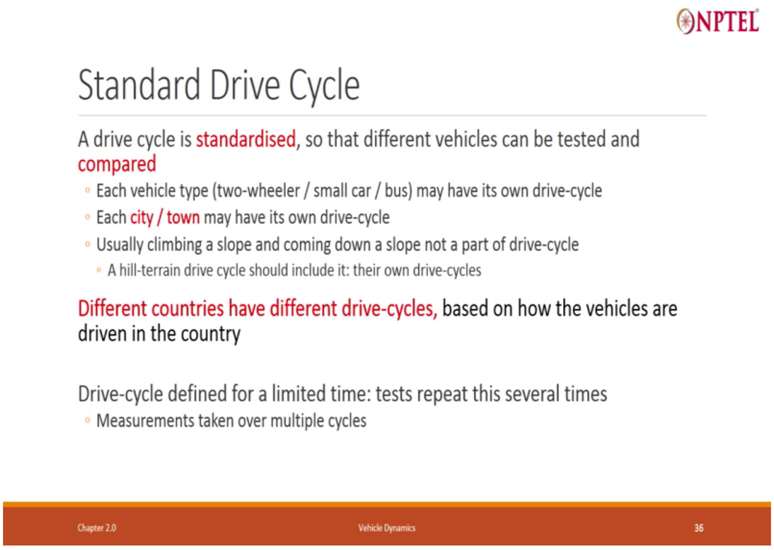
Fundamentals of Electric Vehicles
Technology and Economics
Professor Ashok Jhunjhunwala
Lecture 14
Concept of Drive cycle

(Refer Slide Time: 0:17)



Let me come to the concept of standard drive-cycle. A standard drive cycle is standardized and standard up by some body not normally motor vehicles authority in a country and it is standardized for different vehicles, two wheelers, three wheelers, four wheelers, e-rickshaw, autos, so that vehicle by two manufacturers can be compared that is a purpose and also saying that while you are not unnecessarily wasting petrol because it is important because if you are wasting petrol, it is actually converted into more and more emissions. So, just like those emissions testing, etc. is done, the drive-cycle tests are always done.

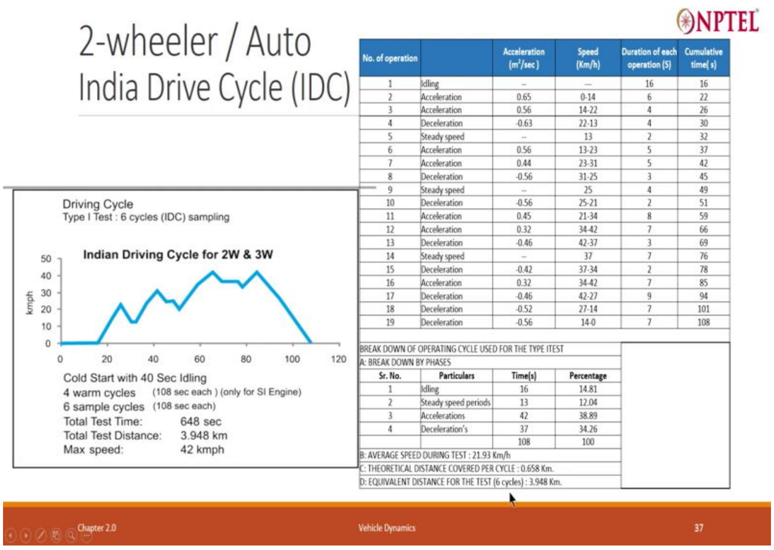
And of course, the slogan (())(1:15) has made this extremely important because I will buy a Maruti because it gives me higher mileage. So, each vehicle have its own drive-cycle. In fact different cities can have different drive-cycle. Why? Because depending on the condition, in the city, the drives standard drive is different. It tries to typically picture a standard drive. But very often, so there is a daily drive-cycle. But very often in cities use the same kind of drive-cycle, in a country, countryside on a, if you are mostly driving countryside drive-cycle is different.

