Making an Electric Micro car

Physics Project

Gautam Krishnan

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Abstract

An electric micro car is a small car specifically suited for city use. This project aims to explain the underlying principles on which a car, and more specifically an electric micro car, is built. After this, an electric micro car will also be made.

Introduction

A micro car is a small car that seats 1-2 people. It is a personal commute vehicle, usually having 3 or 4 wheels. A conventional micro car is powered by an internal combustion engine that has a capacity of less than 700cc.

The advantage of an electric car is that there are fewer moving parts, which make the car light and require less maintenance. An electric car does not need a gear box because the electric motor has high RPM and torque. It does not need a differential (for 1 type of configuration). Neither does it need an alternator nor a radiator.

These absent components significantly reduce the weight of the vehicle, hence increasing the efficiency. Moreover, they do not have to be serviced or maintained.

In all, the electric car is much lighter than a conventional internal combustion engine car. The size and characteristics of micro cars are best suited to be electric.

The following sections discuss the various aspects of making an electric micro car.

Theoretical Considerations

Forces

There are two important forces acting on a moving vehicle that oppose its motion:

1) **Aerodynamic Drag** – This is resistance offered by the atmosphere on the vehicle. It depends on the air density (ρ), reference area (A), and the square of the velocity (v^2). Therefore,

$$F_D \propto \rho A v^2$$

$$F_D = \frac{1}{2}\rho A C_D v^2$$

Where C_D is a constant of proportionality, called the drag coefficient. It is determined experimentally and depends on the shape of the reference area.

It has been found experimentally that a streamlined body (shape of a raindrop) has a lower value of C_D than most other bodies. The list in ascending order of C_D is given below:

Rain drop < **Half rain drop** < **Half sphere** < **Sphere** < **Cone** < **Angled cube** < **Long cylinder** < **Cube** < **Short cylinder**

2) **Friction** – This is the resistance offered by the ground on the tyres. It is given by the following equation:

$$F = \mu N$$

$$F = \mu mg, beacuse\ N = mg$$

Where μ is the coefficient of friction, N is the normal force, m is the mass and g is the acceleration due to gravity.

Work

Work is said to be done when a force causes a displacement in its own direction:

$$W = F \cdot s = Fs\cos\theta$$

Where W is the work done (or obtained), F is the force applied, s is the displacement and θ is the angle between the force and displacement.

This definition is used for mechanical work.

For potential difference, current and charge, another definition can be derived:

$$W = VQ = V(It) = VIt$$

Where V is the voltage (potential difference), Q is the charge, 'I' is the current and t is the time interval.

Power

Power is defined as the rate of doing work or the rate of energy expenditure.

$$\bar{P} = \frac{W}{t}$$

Where $\bar{P}$ is the average power, W is the work done and t is the time interval. Finding work done is, however, not easy in all cases. Therefore, power can be rewritten as follows:

$$\bar{P} = \frac{W}{t} = \frac{F \cdot s}{t} = F \cdot \frac{s}{t} = F \cdot v$$

This definition of power is very useful as force can be calculated and velocity can be fixed (or assumed).

Based on the second definition of work, power can also be defined as follows.

$$\bar{P} = \frac{W}{t} = \frac{VQ}{t} = VI$$

Where V is the voltage, Q is the charge, t is the time period and 'I' is the current.

Torque

Torque (moment of force) is the turning force an object experiences. It is defined as the cross product of force and the perpendicular distance:

$$\tau = F \times r = Fr\sin\theta$$

Torque can also be derived from power:

$$\bar{P} = \tau\omega \Rightarrow \tau = \frac{\bar{P}}{\omega}$$

Where ω is the angular velocity.

$$\omega = \frac{v}{r} = \frac{RPM}{60} * \frac{2\pi}{r}$$

Research

An electric car can be viewed as a part-by-part replacement of an internal combustion engine car. However, some parts will be common, or even same.

The Motor

The motor is the replacement of the internal combustion engine in an electric vehicle. It is what propels the car. The single biggest advantage of an electric vehicle is that the whole engine, which consists of various subparts, is replaced by a single component – the electric motor. This significantly reduces cost, weight and maintenance of the vehicle.

There are various types of electric motors. Before looking at the type, the characteristics best suited for an electric micro car must be looked at. These are given below:

- **Efficiency and Maintenance –** This is one of the most important factors. The higher the efficiency and lower the maintenance, the better suited the motor is.
- **Weight and Size** – The lower the weight and smaller the size, the better is it for a micro car. If the weight is less, the efficiency of the car-motor system will be more.
- **Torque and RPM** – Generally, as RPM increases, torque decreases. A motor that has an optimum balance of both torque and RPM should be chosen.

