Fundamentals of Electric Vehicles
Technology and Economics
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Lecture 10
Power and Torque to Accelerate

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2.3 Power and Torque to accelerate

We now come to another very important topic, what is the power and torque required to accelerate. Remember, first we have to overcome the gradient resistance if there is a gradient but you typically never try to accelerate on a slope so that will not be relevant. But rolling resistance and the aerodynamic resistance and then you have to add the acceleration power. Torque on the other hand will also be required during climb.

Even at a, this torque is independent of velocity, is such force multiplied by the simply the wheel radius. Power has extra velocity component, force does not have so torque will become a problem and we will be looking at the (power) force and this.

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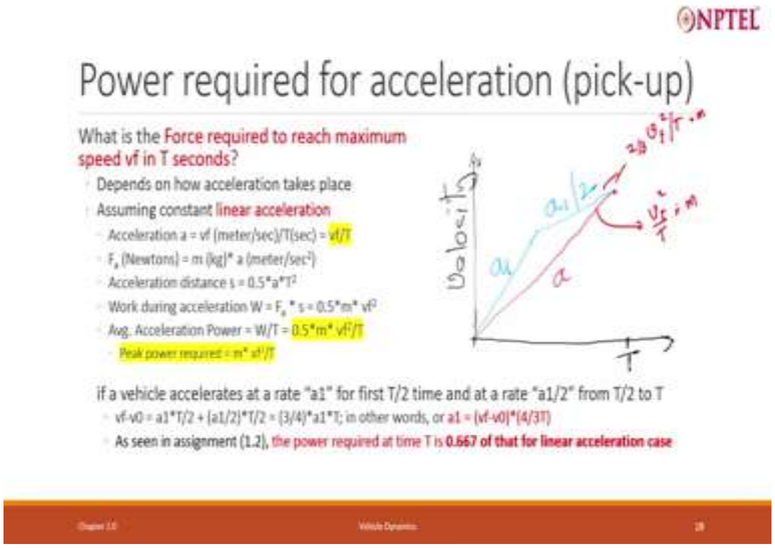


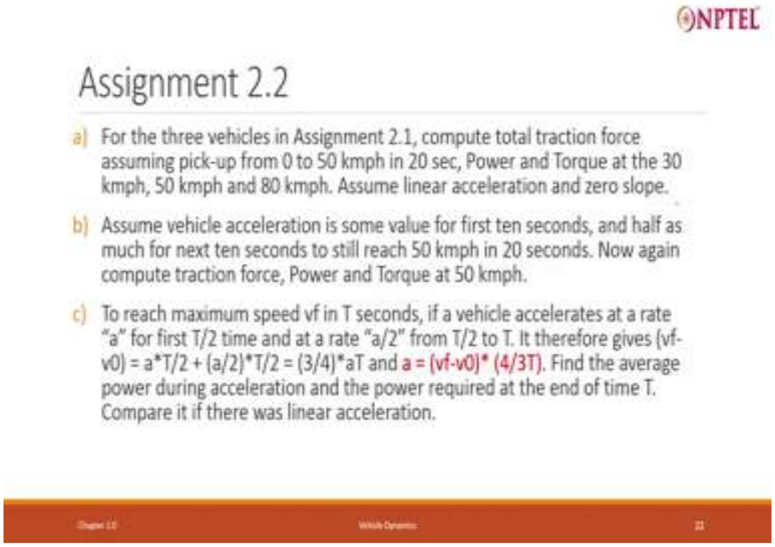
Power required for acceleration (pick-up)

What is the **Force required to reach maximum speed vf in T seconds?**

- Depends on how acceleration takes place
- Assuming constant linear acceleration
  - Acceleration a = vf (meter/sec)/T(sec) = vf/T
  - F_a (Newtons) = m (kg)* a (meter/sec^2)
  - Acceleration distance s = 0.5*a*T^2
  - Work during acceleration W = F_a * s = 0.5*m* vf^2
  - Avg. Acceleration Power = W/T = 0.5*m* vf^2/T
    - Peak power required = m* vf^2/T

if a vehicle accelerates at a rate "a1" for first T/2 time and at a rate "a1/2" from T/2 to T

- vf-v0 = a1*T/2 + (a1/2)*T/2 = (3/4)*a1*T; in other words, or a1 = (vf-v0)*(4/3T)
- As seen in assignment (1.2), the power required at time T is **0.667 of that for linear acceleration case**



Assignment 2.2

a) For the three vehicles in Assignment 2.1, compute total traction force assuming pick-up from 0 to 50 kmph in 20 sec, Power and Torque at the 30 kmph, 50 kmph and 80 kmph. Assume linear acceleration and zero slope.

b) Assume vehicle acceleration is some value for first ten seconds, and half as much for next ten seconds to still reach 50 kmph in 20 seconds. Now again compute traction force, Power and Torque at 50 kmph.

c) To reach maximum speed vf in T seconds, if a vehicle accelerates at a rate "a" for first T/2 time and at a rate "a/2" from T/2 to T. It therefore gives (vf-v0) = a*T/2 + (a/2)*T/2 = (3/4)*aT and a = (vf-v0)* (4/3T). Find the average power during acceleration and the power required at the end of time T. Compare it if there was linear acceleration.