Usually climbing the slope, or climbing down is not standardized as a drive-cycle. But if you are actually driving a vehicle in a place like (())(2:19), which has huge slope going up and down most of the time, it does not make sense to have a daily drive-cycle which is on flat road, you have to define a drive-cycle for (())(2:32) which we will have to take into account the slope up and slow down. So, it is up, one can define, in fact in the things that I am going to give you. While I will mostly talk about flat road, I am going to give you some examples of some assignments where I will say let us have a slope up and down what is the energy consumed per kilometer.

Different countries have different drive-cycles or different continents for example, in Europe vehicles drive at 150 kilometer per hour. In India, they rare they do not drive more than 90 kilometer per hour. So, Europe will have a different drive-cycle, we will have a different prep cycle, US will have different, in fact within US also states have different drive-cycles, because they have different kilometer per hour limits. It will take into account also the average roads, what are your speed limits; they are not supposed to drive at higher speed than speed limit.

Normally drive-cycle is never defined for 100 kilometers, is defined for smaller distances, 2 kilometers, 2.5 kilometers small time and then you keep on repeating that cycle you take because you do not want to take measurements on one cycle because maybe some slight extra energy was used or less energy is used. So, you repeat that drive-cycle 10, 20 times and then take the measurement. So, measurement is taken over multiple cycles.

(Refer Slide Time: 4:10)



With this let me come to the 1st definition of a drive-cycle. This is called India Drive Cycle for 2-wheeler, it is called IDC. It is a drive-cycle defined for 2-wheeler and it is very commonly used. And remember that this drive-cycles have been defined for petrol engine for electric vehicle same thing will be used. But certain things you will see there is practically no reason. It assumes that after you start, your idling for 15 seconds. This idling, why are you defining idling? Idling means you are not, you are just waiting, zero speed.

In electric vehicle, during zero speed we will consume zero energy. By the way auxiliary things like lights etc. are never used in standard drive-cycle measurements, that is extra. Electric vehicle at zero speed will consumes zero energy. In a petrol engine, engine is turned on, kept on and you are resuming, consuming certain amount of energy. So, this is a part of a drive-cycle idling.

Of course, today, vehicles are designed more and more to consume less and less during idling, even petrol engine, they are designed to even turn off and then have a electronic turning on, those are things there. But anyway, we will not consider that we are going to talk mostly about electric vehicle.

We will assume that (())(6:05) has 1st 18 seconds is 0 speed and let me go through this. So, if you see 16 seconds, 1st 16 seconds it is idling, then if you see you are accelerating from time 16 seconds, to 22 seconds, 6 seconds you are accelerating and your acceleration is 0.65 meter per second square, it should have been, I made a mistake here, meter square per second I have taken, so meters per second square, please correct this meters per second square, then you are actually after 22 seconds, I have to say after that you are actually decelerating.

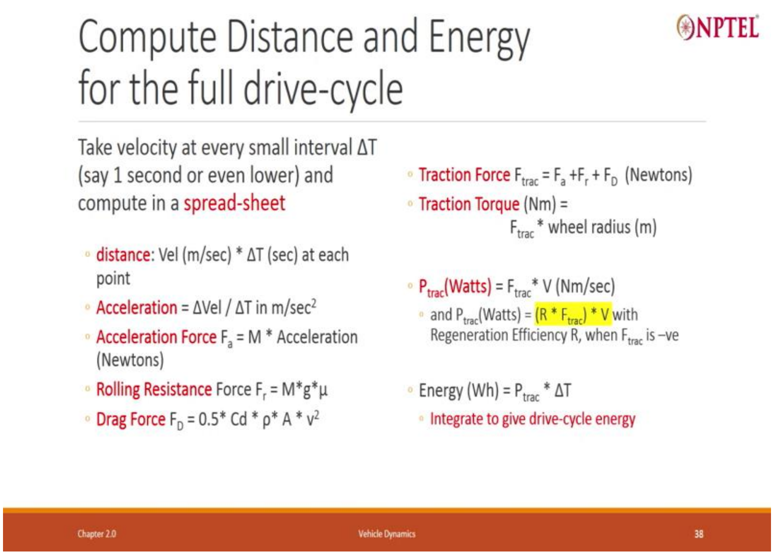
Well, here itself it is broken into two. It is assume 16 to 22 second it is at a certain speed 0.65, then your acceleration slightly decreases, does not show very well in the curve. Why does not show? Because it is not a very fine curve, but this is the important thing acceleration is 0.65, acceleration goes smaller. Then for the next 4 second, it is actually speed is going down then there is a steady speed for a short period of time, constant speed neither 0 acceleration for almost 2 seconds, then you are again accelerating this part, but you are accelerating at a certain speed, then you are accelerating faster or slower, from point 0.56 you go to 0.44.