- **Availability**
- **Price**

A brief description of each of the prominent motors is given below:

1) **Brushed Direct Current (DC) Motors** – These motors use carbon brushes to conduct electricity into the rotor. These motors are manually commutated. They are bulky and heavy. However, they are cheap.
   The cost of maintenance is quite high, as one has to replace the carbon brushes several times (due to wear and tear-Friction).
2) **Brushless DC Motors (BLDC Motors)** – These motors use a Hall sensor or Back EMF (electromotive force) for commutation. Hence, commutation is electronic. The Back EMF is trapezoidal. They have higher efficiency than brushed DC motors. They have high torque and RPM (revolutions per minute). They are quite compact and relatively cheap. However, they suffer from torque ripple.
3) **Permanent Magnet Synchronous Motors (PMSM Motors)** – These motors have extremely high efficiency. They have no torque ripple, are commutated electronically and have sinusoidal Back EMF. They are light and compact. They need very low maintenance. However, they are expensive to procure.

4) **Alternating Current (AC) Motors** – These motors are cheap and require low maintenance. However, they require complex commutation. They need AC current, which is only possible through a DC-AC converter. They have overall high efficiency, but are not available in India.

Each of the mentioned motors can either be air cooled or liquid cooled. Liquid cooled motors generally have better performance than their air cooled counterparts.

The BLDC motor seemed to suit the required parameters for a small, not-too-expensive micro car. However, if one wants a higher efficient car, the PMSM would be ideal. For the purpose of this project, the BLDC motor will be used.

The Motor Controller

This is a crucial component of any electric vehicle. The BLDC motor, as mentioned earlier, is electronically commutated. This is the motor controller's primary function. Using Back EMF and Pulse Width Modulation (PWM), the controller supplies current to the relevant *phase* of the motor. This is how the controller achieves commutation. Commutation is necessary for acceleration.

The motor controller receives the trapezoidal Back EMF of the BLDC motor, and supplies current to it in such a way that the resulting Back EMF is harmonic ,i.e., sinusoidal.

The electric motor has an interesting and useful property. As voltage is increased, the speed or RPM increases. Similarly, as the amperage is increased, the torque increases. This is the principle used by the motor controller to increase or decrease the speed or torque.

The motor controller must have appropriate amperage, both for the motor and the battery pack.

The motor controller can also be programmed to perform secondary functions like regenerative braking and cruise control.

Regenerative braking is the conversion of kinetic energy (from motion) back to electricity (Potential energy). As this conversion happens, the motor acts like a generator, and some energy is reutilized, instead of getting dissipated in the form of thermal energy in the brake pads. This process is also beneficial to the brake pads, which will wear out less.

An alternative to the motor controller is the Hall sensor. A hall sensor is attached to the motor, and it senses the magnitude of magnetic field produced and the rotor position, and accordingly supplies current to it. However, this is not a very nice way to commutate. This method only approximates the rotor position. Moreover, it cannot perform the various secondary functions that a motor controller can.

The Battery

The battery is analogous to the fuel tank of an internal combustion engine. It consists of a number of cells.

Once again, like motors, there are various types of batteries. Before looking at the types of batteries, the best suited characteristics should be looked at. These are given below:

- **Specific Charge** – It is the ratio of the mass of the battery to its mass. A battery with high specific charge is best suited for any car. Due to its small size, a micro car will need a compact battery which can provide optimal energy.
- **Charge Density** – It is the concentration of charge per unit volume. The same argument is true for charge density – higher the charge density, better the battery.
- **Battery Capacity** – The amount of energy batteries can store or the amount of work they can do. In an ideal scenario, the two are the same. In reality, all the energy stored cannot be used.
- **Depth of Discharge** – Batteries can charge to 100%, but all of that cannot be used. Higher the depth of discharge, more the energy that can be used.
- **Amperage** – It is the amount of current a battery can supply in unit time.
- **Ampere-hours** – It is the amount of charge a battery can store.

