Do electric go-karts are getting better than gas-powered ones?

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Abstract: *The paper deals with the electric go-kart performance compared to the gas-powered go-kart specifications. Few French Institutes of technology and engineers school are using the electric go-karts both considered as a teaching tool and a research platform. In order to increase the student motivation, the main objective is to participate to a yearly* pedagogical *challenge for electrical vehicles. To make students more sensitive to sustainable development and clean energy to increase their practical skills on electrical vehicles are side objectives. Since seven years an association devoted to the educational applications of electric go-karts is managing this challenge ending the academic year. Here, the paper deals on what is the best trade off for the go-kart parameters for the best performance in a given way. The first part of the paper discusses with the mechanical background of an electric engine and a gas powered engine. The second part focuses on electrical motorization of the go-kart. It details the motor, batteries and super capacitors features devoted to these machines. The last part is concerned with the instrumentation of the go-kart and draws some conclusions.*

Keywords: go-kart, ecological vehicle, project based learning, power electronics, embedded electronics, sustainable development, battery, motors, charger, transmission.

1. Introduction

The design and realization of any new manufactured vehicle needs, among others, to find a tradeoff between many parameters as power, energy consumption, weight, volume, final cost and autonomy. This is particularly sensitive for electrical vehicles. As an example an electrical go-kart is turning as a good teaching platform in order to make students more sensitive to renewable energy and sustainable development. Since 2006, a French national yearly challenge of electric go-karts takes place in a town located in the middle of France [1], [5]. About 25 prototypes are facing up to each other and show their new ideas and achievements.
This paper focuses on the power which is requested from the engine according to speed, the torque of accelerator to start quickly, various types of engines, controller, different kinds the batteries used as well as the chargers, finally the instrumentation required in order to measure all parameters in real time. As these go-karts have not neither noise disturbance nor pollution. They are more and more used for indoor races. Since 2009, most of these go-karts compete with gas-powered kartings. The section 2 deals with main mechanical parameters of gas-powered and electrical go-karts. Section 3 is more electrical oriented and discusses on motors, controller and batteries installed on these vehicles. Section 4 draws some conclusions.

2. Mechanical background of go-karts

2.1 Main Specifications of gas-powered go-karts.

The 125 cm^3 gas-powered engine installed on go-kart provides a power of 22 kw without gear box and 32 kw with a gear box. The go-karts are by definition of the machines which do not have any suspension and differential. The wheel radius is fixed to 12,5cm. The acceleration value is obtained approximately by 4.5 s to reach 50m and 6.5s for 100m. The high speed rotation at 18000 rpm involves important maintenance and wear engine. The mass of a go-kart with pilot equals approximately 170 kg. The next section details the power required to run at a given speed.

Capacity cylinder	Power max	Variable speed Gearboxes	Acccele Time (50m)	Acccele Time (100m)	Speed max	Weight (Kg)
125 cc 2 stroke	22 KW	no	4.5s	6.5s	120 km/h	120 kg
125 cc 2 stroke	32 KW	yes	4 s	5.9	150 km/h	100 kg
390 cc 4 stroke	11 KW	no	7.5 s	10.4	100 km/h	140 kg

2.2 Power in steady state speed

In the steady state speed, the resistive power depends on the kind of tire, on the road surface on the track slope, but mainly on the air frictions.

$$F_{resistive}(N) = F_{Road} + F_P + F_A \qquad (1)$$

$$F_P(N) = M(kg) \cdot g \cdot slope(\%) \quad \text{with } g=9.81 \qquad (2)$$

$$F_A(N) = f_a \cdot [V(Km/h) + V_{wind}]^2 \qquad (3)$$

The main resistive force is due to the air resistance. The power needed can be observed in a speed steady state on figure 1.

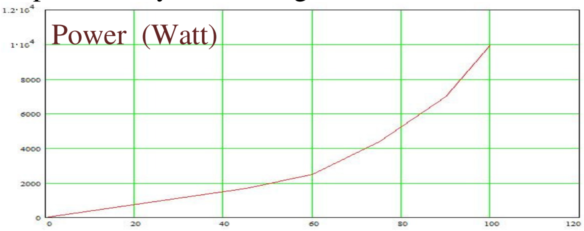

Figure 1: Motive power vs speed [M=200kg, f_a=0,01 N/(m.s^{-1})^2]

The next section is discussing on the acceleration torque the go-kart should have?