Then, you are again decelerating for 3 second, then you are running at constant speed for 4 seconds, then you are decelerating, then you are decelerating for two seconds, then you are again running at constant speed, then you are again decelerating. So, this is how the whole thing is defined for 108 seconds and after that for 12 seconds again you are idling and up to 108 seconds and then you just keep repeating keep repeating.

So, total is defined for 108 seconds and then you actually have to drive it 6 times with the same pattern. Total test time is therefore 6 into 108, 648 second, total distance if you travel you just integrate this kilometer per hour, find out the distance traveled, will come out to be 3.9484 kilometer and maximum speed is 42 kilometer per hour. This is the drive-cycle, it is actually idling for what, 15 percent of time, 16 seconds, steady speed at for 12 percent, acceleration for 42 seconds, deceleration for 37 seconds, this is average speed is 21.93 kilometer per hour. This is a standard drive-cycle.

Now, you drive the vehicle either electric vehicle or a petrol vehicle exactly as per this cycle 6 times and you compute. So, earlier actually there used to be a vehicle track in which you had to drive to do the measurement. Now, there are instruments where the vehicle is kind of made to drive.

(Refer Slide Time: 10:00)



There is a track on which it is made to drive, it is actually not moving, and there are instruments which will capture all the data. What are these instruments called? Dynamometer, so they are these dynamometer, vehicle dynamos. So, what do you do? What is the mechanism that you use to? Now, given this, I want to 1st compute, I know my forces, I know my power for every speed, for every acceleration, I know my drag, I know my rolling resistance, I know my acceleration force, I know my climbing force, in this case, of course there is no climbing, what do I do? Actually, this can be nicely computed on a spreadsheet.

And I will, in fact give you a assignment problem to computed on a spreadsheet, you actually can take every second or every half a second, so 0 to 108 second, if you do it 108, 1 second each, so you take 108 intervals of delta T of 1 second, you calculate the average velocity during that. Or it may be actually increasing, if you want to not take that into account, you take 0.5 seconds, number of points will go up number of lines in a number of rows in a excel sheet will go up, but typically 1 second with average velocity gives you very good result.

So, find the average velocity. And the distance travel in that you can compute as velocity into delta T, velocity is given by the drive-cycle, average velocity for that 1 second, you can compute the delta T, you start writing down every second, what the velocity should be, take V final minus V initial divide by 2, that is average velocity.

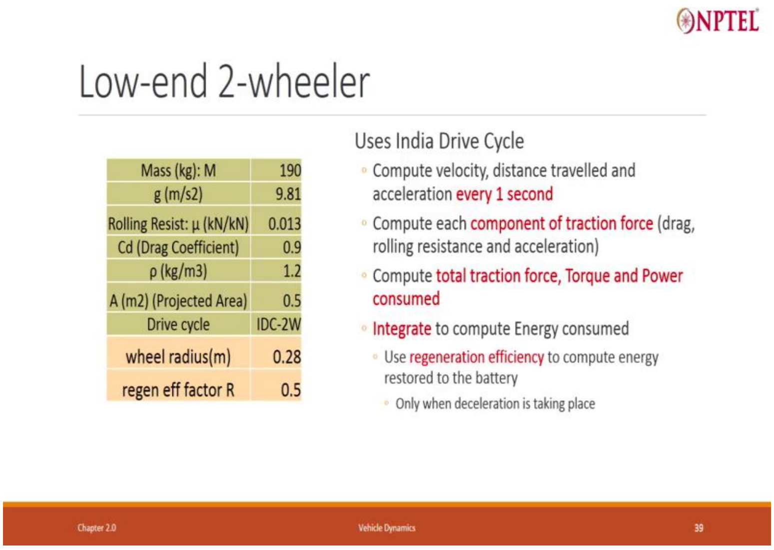
Acceleration is what? You have calculated the delta velocity with every second, it divided by delta T, it will give you acceleration meter per second square. Every second now, you compute the force, acceleration force is more mass into acceleration, mass of the vehicle is known acceleration. So, you have all the 120 value of the acceleration every second, you are doing that, you now compute the rolling resistance, you know your mass, you know that g, you know the value of mu, find out the rolling resistance, you can assume mu to be constant. Also, compute the drag force, 0.5, Cd, rho, A is given, v is changing every second it is changing, average velocity, take average velocity and compute al of that.