- **Price**

  The types of batteries are as follows:

  1) **Lead Acid Battery** – It is one of the cheapest batteries. However, it has relatively low specific charge, charge density and depth of discharge. It is quite heavy and has a relatively short life.
  2) **Lithium Ion Batteries** – There are various types of Lithium Ion batteries. They generally have high specific charge, charge density and depth of discharge. They have a long life of more than 10,000 cycles. However, they are quite expensive.
  3) **Nickel Metal Hydride Batteries (NiM_xH_y) –** They are cheaper than Lithium Ion batteries, but more expensive than Lead Acid batteries. They have unusually high charge densities. However, other factors are similar to Lead Acid batteries. They are not widely available because of patent rights.
  4) There are other types of batteries like Nickel Cadmium (NiCd), Zinc Bromide ($ZnBr_2$) flow, Sodium Nickel Chloride (NaNiCl), and Zinc air batteries. However, they are not as efficient as the above mentioned batteries.

The Lithium Ion battery seemed the best fit for a micro car. The following will use the Lithium Ion battery for theory and calculations.

A battery pack usually comes with a battery management system (BMS), which is responsible for indicating when the battery is fully charged, is going to discharge, or is becoming too hot.

The configuration

A micro car must be light and compact. Any electric vehicle is powered by an electric motor. In general, electric motors have very high RPMs. Therefore, unlike an internal combustion engine, they do not need a gearbox. This further reduces the weight of the car and reduces maintenance.

The fewer the number of moving parts in a vehicle, less is the maintenance.

If the car is to have 4 wheels, it will also need a differential. A differential adds to the weight and complexity of the car. Therefore, to avoid using a differential, a 3-wheel configuration can be used. A 3-wheel configuration will also decrease weight due to the 4th wheel. This is described below:

1) **Delta Configuration** – 1 wheel forward and 2 wheels in the rear. This configuration is easier to manoeuvre (steer), but is less stable and has more aerodynamic drag. The braking, especially at turns, is unstable. It is safe only at low speeds. This configuration needs a differential for the rear 2 wheels. Auto rickshaws typically use this configuration.

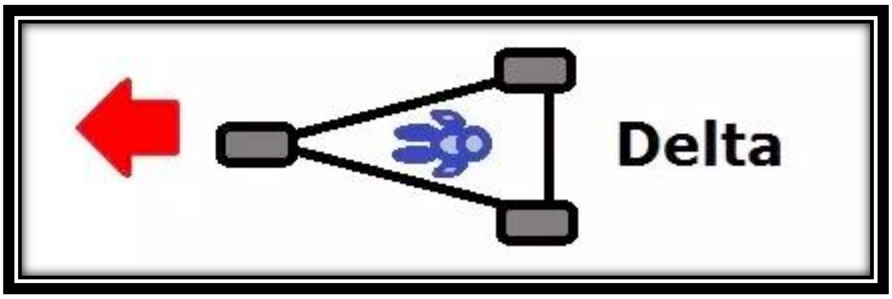

Figure 1

2) **Tadpole Configuration** – 2 wheels forward and 1 in the rear. This configuration is much more stable, has less aerodynamic drag, and has increased braking stability. It is easier to power, as the motor is connected to only one wheel in the rear.

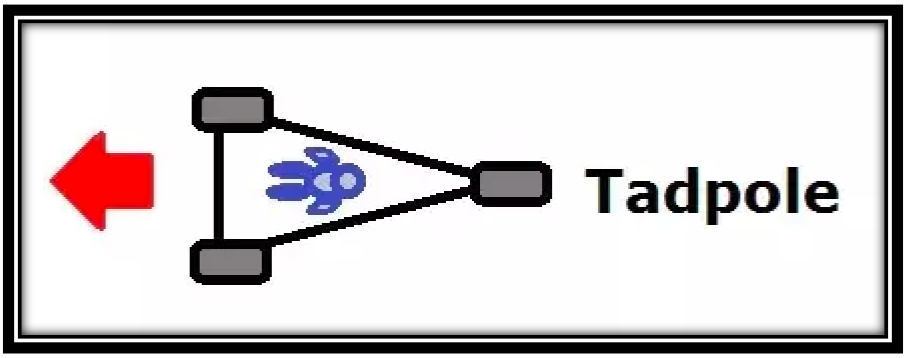

Figure 2

The tadpole is the safer 3-wheeled configuration. The discussions below will use this configuration.

The Suspension System

The suspension is comprised of a spring and a damper (or shock absorber). The spring reduces the "bumps" felt, and the shock absorber dissipates the energy absorbed by the spring in the form of heat. The 3-wheeled configuration calls for a different suspension in the front and back.

There are 2 popular front suspensions:

1) **The Macpherson Strut suspension** – Mainly used for small cars. It has a spring and inbuilt damper. It is built in such a way that helps in easy steering. It is cheap, light and easy to maintain. One limitation is the presence of "Camber angle" (an angle that is present between the tyre and the road to the perpendicular).
2) **Double Wishbone or Double A-Arm suspension** – It is relatively heavy and expensive, but takes care of the camber angle. It is better for heavy and fast vehicles.