2.3 Torque acceleration

An electric go-kart is heavier than a gas-powered one. Its mass with pilot equals 250 kg. To reach the 100 km/h speed within 4 s, the engine

The torque required by the engine depends on the value of the speed reduction thus the choice of the maximum speed. Therefore, a compromise must be found between the maximum speed (6) and the acceleration torque (5) that can feed the controller.

$$T_{motor} = (F_{wheel} \cdot radius) \cdot Gear \qquad (5)$$

$$V_{max}(m/s) = N_{max\ motor} \cdot 2 \cdot \pi \cdot radius \cdot Gear / 60$$

It is the choice of the transmission type that gives priority to the acceleration torque or maximum speed. This is discussed on the following.

Acceleration torque has to be higher than the value given by the following equation (4):

$$F_{wheel} = M\frac{dv}{dt} + F_{Resistive} = 1250N + F_{Resistive} \qquad (4)$$

2.4 Transmission

The maximum speed value of electrical motors equals approximately 5000 rpm. Therefore, a speed reducer between the engine and the drive shaft is used to fit the go-kart speed. That gives a better acceleration torque. Some notched belts are used between the engine and the transmission shaft. But given the high value of the acceleration torque, the notched belt strain is getting higher to prevent from jumping. This implies important losses. To free from the notched belts the chain transmissions are used now.

The table 1 shows two types of transmission pulleys and with a twin motorized go-kart whose upper bound controller current equals 200 A. The 2 engine constant torques equal 0,164 N.m/A. They supply 65 N.m as maximum engine torque.

The table 1 indicates the maximum speed, the mass inertia moments occurring on the shaft the time to reach 50m and 100 km/h, as well as the current in a steady state speed.

The reduction speed for a go-kart to reach any distance in a minimum time is given by the following equation (7):

$$Gear = \left[Dis\tan ce \cdot \frac{(Torque_{motor} - Torque_{load})}{N^2 \cdot (\frac{2 \cdot \pi}{60})^2 \cdot radius^3 \cdot Mass} \right]^{\frac{1}{3}}$$

The load torque is neglected by reference to the starting torque in order to lighten the calculation. A reduction gear ratio of 13/44 is required for an indoor go-kart running on 50 meters maximum straight tracks. In order to optimize the transmission according to the track, a gear box should install on the machine. The table 1 and the figure 2 show the acceleration and the steady state of the engine for a reduction ratio equal to 17/44.

Table 1 : motors specifications vs the reduction gear ratio

U_{batt}	I_{limit} motor	Reduction Gear Ratio	Inertia kg.m^2	V_{max} (km/h)	t(s) V=100km/h	t(s) 50m	I (A) ST battery
96V	200A*2	25/44	1.26	150	11.8	5.3	340A
96V	200A*2	17/44	0.58	100	5.3	4.4	100A

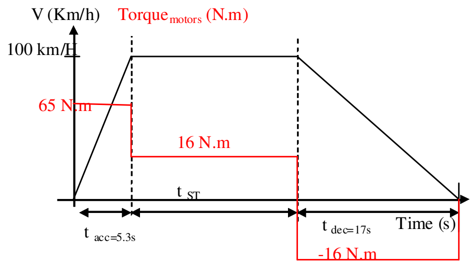

Fig 2 : motor torque and speed on a loading bench with a 17/44 reduction ratio

Depending on the parameter settings, the limitation current and the number of Depending on the parameter settings, the limitation current and the number of accelerations, the engine will heat. Thus, the gas-powered equivalent current of the motor is determined during a working sequence that is a lap by the following equation:

$$I_{m\ equ} = \sqrt{\frac{\sum_{i=1}^{n} (I_n)^2 \cdot t_i}{\sum_{i=1}^{n} \cdot t_i}} = \quad (8)$$

The gas-powered current equivalent must be lower than the rated current of the engine.

The repeated accelerations due to corner of the track can destroy the engine because of the motor current getting higher than rated current. Moreover, all the motorizations need forced ventilation which consumes from 100W up to 1000W. The next part is concerned with the different kinds of controller.