You go on, now since you have computed the acceleration force, rolling resistance, drag, this you compute what is called Total traction force. You also compute the traction torque, you know the force multiplied by field meter. So, every second what is the torque that are required. So, you have data for every second for the traction force, you have for traction torque.

You have the power consumed; it is a force multiplied by velocity. So, you already have got the total traction force, you take the average velocity multiply that you get every second, what is a power consumed, and if there is a deceleration and you want to take that into account, take the value of R, if R is negative, then you take R into F track into V, so R is equal to 1, if it is acceleration, if there is a deceleration means F track will be negative, then R will be equal to 0.3 or whatever.

Of course, track, the traction power there will be negative, negative. So, you take minus of that then you compute the energy requirement. What is the energy requirement? The power you have got for 1 second, integrate the power or take the power in the beginning and power in the end and subtract it divide by 2 multiplied by 1 second that will give you the energy. So, you have the traction force, torque, power and energy, you compute, create a spreadsheet.

(Refer Slide Time: 14:46)

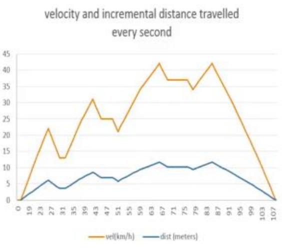


And I, and for example, I will actually do that for a 2-wheeler, where I have given all the, these are parameters that you have to put in the spreadsheet, the mass, g, rolling resistance, drag, rho, A drive-cycle, you can just give the name. As per drive-cycle your velocity is changing, you have to enter the velocity as per drive-cycle, wheel radius you have to define regeneration efficiency you have to define. And, based on that use India Drive Cycle, compute velocity is distance travel and acceleration every second compute each component of traction force drag, rolling resistance and acceleration, compute total traction force torque power consumed, integrate the power consumed to compute the energy consumed. Use regeneration efficiency to compute the energy restored to the battery only when deceleration is taking place.

(Refer Slide Time: 15:56)

Spread-sheet for a typical 2-wheeler

time(s)	vel(km/h)	dist (meters)	vel (m/s)	dv/dt
0	0		0	
16	0	0	0	0
17	2.3333	0.6481	0.6481	0.6481
18	4.6666	1.2962	1.2962	0.6481
19	7	1.9444	1.9444	0.6481
20	9.3333	2.5925	2.5925	0.6481
21	11.6666	3.2407	3.2407	0.6481
22	14	3.8888	3.8888	0.6481
23	16	4.4444	4.4444	0.5555
24	18	5	5	0.5555
25	20	5.5555	5.5555	0.5555
105	6	1.6666	1.6666	-0.5555
106	4	1.1111	1.1111	-0.5555
107	2	0.5555	0.5555	-0.5555
108	0	0	0	-0.5555



(total distance = 658 m)

Chapter 2.0 Vehicle Dynamics 40

So, this is the kind of spreadsheet that you create. If you see, this is for 2-wheeler, the IDC that I gave you, velocity is 0, so in fact 0 to 16 second I do not write 0 1 2 3 4, why because all going to be 0 0 0 0. So, I actually from 0, I come to 0 seconds, the velocity is 0 kilometer per hour. And distance travel even in meter per second, of course, from kilometer per hour converted into meter per second. How can I do? By dividing by 3.6, so I have to divide by 3.6 to get 0 meter per second I calculate what the acceleration is.