The Macpherson Strut suspension is good enough for a micro car that will not exceed a speed of 70 Km/h.

The rear suspension can be one that is used in motorcycles or 2-wheelers:

1) **Mono Shock Absorbing suspension** – It is used for lighter and faster 2-wheelers. It is expensive.
2) **Dual Shock Absorbing suspension** – Used for heavier and slower vehicles. It is cheap and easy to maintain. It is more robust and can withstand more weight (than a typical motorcycle).

For the single rear wheel, the Dual Shock absorbing suspension is better suited.

Braking System

While regenerative braking can provide braking in many situations, in sudden braking a conventional braking system is required. A conventional braking system uses friction to dissipate kinetic energy in the form of heat. When the brake pedal is pressed, hydraulic or brake fluid is released which makes the brake pads touch the disc or drum.

There are 2 types of brakes:

1) **Disc Brakes** – These brakes use a “disc”. The brake pads go and rub against the disc from the outside. They are highly efficient.
2) **Drum Brakes** - These brakes use a “drum”. The brake pads go and rub against the drum from the inside, by touching the circumference of the drum. They are less efficient than disc brakes, but are cheaper.

Parametric Assessments

Motor Power

Power = $P = F \cdot v$

Where F = force, v = velocity.

For calculating the motor power, the force is that which is needed to propel the car and the velocity is the maximum velocity at which the car will travel.

Force

Force to propel the vehicle is the sum of the following forces:

1) Force to overcome friction (Rolling resistance) – This is equal to the force offered by friction:

$$F = \mu mg$$

Where μ = coefficient of friction, m = mass of car, g = acceleration due to gravity = 9.8m/s^2.

For the mass of the car, a rough estimate must be used. The coefficient of friction, $\mu \approx 0.04$ for rubber and tar (what roads are made of). Assuming m = 400 kg:

$$F = 0.04 \times 400 \times 9.8$$
$$= 156.8 \text{ N}$$

2) Force to overcome Aerodynamic drag – This is equal to the resistance offered by air. It is given by the equation:

$$F_D = \frac{1}{2}\rho A C_D v^2$$

Where ρ = Air density $\approx$ 1.29 kg/m^3,

A = reference Area,

C_D = Drag coefficient,$0.04 \leq C_D \leq 1.15$,

v = velocity of the car.

For A, an approximate of the front area of the car must be taken.

Assuming Width = 1m, Height = 1.5m, A = 1.5 m^2,

v = max velocity = 65 km/h = 65*(5/18) m/s,

Assuming$C_D \approx 0.6$,

$$F_D = \frac{1}{2}(1.29)(1.5)(0.6)\left(65 \times \frac{5}{18}\right)^2$$
$$\approx 189.2448 \text{ N}$$

3) Force to propel vehicle in absence of dissipative forces

– This is just the product of the mass and acceleration

Over here it is assumed that acceleration = a = 1m/s^2:

F = ma

= 400×1

= 400 N

Therefore, total force = sum of forces

= 156.8 + 189.2448 + 400

= 746.045 N

Power

Power =

$$P = 746.045 \times \left(65 \times \frac{5}{18}\right)$$

P = 13,470.26 W

≈ 13.47 kW

This is the power of the motor. However, this is quite large for a micro car. Therefore, a permanent step down gear ratio can be used to reduce the power of the motor. It will also reduce the RPM.

Using a 1:3 gear ratio:

P = 13.47/3

$\approx$ 4.490kW

For the purpose of procuring a motor, a 5kW motor can be used (Round up to nearest kW).

Battery Capacity

Batteries come of various voltages, and so differ in the amount of "Ah" or Ampere-hours they store. For a given desired range, however, all batteries will have the same capacity. The capacity is calculated in the following fashion. Note, the below calculations are only for Lithium Ion Batteries.

Watt Hours/km = Power (in watts)/Velocity

= 4490/65

≈69.1 Wh/km = 69.1 VAh/km [1 Wh = 1VAh]

Using this, a table can be made for the various voltages. It is assumed that the range is 100 km (Range = R).