3. On electrical motorization

3.1 Types of motor and controller

The table 2 shows three types of electrical motors. The D.C. motors are mostly associated with a convertor switcher that limits the starting current. As the sizes of these motors and controller are small, it is possible to put 2 motors on the same drive shaft that sums the torque values consequently. Two controllers are often used. They allow the motors to supply the same torque by control the acceleration set point slightly. The following curve shows the voltage and the current of a twin engine go-kart versus time.

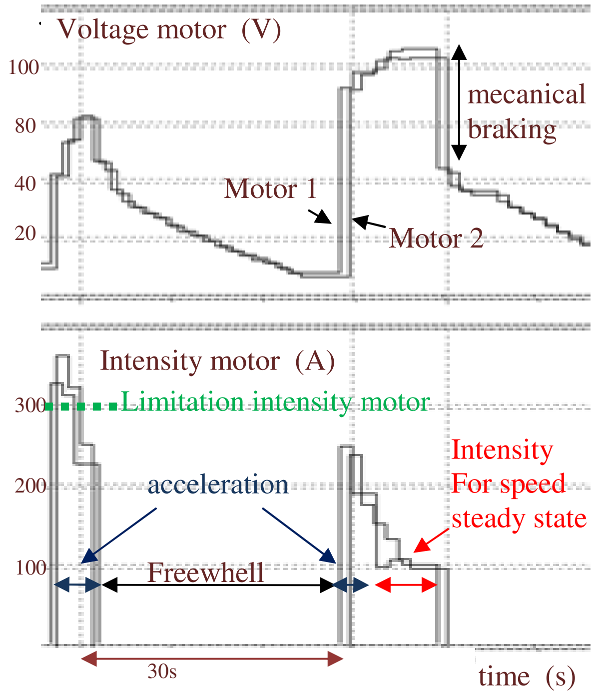

Fig 4 : Voltage et intensity for 2 moteurs brush DC 28 kW nominal

As shown on figure 4 the two engines roughly absorb the same currents so the controller are well settled.

The outrunner brushless motors free more room than the classical D.C. motors. They do not need brushes maintenance. On the opposite, the controller is a little bit more complicated to realize than a chopper. Indeed, it is a 3-phase inverter which feeds the coils depending on a position sensor of the rotor. In that brushless background, a twin-engine go-kart is now testing on a bench. On the other hand, the asynchronous motor and its controller take too much room that makes impossible the installation of two motors.

The asynchronous motor is controlled to the flux oriented vector. The flux oriented vector allows the maximum torque at start and retains the vehicle at null speed without using the zero-current brakes. The asynchronous motor with its index of protection IP 55 is ideal for the hiring of go-kart.

All the controller can feed back energy to the batteries. To prevent batteries from destruction, it is necessary to check the energy received. The next section focuses on batteries specifications.

Tableau 2. Different kinds of electrical motors

Kinds of motor	voltage max	I_{nom} (A)	I_{max} (A)	P_{mot} (kW)	Weight (kg)	Long*Ø & volume cm^3	Price 2012	N_{max} (Rpm)	IP
DC with brush	96V	145	400	14	11	11*20 => 690	1600€	4000	22
Brushless DC	48V	300	400	15	2	8.5*11 => 290	1300€	8000	22
Asynchronous	28V	150	300	10	20	30*18 => 1700	1500€	4500	55

3.2 Battery

The basic equipment for electric karts includes 4 lead-acid batteries with a motor of 10 kW, the autonomy is 10 to 15 minutes [4].
The voltage of two motors prototypes requiring 54 kW at start and only 10kW to 30kW as normal rated power went from 48V to 72V and now 96V in order to decrease the current supplied by the batteries.

Fig 5 : 2 motors go-karts with normal rated power 28kW. 48V lead-acid(left) and 96V LiPo (right) e-kart challenge 2011.