Typically, a vehicle is often defined when you go to purchase a vehicle this is how much acceleration it gives, you typically ask if I want to go to the maximum velocity in how many seconds can I go to maximum velocity.

When I start at zero, do I go to the final velocity vf in t seconds. T can be 10 seconds, 20 seconds that often becomes a comparison between one vehicle and another. So first that we will calculate what is the force required to meet, go to the maximum velocity. So let us first assume a linear acceleration that the acceleration is constant, acceleration is A so velocity starts, acceleration is A, at time t it reaches the final velocity vf.

What is the acceleration? The final velocity is vf and divided by t time taken is t. So that is the acceleration that is required if it is a constant acceleration. So what is the force? It is mass into the acceleration which is vf by t. What is the acceleration distance? When it goes t seconds what is the distance that will travel and if you remember your formula half ft square s equal to u t plus half ft square, u was zero, the initial velocity was zero so half at square.

What is the work done during acceleration? Well force into distance or old physics formula and that comes to 0.5 mv square. And what is average acceleration power? Well total work done divided by the time, so it comes to half mvf squared by t. Now that is the average acceleration, but if see that is the average acceleration, but when it is the maximum velocity, the velocity will be vf at that time peak power requirement will be mvf square by t.

So it will be double the average that is the power required at peak power required because when the velocity is vf, it is mvf square by t but that time it is actually v traveling at that speed, so mv so p leave the peak power. So what we often sort of say, do I really need to accelerate linearly? Because power requirement always will have a extra v term, force maybe constant. Power will have a v component.

So if force is constant in the beginning my power requirement is small, in the end my power requirement is very large that is the reason peak power requirement is mvf square by t. So can I actually go faster, higher acceleration in the beginning, why? Because my power requirement will be small acceleration will be higher. So but the velocity will be my the force required will be higher, but the power requirement will be small because velocity is small.

And later on travel at lower velocity, lower acceleration lower acceleration. So can I spit into A1 and A1 by 2? What happens to the power requirement, the peak (power), average power requirement you will find if you do this and I have given this problem in assignment number 1.2 where you will see that the peak power requirement goes down by 0.667 percent.

If 50 percent of time you travel at a speed A1 and the 50 percent time you travel at a speed A1 by 2 and you reach exactly vf at time t. This is the problem that has been defined in assignment number 2. If you calculate it you will find that the power requirement is at time t is 0.667 times what would have been the linear but the average power will be seen.

In the beginning you are going at a slightly higher acceleration so that time the power requirement is larger later on you are going lower acceleration your so the average power requirement will depend on the total energy and total energy will be given by these expressions. So basically, what I am pointing out, that i need only two third of the vf by square by t.

Out here I require only two third of the vf square by t whereas in linear case I require multiplied by of course m, vf square by t multiplied by m. So I actually require less power so very often the vehicle may be power constraint. So if the vehicle is power constraint, motor is power constraint you do not want to go at a constant acceleration you may go on to accelerate in the beginning more and then slow down.

On the other hand there may be cases where you may where a peak power requirement is not there you can actually do something like this. This actually is given in assignment number 1.2 this problem is actually given when you solve this for this you will actually be able to determine this. So I just wanted to point this out and leave it out here.

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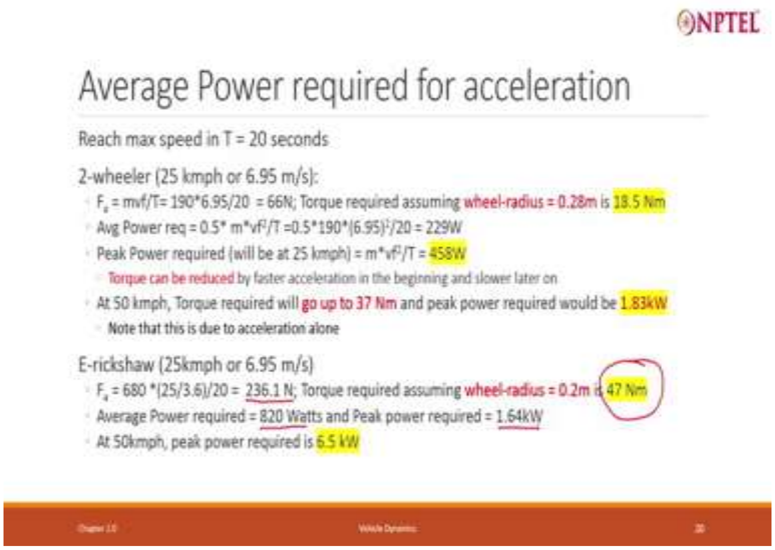