Voltage	V	36	48	60	72	144
Ah/km	(Wh/km)/V	69.1/36 ≈ 1.9	69.1/48 ≈ 1.4	69.1/60 ≈ 1.2	69.1/72≈ 1	69.1/144 ≈ 0.5
Ah (80% efficiency)	(Ah/km)*R/(80%)	1.9* 100/0.8 ≈ 239.9	1.4* 100/0.8 ≈ 179.9	1.2* 100/0.8 ≈ 143.9	1* 100/0.8 ≈ 119.9	0.5 * 100/0.8 ≈ 60.0
Ah for Li Ion	Ah * 1.05	239.9*1.05 ≈ 251.8	179.9*1.05 ≈ 188.9	143.9*1.05 ≈ 151.1	119.9*1.05 ≈ 125.9	60.0 * 1.05 ≈ 63.0
Wh	(Ah for Li Ion) * V	251.8 * 36 ≈ 9066	188.9 * 48 ≈ 9066	151.1 * 60 ≈ 9066	125.9 * 72 ≈ 9066	63.0 * 144 ≈ 9066
kWh	Wh/1000	9066/1000 ≈ 9.1	9066/1000 ≈ 9.1	9066/1000 ≈ 9.1	9066/1000 ≈ 9.1	9066/1000 ≈ 9.1

As is seen from the table, the Capacity or the kWh is not different for different voltages. In the 3rd row of the table, 80% efficiency is assumed. This assumption can be made for any battery. However, in the 4th row, the Ah is multiplied by 1.05. This is an approximation. The Lithium Ion battery can only supply about 95% of its mentioned capacity (1/95% ≈1.05).

By increasing the voltage, the amount of Ah can be reduced. For the case of the micro car, a 48V battery was chosen.

RPM (Revolutions per Minute)

RPM can be calculated as follows:

Wheel Radius = 10 inches = 10*0.0254 m [Assumed]

Distance travelled in 1 hour = Velocity = (65×1000) m

Distance travelled in 1 minute = $(65 \times 1000)/60$ m

Circumference of wheel = linear distance travelled per rotation =

$2\pi r = 2\pi*(10*0.0254)$ m

RPM = Distance travelled in 1 minute / linear distance travelled per rotation =

$[(65 \times 1000)/60] / [2\pi*(10*0.0254)]$

≈ 679 RPM

Torque

Output Power = Torque × Angular Velocity

Torque = Output Power/Angular Velocity

For calculating torque, angular velocity is first calculated.

Angular velocity = ω = velocity/radius

$$= \frac{65\times\frac{5}{18}}{10\times0.0254}$$

= 71.085 rad/s

Output power = Input Power × Efficiency

= 4490 × 80%

= 3592 W

Therefore, torque =

3592/71.085

≈50.53 newton-metres

Calculation Summary

The summary of all the calculations is given in the below

Assumed	
Max Vel(km/h)	65
Gear Ratio	3
Mass (kg)	400
Length (m)	2.5
Width (m)	1
Height (m)	1.5
Wheel Radius (inches)	10
Acceleration (m/s^2)	1
Desired Range (km)	100
Efficiency of Battery	80%
Linear Distance (m)	1.596
RPM	678.8
Angular Velocity (rad/s)	71.08
Output Power (W)	3592
Torque (Nm)	50.53

Forces					
F_1	Air Resistance	Coefficient of Drag = 0.6	189.24479		
F_2	Rolling Friction	Coefficient of Friction = 0.04	156.8		
F_3	Force for Proulsion		400		
Total Force = $F_1 + F_2 + F_3$ (N)			746.04479		
Power (Watts)	13470.25				
Power (kW)	13.47				
Power of Motor (with gear ratio)	4.490				
Watt-hour/km	69.1				
Battery Capacity					
Voltage	36	48	60	72	144
Ah/km	1.9	1.4	1.2	1.0	0.5
Ah (80% Efficiency)	239.9	179.9	143.9	119.9	60.0
Ah for Li Ion	251.8	188.9	151.1	125.9	63.0
Wh	9066.5	9066.5	9066.5	9066.5	9066.5
kWh	9.1	9.1	9.1	9.1	9.1

snapshot of the spread sheet.

Learning and Difficulties

This project shed light on many aspects of automobiles that were previously vague and obscure. Some of them are listed below:

1) How various components of Physics come together to move a car.
2) The different types of motors and how some of them work.
3) How to control a motor and Pulse Width Modulation (PWM).
4) Why electric cars do not need gear boxes, differentials, alternators or radiators.
5) The different types of batteries.
6) How batteries evolved.

Due to the Covid-19 pandemic, a first-hand experience was not possible (car is yet to be made). All the research was theoretical and based solely on other people's findings. Procuring the parts was also challenging due to the situation.

Conclusion

After performing a large number of simple calculations, most aspects of the micro car can be known.

With the above information, the electric micro car is currently being implemented.

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