The go-karts on figure 5 carry the same twin motorization with two different types of batteries. The weight on the go-kart equipped with a LiFeYPO4 accumulator is divided by 2 while the autonomy is multiplied by 4 that represents approximately 40 minutes.
For the moment, no prototype is equipped of a 400V battery with 100 elements of 20 A.H for 5000€ cost that allows to use industrial controller but a study is on the way [3].
The major trouble occurs when only one battery element is getting wrong. That badly decreases the autonomy.
The table 3 shows that an important rate of discharge provokes a battery price raising and cuts down the battery life. 30% of the price of a go-kart corresponds to the accumulator price. The table also gives the specifications of different types of batteries.

kinds of battery	Size & Volume dm^3	Mass kg	Price 2011	charge rate max	discharge rate max
Plomb 6S 72V 20A.H	60 dm^3	140 kg	1600 €	100 A=5C	400 A
Lipofer 90A.H 28S 96V	220*145*61=40 dm^3	60 kg	2800 €	90A=1C	300A = 3C
Li-po 100A.H 25S 96V	35 dm^3	55 kg	**6000 €**	100A=1C	500A = 5 C
Supercondo 72V 94F 30S	515*263*220=30 dm^3	25 kg	4500 €	**800 A**	**800 A**

Table 3 : specifications of batteries

Chargers
With 1C charge rate of battery, the chargers are charging up to 80% the batteries within 1 hour. The lead-acid battery chargers are easy to realize. Their threshold voltage must be limited up to 14.4V for gel Yellow Optima batteries in order to minimize the gas emissions. Their charging current must be upward bound to prevent the battery from destruction [2].
For the Li-Po accumulators, the charging current must also be saturated. And the threshold voltage of each element does not be overtaken. The Battery Management Sytem –BMS- voltage carries out the voltage supervision. The current decreases for the threshold voltage of each element not do overtake. The figure 6 shows the charging current as well as the voltage of each element vs time.

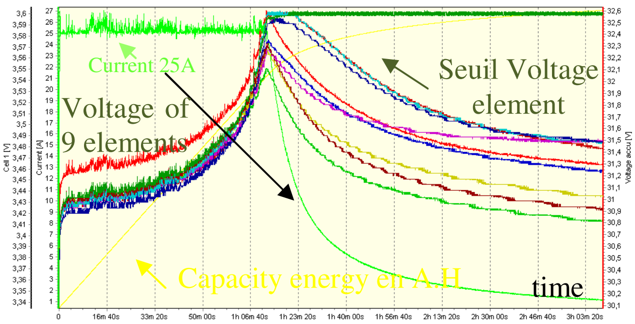

Fig 6 : battery charge of 9 ements li po fer.

As one element is charge up to the 3.7V threshold voltage (100%), all the other elements are unbalanced. Therefore, each element should be charged independently to obtain a 100% charge.
The number of battery elements requires for each one independent charger with a current equal to 1/10 as the loading rate.
As this solution is rather expensive, many manufacturers propose stabilizers with resistor

that deflects the charging current of full charged elements.

If the batteries Li Po are full charged, the regeneration will not be possible without lead some elements to destruction.

The table 3 shows that the discharge rate of the batteries is low wrt to the maximum current supported by the motors.

Thus, a super capacitor can be used to provide the impulse starting current.

3.3 On super capacitors

During the accelerations phases, all vehicles need high power in a short time. Using chemical batteries the electro conversion takes a response time delay to give back this current. The electrical energy inside super capacitors is stocked in an electrostatic form by an accumulation of ionic charges on the interface electrode/electrolyte. The super capacitors have a high power but a low energy compared to the batteries. The super capacitors offer high number of charge/discharge cycles about 1000 times more than a battery. The super capacitor voltage equals to 2.7V is relatively low. And many of them should be connected in series to feed an electrical vehicle. And it is necessary to manage the charge, the discharge and the balance of super capacitors.

The power converters must limit the input and output currents of the batteries or super capacitors. These converters must also monitor and limit the maximum voltage of each battery element. One answer is that the battery and the super capacitors provide energy to a continuous bus DC via two current half bridge converters (chopper 1 and chopper 2). This continuous bus allows feed the motor controller. In order to ease the choppers command, this bus stands for a voltage regulation.

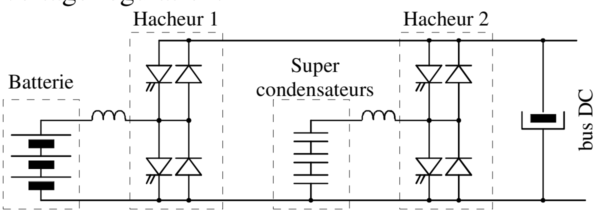

Figure 5 : Power supply of a continuous bus by super capacitor and battery.

The two converters switchers have to adjust the voltage levels of the elements.

