motor*

Locomotion The used motor is a three-phase synchronous "Brushless" with a rotor of permanent magnets, iron-silicon core and an aluminium shell. The use of this type of motors is typical for the application of electric mobility, because it shows a good torque and power curve with a reduced weight; but its main advantage is that doesn´t have components in friction, for what it is very reliable and practically doesn´t need maintenance. In addition, it mentions that only for electric vehicles that use motors of considerable sizes would be necessary the change of refrigerant every 5 years and the oil motor every 100.000 Km, the long duration of the oil is due to the electric motor, the oil doesn´t lose its viscosity due to shearing effect and doesn´t contaminate with combustion waste either. The limiting factor is the worsening due to thermic changes and the oxidation.

Because the power source is of continuous current, it is required the use of an electronic speed control (ESC) for the functioning of the motor (see Fig. 4). ESC is in the charge of detecting the rotor´s relative position with respect to the stator by gyroscopic sensors and emulate similar sine-waves by pulsing in its Fourier Series´ decomposition.

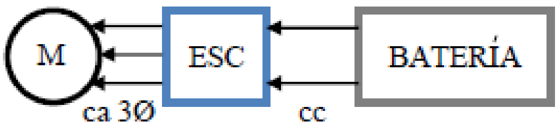

Fig. 4. Basic Block Diagram for the Motorization System.

D. *Batteries*

Battery Selection

The Batteries are a fundamental part of an independent electric system of mobility. Being the limiting factor the capacity of accumulating energy per unit of mass and volumen, this means that there is a limitation to the autonomy that is own of the vehicle (Table 1.)

It was analyzed the different battery´s technologies one by one and it was made a decision, that the best option was to equip the system by lithium batteries due to the greater capacity related to the specific density of energy vs mass and volume (Table 1.)

According to lithium technologies it was selected the lithium- phosphate technology, despite it has a lower energy density in comparison to lithium-cobalt and lithium-magnesium technologies and even it has a more expensive price that evidence an absolute superiority in matters of security, what is an fundamental aspect of the design of any mean of transport (Table 1), (A123 Systems Inc., 2011), (Sandia National Laboratories, 2006).

In addition, lithium-phosphate technology has a lifetime up to 10 times over acid lead technology (Buchmann, 2013), even having a greater lifetime in relation to the other elements that are part of the electric unicycle.

Batteries Implementation

After selecting the technology and knowing it is commercially available, it was imported 13 cells of LIFEPO4 technology for its acronym in English of Lithium Iron Phosphate Polymer, of the brand A123, with a nominal capacity of 20Ah, nominal voltage of 3,3V per cell and an energy density of 131Wh/kg [10].

In order to have a bank of 20Ah @ 38V, it was made a series of 12 cells, because the cells have an aluminium terminal and the other is made of copper for reason of their electrochemical properties that have inside the cell.

In the design was thought a glass fiver enclosure of 7 mm thick with the purpose of giving mechanical protection to the batteries and a confinement in case of an accident; it is important to emphasize that during the manipulation of the batteries is always necessary to take into account that it is accumulated energy, what is potentially dangerous.

The chosen battery has Lithium Iron Nano Phosphate patented by the brand A123 System complying with the standard EUCAR 3 [10] for penetration tests, overcharge, discharge, external and crushing short-circuit, this means that the battery can have leakage or filtration of electrolyte, but it will not ignite or explode either, only after exceeding the thermic limit of the battery it enters into thermic race and would produce smoke emissions , but it would not have flames or explosions either, reasons which it complies with the standard EUCAR 4 [10] for thermic balance test. It confirms the main advantage of this kind of batteries that is focused on security.

Batteries Test

After implementing the batteries it was realized the different charge and discharge tests in different current intensities; important data were gotten that allowed us to characterize the functioning of the battery.

In charge and discharge curves is particular the fact that the charge curve is always a bit over and in front of the discharge curve, this is due to during the charge and discharge is dissipated a bit of energy in the form of heat inside the battery (Fig. 5)

After integrating the necessary electric energy to the charge and the electric energy in the discharge, it was gotten an energy efficiency of 98,43%; this value so upper is due to the internal resistance of the battery is very low, what creates high levels of short-circuits, low looses due to a thermic power in the interior of the batteries and presents drops in voltage that are very low at the terminal, even in front of discharge of the high current demand.

It must highlight that even in levels of charge of 1C (complete charge of the battery in 1 hour) in which Joule effect must cause a bit increasing of the internal resistance, which was not appreciable, even counting with measurement equipment with a good precision.

This low internal resistance is an additional advantage of this technology in batteries.

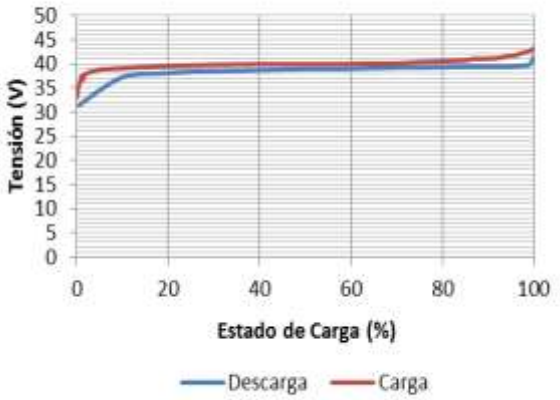

Fig. 5. Charge vs Voltage State, Charge and Discharge States.