So, from 16 17 18 19 20 21 my velocity keeps on changing I take those velocity point take the average velocity point and compute my, take the average velocity point from 0 to 2.33 the average velocity is 0 point 6481 between 2.33 and 4.66 average velocity I calculate, well velocity is 2.33 and 4.66. How I made a mistake? Velocity is, an acceleration is constant, this is a delta velocity this I am taking as delta velocity this, I think delta is not visible it is a delta velocity and with the average I am able to do that.

So, this is what the velocity versus kilometer per hour I can plot that, is the same as the drive-cycle and I can also travel the distance that is travel in each time. Remember, distance also traveled in deceleration I am actually just keeps on adding the distance, this is the individual distance travel, incremental, this is the incremental velocity incremental distance, incremental velocity, incremental distance, this is a incremental distance, this is a incremental velocity, I have to integrate to find out the total distance that I have traveled, total distance that I will travel is 658 meter.

So, remember that distance here as goes it travels to 5 meters then it goes down and keeps on going up and down. But, what is happening is that if I integrate it, it will give me 658 meter, incremental distance is that much, these are incremental distance and incremental velocity. I can compute the acceleration.

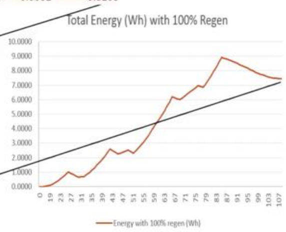
(Refer Slide Time: 18:41)

100% regenartaion efficiency

Fa (N)	Frr (N)	Fd (N)	F_{trac} (N)	Torque (Nm)	P_{trac} (kW)		Energy with 100% regen (Wh)
Mdv/dt	Mgμ	0.5ρCdAv²	Fa+F_R+Fd	Ftrac*r	Ftrac*v	Ptrac*dt	
100.4630	19.7672	0.4537	120.6838	33.7915	0.1173	0.0000	0.0434
100.4630	19.7672	1.0208	121.2509	33.9503	0.1965	0.0001	0.0980
100.4630	19.7672	1.8148	122.0449	34.1726	0.2769	0.0001	0.1749
100.4630	19.7672	2.8356	123.0658	34.4584	0.3589	0.0001	0.2746
100.4630	19.7672	4.0833	124.3134	34.8078	0.4432	0.0001	0.3977
86.1111	19.7672	5.3333	111.2116	31.1392	0.4634	0.0001	0.5264
86.1111	19.7672	6.7500	112.6283	31.5359	0.5319	0.0001	0.6742
86.1111	19.7672	8.3333	114.2116	31.9792	0.6028	0.0002	0.8416
86.1111	19.7672	10.0833	115.9616	32.4692	0.6764	0.0002	1.0295
-96.8750	19.7672	8.1263	-68.9815	-19.3148	-0.4000	-0.0001	0.9184
-96.8750	19.7672	6.3802	-70.7276	-19.8037	-0.3659	-0.0001	0.8168

Total Energy decreases when Power is negative

-86.1111	19.7672	17.5208	-48.8231	-13.6705	-0.4069	-0.0001	2.4647
-86.1111	19.7672	15.1875	-51.1565	-14.3238	-0.3979	-0.0001	2.3541
-86.1111	19.7672	13.0208	-53.3231	-14.9305	-0.3851	-0.0001	2.2472
-86.1111	19.7672	0.3333	-66.0106	-18.4830	-0.0917	0.0000	7.4619
-86.1111	19.7672	0.0833	-66.2606	-18.5530	-0.0552	0.0000	7.4466
-86.1111	19.7672	0.0000	-66.3440	-18.5763	-0.0184	0.0000	7.4415