Moreover for the super capacitors, the voltage variation (V) linked to the variation of energy ΔW given by the following equation:

$$\Delta W_{(Joule)} = \frac{1}{2} C_{SC} \left(V_{max}^2 - V_{min}^2 \right) \qquad (9)$$

The two choppers command basis consists in maintaining the bus DC voltage at a constant value that will feed the reversible controller of the vehicle.

In order to extract 90% of the maximum energy stored in the super capacitors, it is necessary that:

$$V_{min} = \frac{1}{3} V_{max} \qquad (10)$$

Sizing the super capacitor needs to know what is the maximum power. In case of discharge at a constant power, the maximum power is

$$P_{max} = V_{min}\ I_{SC\_max} = F_{max}\ Vitesse_{max} =$$

$$\Delta W = \frac{1}{2} C_{SC} \left(V_{max}^2 - \left(\frac{P_{max}}{I_{SC\_max}} \right)^2 \right) \qquad (11)$$

Thus, the maximum power will establish the acceleration.

A good compromise sets the maximum power equal nearly to the nominal output power during a dozen of seconds for the acceleration doubles. Thus, the super capacitors supply a current value close to the batteries ones in the acceleration peak demand.

Given a 2 motors go-kart able to take over 600 A at start. Using the 67 W.H super capacitor on table 3 with a 72V battery voltage and a 2*28kW power giving a 266A discharge current for super capacitors and a 266A discharge current for batteries with 24V as the minimum voltage, the effective energy equals 60W.H and the discharge time is given by

$$t(s) = \frac{3600 \cdot \Delta W_{(W.h)}}{V_{BusDC} \cdot I_{busDC}} = \frac{3600 \cdot 60}{72 \cdot 266} = 11s$$

At the end of the discharge, the super capacitors have to supply the current given by the following equation:

$$I_{SC} max = \frac{V_{BusDC} \cdot I_{busDC}}{V_{min}} = \frac{72 \cdot 266}{24} = 800A$$

As the volume price of super capacitors are important, the experimentation has carried out only on electric bicycles.

But two troubles on the vehicle behavior are due to the super capacitor management. First, the acceleration is decreasing if the super capacitors are empty. Second, if the super capacitors are full, the electric brake system will not work.

Note: As the batteries enable more power in a given then the super capacitors are not use full anymore.

Moreover since a couple of years, the manufacturers are offer lithium batteries rates of discharge rates equal to 15C.

It is also possible to mount two batteries elements in parallel to double the output current.

Keeping in mind that an element in short-circuit will destroy the parallel element.

All running parameters of batteries, super capacitors and motors can be checked in real time using an embedded instrumentation.

4. Instrumentation and conclusion

4.1 Instrumentation

The basic embedded instrumentation should offer to check the performance of the prototypes and to monitoring the parameter settings in real time.

The controllers are heating protected thanks to the current measurement.

But, the motors are protected only by internal temperature measurement. It is difficult to measure the engine cooling indeed.

The voltage of each battery element is permanently monitored to know when an element is damaged due to its high internal resistance or when the energy fails. The instrumentation takes account of the current battery to know the energy consumption and to compare it with the recharge energy.

All parameters are obtained by wireless communications with PC on stands and in a real time that allows to adjust the controller with accuracy.

4.2 Conclusion

The go-kart as a teaching support is used in technical field activity as electrical engineering or mechanical engineering and also in theoretical field activity as physics and mathematics. The use of this teaching support is also adequate with the syllabus of undergraduate students and bachelor of technology students. The go-kart teaching tool turns all mechanical parameters such as forces and powers into their electrical analogy representation. The go-kart allows understanding some facts.

The technical choice of these prototypes can be found on all types of electrical vehicles. Many compromises should be done to obtain the right technical choice. As an important parameter, the weight of a go-kart without pilot is chosen equal to 200kg.

The prototypes are mainly built by students in different institutes of technology and engineers schools. Some electrical go-kart manufacturers of are also selling their vehicle to rental companies.

A reliable prototype built in one or two academic years is sometimes difficult for students who have also to manage a budget. The cost of go-kart prototypes is of 4000 at 8000 Euros range depending on the technology used. That is the price of a competition go-kart. The energy consumption cost for an electrical go-kart is five times less than the gas-powered one.

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