

CAR MOTOR SIZING

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It is quite reasonable to get a good idea of the size of the electric motor required for a conversion by looking at the power and torque of the original ic engine fitted to the car and selecting a similar sized electric motor. Also useful is talking to others who have already done a similar conversion, and checking internet blogs etc to see which motor size selected by them most nearly meets your performance requirements, while this all quite subjective, it gives a realistic guide. Peter Campbell bought "evalbum" to my attention as he found this a good source of information on past conversions.

I used a similar subjective process initially in selecting likely motors for use in a conversion. However there is no substitute for having to write a paper for other people's guidance to expose your own lack of detailed knowledge and precision!

Electric motors, unlike ic motors, do not lose much efficiency when run at part load. So it is quite ok to err on the side of a bit larger when selecting a motor (while keeping cost and weight in mind), using a slightly larger motor will not cause significant reduction of range.

After going through the above subjective process, the following is the method I use to evaluate in detail the appropriate size, transmission ratio etc. for electric motors for cars.

In selecting motors for this exercise I have given a Google or similar search name rather than an exact internet address, I have found in the past that my bookmarked sites sometimes do not come up as some minor change has been made in its address. The name in Google generally finds it again easily.

Units

As far as possible I have used metric units based on the meter "m", kilogram "kg" & second "s". Where data is in imperial units I have converted it into metric ones.

Some of the concepts that may not be familiar to everyone include:-

a. While the mass of something is in kilograms, force is not measured in kilograms weight but in Newtons, shown as "N" in calculations. The Newton is the force required to accelerate a mass of 1 kg at 1 meter per second per second (m/s/s). The force of gravity will accelerate a falling object at appx 9.8 m/s/s, I have generally rounded this up to 10 for easy calculations, and denoted it as "g". So a 1500 kg car pushes on the ground with a force of 1500 kg x acceleration of 10 m/s/s, ie. 15000 N.

b. I have rated the car's acceleration as a percentage of a "g" (which is 10 m/s/s), so an acceleration of 4 m/s/s is equivalent to 0.4 g. This also means that the car can just move up a hill slope of 40%.

c. Torque is a twisting moment and is the product of a linear force and a radius of action, it is measured in Newton meters

Torque = force x radius.

So a force of 1000 N acting through the outer edge of a wheel with a radius of 0.3 m produces a torque of 1000 N x 0.3 m = 300 Nm

d. The Pi referred to below is the ratio of the circumference of a circle to its diameter, Circumference = Pi x diameter (Pi is about 3.14 and is on all scientific calculators).

e. Speed is measured in meters per second, m/s. So car speeds which are conventionally given in kilometres per hour need to be converted to m/s when calculating car power etc. There are 1000 m in a km and 3600 seconds in an hour, so to get m/s from km/hr, multiply the speed in km/hr x 1000 to get m/hr and divide by 3600 to get to m/s.

$$\frac{\text{km/hr} \times 1000}{3600} = \text{m/s}$$

$$\frac{\text{km/hr}}{3.6} = \text{m/s}$$

$$\begin{aligned} \text{eg } 100 \text{ km/hr} &= \frac{100 \text{ m/s}}{3.6} \\ &= 27.78 \text{ m/s} \end{aligned}$$

f. Rotational speeds are commonly given in revolutions per minute, for calculations these need to be in the basic unit of revs per second, simply divide by 60 to convert.

$$\begin{aligned} \text{eg } 3000 \text{ rpm} &= \frac{3000 \text{ rps}}{60} \\ &= 50 \text{ rps} \end{aligned}$$

Car Weight

Firstly the weight of the donor car has to be determined. The car in my case is a Citroen Xantia, making a reasonable allowance for motors and batteries, I expect the car to weigh around 1500 kg, well within the upper weight limit for the car as set by Citroen.

Tyre radius

I am using "Michelin XM1+" tyres which have low rolling resistance, as well as suiting the donor car. If you type "energy XM1+ technical data able tyres" you will get a table of tyre sizes and their rolling circumferences. Print it off, you will need it. There will be similar data for other tyre brands on the net, but finding it is not trivial!

My current car uses 205/60 R15 tyres and the sheet gives the rolling circumference as 1912 mm. Note that this is not the figure you get by measuring the tyre diameter and calculating the circumference, it takes into account the flattening of the tyre as it rolls along the ground.

If all else fails, mark the bottom edge of the tyre, mark the spot on the ground that corresponds to that point and roll the car forward exactly say 10 turns of the tyre, mark the ground again and measure the rolling distance between the marks. Divide by 10 and you have a reasonably accurate circumference.

Circumference $C = 2 \times \text{Pi} \times \text{radius } R$

$$\begin{aligned} R &= \frac{C}{2 \times \text{Pi}} \\ &= \frac{1912}{2 \times \text{Pi}} \\ &= 304.3 \text{ mm in my case} \end{aligned}$$

Motor Torque

The critical factor in car performance is torque not power. Although a guess at the likely power based in the current IC power gives a reasonable start.