Chapter 2.0 Vehicle Dynamics 41

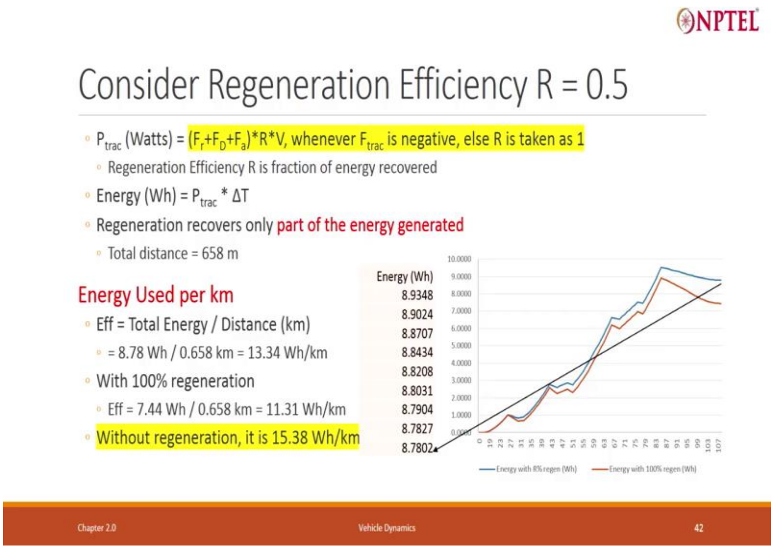
Once I have computed the acceleration, I can now compute the acceleration force Mdv by dt rolling resistance for every line, every row, I can calculate the drag, I can calculate the traction force, I can compute therefore traction forces total acceleration for rolling resistance per track, very easy to overlook in spreadsheet. Torque I can get multiplied by radius, wheel radius, power I can consume, because I multiply F track by velocity I compute power kilowatt and I multiplied by delta T, what is the power consumed this has many more decimal places have not shown and then I compute by energy, by simply integrating, at 100 percent regeneration efficiency. I can also compute at R percent, regeneration.

If you see the energy consumed, sometime goes negative. The net energy consume integration, why? Because my power consumed is negative. This is the regeneration that is going on. So, I am taking the regeneration efficiency into account, in this case, regeneration efficiency is 100 percent. So, this spreadsheet will be able to tell me, what is the energy that I consumed, what is the power that I consumed at every second, I can also find out the distance that I consumed, which I did that in the previous thing, the distance that I consumed.

And from here, these two, I can consume the watt hour per kilometer; I am showing the same thing in this site, this energy comes here. So, I am hidden part of the, I have taken this part of the data. And then I also take the data more. And if I see this, I am here plotting for the whole, I do not have 108 rows, I am only showing limited number of rows, but I am actually plotting for all of the 108. What is the energy consumed, in a free energy consumed, how is the energy consumed? Going up and down, and I find the total energy consumed for 100 percent regeneration is about 7.441 kilowatt. That is a total energy consumed.

If you see energy consumed keeps on building up. But it goes down, it goes down why? Because it is actually decelerating, in the end it is decelerating. So, this is the regeneration in efficiency, energy and regeneration energy since I have consumed made it equal to the (())(21:35) R equal to 1, it considerably goes down.

(Refer Slide Time: 21:43)



What, if I do not take R equal to 100 percent? But, if I take R less, so R equal to 0.5, if I assume R equal to 0.5 what happens whenever traction force is negative, else R is taken as 1 otherwise it is R equal to 0.5. So, energy consumed is same P track and delta T. Regeneration recovers only part of the energy.

My total distance traveled remains the same 658 meters. But, now look at this red curve, red curve is assuming, red curve is with a 100 percent regeneration. Blue curve, it is slightly higher by regeneration, see in the beginning it is the same. But regeneration does not recover the full, it is only recovering 50 percent, R is I have taken as 0.5, so it is not recovering full 50 percent if it is recovering, I am consuming more I am consuming 8.78 watt hour in 658 meters my average energy consumed is 13.34 watt hour per kilometer.