TABLE 1. RECHARGABLE BATTERIES CHARACTERISTICS [12].

Specifications	Lead Acid	NiCd	NiMH	Li-ion Cobalt	Li-ion Manganese	Li-ion Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–190	100–135	90–120
Internal resistance (mΩ)	<100 12V pack	100–200 6V pack	200–300 6V pack	150–300 7.2V	25–75 per cell	25–50 per cell
Cycle life (80% DoD)	200–300	1000	300–500	500–1,000	500–1,000	1,000–2,000
Fast-charge time	8–16h	1h typical	2–4h	2–4h	1h or less	1h or less
Overcharge tolerance	High	Moderate	Low	Low. Cannot tolerate trickle charge		
Self-discharge/ month (room temp)	5%	20%	30%	<10%		
Cell voltage (nominal)	2V	1.2V	1.2V	3.6V	3.8V	3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75	1.00		2.50 – 3.00		2.80
Peak load current Best result	5C 0.2C	20C 1C	5C 0.5C	>3C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to °F)	–20 to 65°C (–4 to 49°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months (toping chg.)	30–60 days (discharge)	60–90 days (discharge)	Not required		
Safety requirements	Thermally stable	Thermally stable, fuse protection common		Protection circuit mandatory		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		

IV. RESULTS

A It is developed an Finished the assembling process of the electric unicycle, it was continued realizing the field tests corresponding to evaluate the performance system.

The tests protocol is the process which evaluates the electric unicycle performance in order to guarantee the optimal functioning during the circulation through different kind of roads, distances and slopes.

The protocol application has as a goal to verify the electric unicycle functioning to contribute to the mobility of people in congested and reduced urban sectors

Balance Tests.

In the Table 2, it is appreciated the initial spin angle that the electronic accelerator must travel to determine the speed of the electric unicycle comes to stabilize and reduce freely without losing the balance, the Table 2 shows the realized tests with gyroscopic sensors.

TABLE 2. BALANCE TESTS.

	Angulo posición arranque	Velocidad (Km)	Tiempo de Frenado (s)	Distancia (m)
Prueba 1	5	6	3,8	15
Prueba 2	5	5	3,3	15
Prueba 3	5	5	3,6	15
Promedio	5	5.33	3,56	15

Tests and Comparisons.

After the electric unicycle tests, it is shown the superiority of this mean of transport in relation to energy efficiency vs mean of conventional transport, even without being included improvements.

A complete charge of the battery system demands 765Wh in direct current.

The battery completely charged has the capacity of 753Wh, because the others are dissipated by heat, it makes us conclude that the charge and discharge process of the battery has an efficiency of 98,4% what is relevant. (Fig. 5).

After some tests with the batteries completely charged, it was determined that our electric motorcycle has a median autonomy of 85 Km in flat terrain. Taking into account that a gallon of gasoline has an energy capacity around 34 000 Wh [13], it is possible to compare the results in relation to the typical consumptions of an compact automobile and a small scooter (Table 3).

Analyzing the data, it was determined that the transport in the electric unicycle presents an energy efficiency very high, 2400% greater than the transport in motorcycles, and 8000% in comparison to the automobile. In spite of the impressive data, it is an expected result, because the electric unicycle mass is much lower that the thermic engines that are very inefficient due to theoretical restrictions of the Carnot´s cycle.

The electric unicycle can be seen in the Fig. 2.

TABLE 3. ENERGY COMPARISON BETWEEN MEANS OF TRANSPORT.

Medio de Transporte	Energía a ser empleada (Wh)	Energía acumulada en:	Autonomía (km)	Utilización Energética (Wh/km)
Bicicleta Eléctrica	765	Baterías 36V@20Ah	82	9,3
Motocicleta	34000	3,78 l Gasolina	150	226
Automóvil	34000	3,78 l Gasolina	45	755

V. CONCLUSIONS

The electric unicycle as mean of transport involves the design in SolidWorks, automotive engineering and electronics, even anatomic and ergonomic studies, being a practice where the work is multidisciplinary.

It was designed and constructed a mean of transport based on electric energy, easy to drive in urban zones to improve the people viability, getting a speed of 22 km/h.

It was chosen a lithium-phosphate battery to present a great lifetime (12V), with a gyroscopic sensor respectively that sends the signals to a Brushless electric motor of 500W.

The electric unicycle doesn´t contaminate, in an acoustic or atmospheric way, besides it doesn´t provoke vehicular traffic congestion, being a great, novel and technological contribution.

After the research process, development and tests in the mobility system, it is clear the width superiority in respect to efficiency, in comparison to conventional mean of transport.

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