I will base these calculations on UQM motors, as recently found by one of our members, type in “uqm electric vehicle motor” and then click on “products”, then on “electric propulsion systems” and lastly on the motors you want data on, in my case “power phase 75” & “HiTor”. Print the data sheets off and you can then follow these calculations. Similar data is available for other motors, but seldom as complete as UQM’s.

What slope do you want to climb, how quickly do you want to accelerate at the lights and to pass a truck at speed? In my case I want to be able to climb a slope of between 30 & 40%, which equates to 0.3 to 0.4 g.

Since 1 g is appx 9.8 m/s/s, call it 3 to 4 m/s/s in my case.

I intend to use two motors driving each front wheel separately, so I double the torque produced by each motor to calculate the acceleration of the car.

Note that for the purposes of these calculations we will ignore rolling resistance and wind resistance, these can be taken into account at a later stage if need be.

AC MOTORS

a. PowerPhase 75

The power phase 75 motor produces 240 Nm at short term peak, double this for two motors gives 480 Nm for the car.

Now the torque $T = \text{Force } F \text{ at the tyre outer perimeter} \times \text{radius}$

Force $F = \text{mass } M \times \text{acceleration } A$

$$= 1500 \times 4 \text{ N}$$

$$= 6000 \text{ N}$$

$$T = F \times R$$

$$= 6000 \times 0.304 \text{ m}$$

$$= 1,824 \text{ Nm}$$

The motors produce 480 Nm, so we need a drive ratio of $1824/480$
ie 3.8 to 1.

The motor produces flat torque output up to 3000 rpm, ie 50 rps (divide by 60).

So the car will continue at the same acceleration up to a motor speed of 50 rps.

From above we have geared the motor down by 3.8:1

50 rps corresponds to

50 rps at the wheel

3.8

Speed = circumference $C \times \text{wheel rps}$

$$= \frac{50}{3.8} \times 1.912 \text{ m}$$

$$3.8$$

$$= 25.16 \text{ m/s}$$

$$25.16 \text{ m/s} \times 3.6 = 90.57 \text{ km/hr}$$

So the car will accelerate at a constant 0.4g up to 90 kph.

The motor will run well above 3000 rpm but at reduced torque.

At 120 kph, which corresponds to:-

$$\frac{120}{90.57} \times 3000 \text{ rpm} = 3974.8 \text{ rpm}$$

$$90.57$$

From the torque graph this equates to 180 Nm per motor, two motors is 360 Nm.

$$T = F \times R$$

$$F = \frac{T}{R}$$

Remember the motor is geared down

$$\begin{aligned} \text{Force} &= \frac{360 \times 3.8}{0.304} \\ &= 4500 \text{ N} \end{aligned}$$

$$F = M \times A$$

$$A = \frac{F}{M}$$

$$= \frac{4500}{1500}$$

$$= 3.0 \text{ m/s/s or } 0.3g$$

Still very respectable.

At 150 kph, motor speed is

$$\frac{150}{90.57} \times 3000 = 4968.5 \text{ rpm}$$

Torque is 140 x 2

$$F = \frac{T}{R}$$

$$= \frac{140 \times 2 \times 3.8}{0.304}$$

$$= 3500 \text{ N}$$

$$A = \frac{F}{M}$$

$$= \frac{3500}{1500}$$

$$= 2.33 \text{ m/s/s or } 0.233 \text{ g}$$

This is still not shabby, passing trucks is no problem.

These calculations can be repeated for 0.3 g which gives less brisk acceleration but gives a flat torque characteristic up to a higher speed, around 120 kph. Less acceleration but lower motor speed, take your choice.

As an exercise calculate the 0 to 100 kph figures for yourself for each 0.3 and 0.4 g, neglecting wind and rolling resistance.

b. HiTor

The HiTor motor is a very interesting one indeed. It is designed to drive the car's drive shafts directly with no reduction system, but it is less powerful.

Motor speed is wheel speed, torque is flat to 1000 rpm, 16.667 rps.
car velocity is $16.667 \times 1.912 \text{ m/s} = 31.87 \text{ m/s}$
 $= 114.72 \text{ kph}$

Peak torque is $2 \times 440 \text{ Nm}$

Force is $\frac{2 \times 440}{0.304} \text{ N} = 2894.74 \text{ N}$

$F = MA$

$A = \frac{F}{M}$

$= \frac{2894.74}{1500}$

$= 1.93 \text{ m/s/s}$ or 0.193 g .

calculate the 0 to 100 kph figure and it is a bit slow.

Use 4 motors with all wheel drive and it becomes much better! But the motors are far too expensive to allow that.

The saving grace with the HiTor motors is that the weight and efficiency losses of the reduction system is saved, the Power Phase 75 is probably around 5% worse than the above calculations show due to these losses.