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Average Power required for acceleration

Reach max speed in T = 20 seconds

2-wheeler (25 kmph or 6.95 m/s):

- F_a = mvf/T= 190*6.95/20 = 66N; Torque required assuming wheel-radius = 0.28m is 18.5 Nm
- Avg Power req = 0.5* m*vf^2/T =0.5*190*(6.95)^2/20 = 229W
- Peak Power required (will be at 25 kmph) = m*vf^2/T = 458W
  - Torque can be reduced by faster acceleration in the beginning and slower later on
- At 50 kmph, Torque required will go up to 37 Nm and peak power required would be 1.83kW
  - Note that this is due to acceleration alone

E-rickshaw (25kmph or 6.95 m/s)

- F_a = 680 *(25/3.6)/20 = 236.1 N; Torque required assuming wheel-radius = 0.2m is 47 Nm
- Average Power required = 820 Watts and Peak power required = 1.64kW
- At 50kmph, peak power required is 6.5 kW

So what is average power required for acceleration and what is the peak power required for acceleration? If I take a two wheeler and suppose i want to reach only 25 kilometers per hour in 20 seconds, 25 kilometers per hour is 6.95 meters per second. I calculate my force required is 66 Newtons, my torque requirement is 18.5 newton meter this is due to acceleration alone, I have not taken other forces. Average power requirement is 228 new watt, peak power requirement is 458 watts.

As I pointed out that is possible to reduce peak power by first accelerating faster and then slower down. At 50 kilometer instead of 25 km suppose in 20 second I want to reach 50 kilometer, torque requirement will go up to 37 newton meter and peak power requirement will go up to 1.83 kilowatt.

So this is the difference between a 2-wheeler which goes to 25 kilometer versus 50 kilometers per hour. So your motor requirement will become much bigger battery requirement will become much bigger. And note that this is due to acceleration alone. We will require to also overcome the other resistances like rolling resistance and aerodynamic resistance Similarly you compute for E-rickshaw.

E-rickshaw the force is much more because you have a weight of 680 instead of a weight of 190. So the force required is 236.1 newton and therefore torque requirement is 47 newton meter. Average power requirement due to this acceleration is 1.64 kilowatt sorry 820 watt but the peak power requirement is 1.64 kilowatt. At 50 kilometer now e-rickshaw does not travel at 50 kilometer per hour. But if it were allowed to travel our peak power requirement would have gone up to 6.5 kilowatt.

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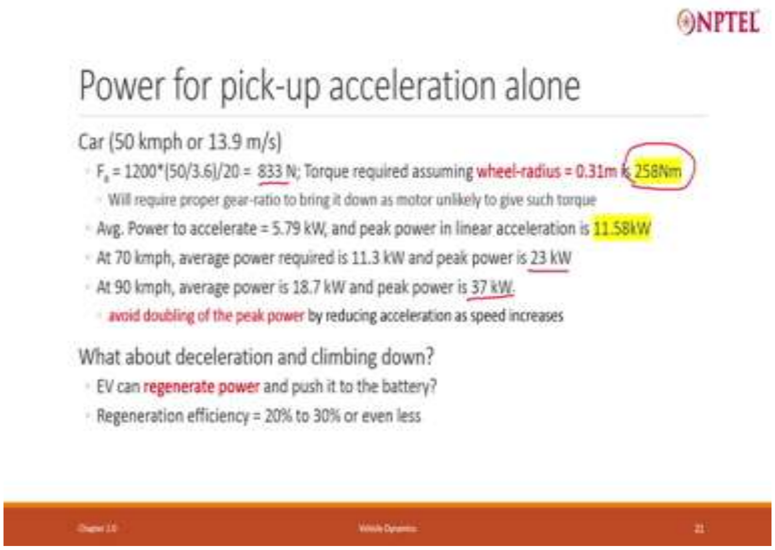

Power for pick-up acceleration alone

Car (50 kmph or 13.9 m/s)

- F_a = 1200*(50/3.6)/20 = 833 N; Torque required assuming wheel-radius = 0.31m is 258Nm
  - Will require proper gear-ratio to bring it down as motor unlikely to give such torque
- Avg. Power to accelerate = 5.79 kW, and peak power in linear acceleration is 11.58kW
- At 70 kmph, average power required is 11.3 kW and peak power is 23 kW
- At 90 kmph, average power is 18.7 kW and peak power is 37 kW.
  - avoid doubling of the peak power by reducing acceleration as speed increases

What about deceleration and climbing down?