For a slightly smaller, two wheel drive, lighter car with smaller diameter wheels, the HiTor is probably ideal.

Efficiency

The power and torque curves both show efficiencies. At around 100 kph the Xantia will need around 23 kW to cruise on the flat, at such low power outputs the efficiency of the PowerPhase 75 is around 85% at realistic speeds, the HiTor appears to be similar.

Be very careful of efficiency figures eg the AC motor examples above quote overall motor plus controller efficiencies whereas the NetGain motor efficiencies are for motor alone, you have to separately find the controller efficiency and multiply it by the motor figure to get the complete efficiency for the drive system.

DC MOTOR

When you look at the torque curve for a DC motor it is generally nowhere near flat, accordingly the sizing process is a bit more complex. Like the internal combustion engine, which also has a sloping torque curve, DC motors also generally need a gearbox to get the best out of them. The approach generally taken is to retain the existing clutch, gearbox & diff assembly and drive it with the DC motor via an adapter plate. So in this instance there will be a single motor.

The design process is very similar to that for the AC motor above. Calculate the torque needed, tyre circumference etc as before.

Select a likely motor and calculate the output torque at the wheels from the motor and gearbox data in each gear, then compare it with the desired output torque for the performance selected, ie the 0.3 to 0.4 g range as above.

For a motor I have used NetGain Motor's Warp 11, unfortunately the data is in imperial units which have to be converted, multiply ft lbs by 1.356 to get Nm & multiply HP by 0.746 to get kW. Type in "netgain warp 11 motor" into google and then click on the data sheets.

c. Warp 11

The initial torque is higher at low revs, 140 ft lbs, 190 Nm falling to 10 ft lbs, 13.6 Nm @4000 rpm.

From the donor car's data, in 1st gear the overall drive ratio is 13.84 to 1, so torque at the wheels is:-

$$190 \times 13.84 = 2630 \text{ Nm.}$$

We note from the AC calculations above that a torque of 1824 Nm accelerates the car at 0.4 g, so the cars initial acceleration is :-

$$\frac{0.4 \times 2630}{1824} = 0.557 \text{ g which is quite quick!}$$

The motor can run at up to 1300 rpm at this torque ie

$$= \frac{1300}{13.84} = 93.93 \text{ rpm at the wheels}$$

$$\frac{93.93}{60} = 1.566 \text{ rps}$$

The tyre circumference is 1.912 m

$$\begin{aligned} 1.566 \times 1.912 \text{ m} &= 3.0 \text{ m/s} \\ &= 3.0 \times 3.6 \text{ km/hr} \\ &= 10.8 \text{ km/hr} \end{aligned}$$

To calculate the max speed in 1st gear, the motor can run up to 4000 rpm which is
 $\frac{4000}{13.84} = 308.6$ rpm at the wheels

$$\frac{308.6}{60} = 5.144 \text{ rps}$$

tyre circumference is 1.912m so speed at 4000 rpm is
 $5.144 \times 1.912 = 9.8$ m/s
= 35 km/hr, after that it blows up.

But at this speed the acceleration is very low

In 5th gear the overall ratio is 3.04 so the torque at the wheels is:-

$$190 \times 3.04 = 578 \text{ Nm}$$

This is $0.4 \text{ g} \times \frac{578}{1824} = 0.13 \text{ g}$, not very exciting at all.

This acceleration continues up to 1300 motor rpm ie
 $\frac{1300}{3.4}$ rpm at the wheels, which equates to

$$\frac{1300}{3.4 \times 60} \text{ rps} = 6.37 \text{ rps}$$

$$\begin{aligned} 6.37 \times 1.912 \text{ m/s} &= 12.18 \text{ m/s} \\ &= 12.18 \times 3.6 \text{ km/hr} \\ &= 43.9 \text{ km/hr} \end{aligned}$$

Motor top speed will be 4000, at 3.4 to 1,
rpm at the wheels = $\frac{4000}{3.4}$

$$= 1176 \text{ rpm}$$

$$\frac{1176}{60} = 19.6 \text{ rps}$$

$$\begin{aligned} &= 19.6 \times 1.912 \text{ m/s} \\ &= 37.5 \text{ m/s} \\ &= 37.5 \times 3.6 \text{ km/hr} \\ &= 135 \text{ km/hr} \end{aligned}$$

In practice it will never make it as the torque is so low at 4000 rpm that it will probably never exceed the rolling and wind resistance at this speed.

The torque and speeds in intermediate gears can be calculated in the same way. With this motor the low gear performance is quite exciting, but the top gear cruising performance is inadequate for highway use. It would however be a good city car.

In practice drivers will find which gears are most useful and probably only use the most useful 2, after all the electric motor will take off from zero speed and the clutch is not needed for this. Many drivers find they do not need to use the clutch to change gear.