- EV can regenerate power and push it to the battery?
- Regeneration efficiency = 20% to 30% or even less

And I do the same thing for a car, car at 50 kilometer per hour or 13.9 meters per second. Let us say in the same 20 second my force requirement is now 833 newton meter but look at my torque requirement is 258 newton meter, this is due to acceleration alone. Remember for the car even for climbing the torque requirement was very large.

So we have to put all these things together and generally you will not be able to your motor will not be able to handle this so you will require a appropriate gear. We will talk about gears also in this course as we go on. Average power requirement to accelerate is 6 kilowatt not that bad. Peak power requirement is 12 kilowatt and this is at 50 kilometer. If I went to 70 kilometer my peak power requirement is going to go to 23 kilowatt.

And if I went to 90 kilometer per hour my peak power requirement will go to 37 kilowatt. So if you see if I go higher and higher speed and I still want to accelerate in 20 seconds my power requirement will go higher and higher and higher. And generally ofcourse you do not go to this higher peak power because you accelerate faster in the beginning and then slower and that can probably bring it down to 18.7 kilowatt.

So the point that I am making is there is a fairly large requirement for power and torque due to acceleration. We will be putting that together but remember we will again talk about what happens when climbing down well climbing down will gain some energy maybe or whatever deceleration instead of acceleration, deceleration I will gain some energy, maybe I will only gain 30 percent of that energy.

So but the effective energy used becomes smaller, energy used smaller, power used is not smaller because remember power is used at the time of acceleration you also use that much energy except you recover back that energy during deceleration okay.

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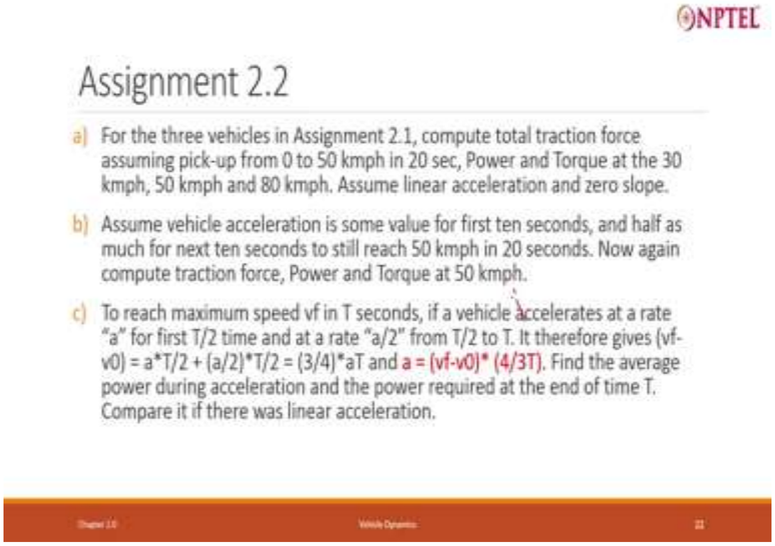

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So this is what we will do and there are 3 assignment problems that I have defined by now. I think we have done enough for you and this is our little bit tedious assignment. You have to actually do the work for the three vehicles, 2-wheeler, 3-wheeler and 4-wheeler that we have defined in assignment number 2.1. Compute total traction power, assuming pickup speed from 0 to 50 kilometer per hour. We had in 20 seconds we had already computed the rolling resistance and the aerodynamic resistance.

You also compute the power and torque at 30 kilometer, 50 kilometer and 80 kilometer assuming linear acceleration and zero slope. Another problem assume vehicle acceleration is some value in the first 10 second and half as much over the next 10 second to still reach 50 kilometer per hour in 20 seconds. Now again compute the traction force, power and torque and this actually problem number c is what you need to do before b because this will give you the kind of expression that you will require to compute that.

So these are the three problems that I would like you to do and I think we have pretty much learnt the individual forces, the rolling resistance, the aerodynamic resistance, the gradient resistance and acceleration. We have learnt forces required, we have learned the torques required, we have learned the power required and to some extent we have talked about energy required including the regeneration.

But you know these are number of computations that you did individually. Your mind would be very confused you still do not have a total picture what are these numbers mean.

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2.4 Putting it up all together

So in my next section I am going to put it all together instead of doing it in pieces we will put it together and then try to compute what does it really mean what does each kind of vehicle will imply and we will do that.