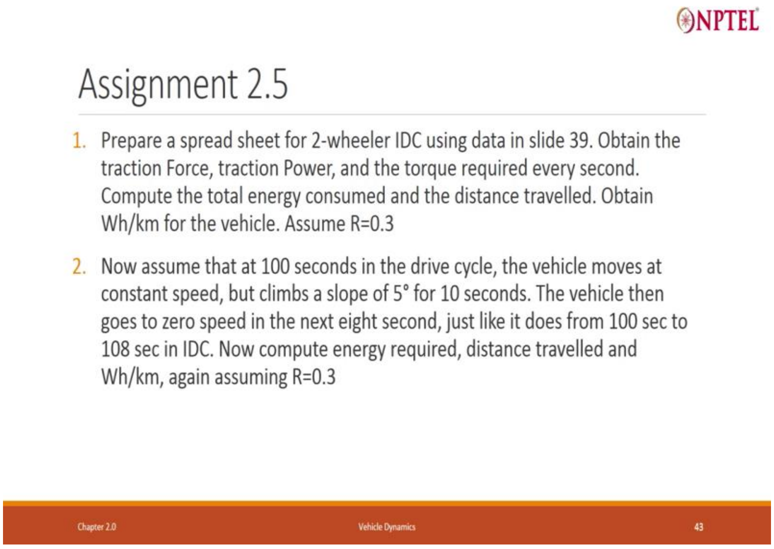
If I took 100 percent regeneration, actually I consume less 11.31. If I assume no regeneration then I, my curve will be different I am not shown there instead of 50 percent if I consume no regeneration, the negative part will not come will come as flat it goes up to 15.38 watt hour per kilometer.

What is do these numbers tell you? These numbers are very important. This is actually for a low speed 2-wheelers India Drive Cycle low weight 180 kg, 190 kg is what I assume, actually you need to consume even without regeneration about 16 watt hour per kilometer. Of course, I have made number assumption here, this is as per theory as you mean that as the all the forces in reality what happens I should get pretty much close to this, very close to this because my rolling resistance is actual, my drag is actual what is not ideal is motor there is a loss in the motor, I am not taking that into account, there is a motor controller, there is a loss in the motor controller. So, the losses I am not taking into account. So, to the extent I am not taking into account losses, that much energy consumed will become more.

So, if I assume that there is 20 percent losses, which is somewhat high, my 15.38 may go up by another 3.2 watt hour, so 17 to 18 watt hour without regeneration. With regeneration, depending on the amount of regeneration, it should be 15, 16 watt hour per kg. Another thing that I am not taking into account is auxiliary, is light on.

Whenever that is turned on, there will be some extra energy consumed. But here still a light 2-wheeler should not consume more than 20 watt hour per kilometer. A good one may consume 16, 17 watt hour per kilometer (())(25:30) watt hour per kilometer, that is what I can even from computation I can tell you. This I did for a two wheeler. I will stop here. And in the next class, there is a assignment.

(Refer Slide Time: 25:49)



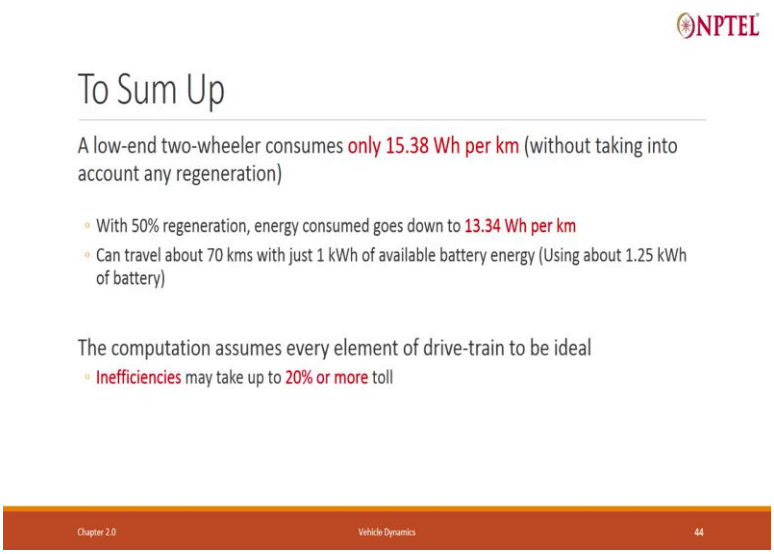
The assignment is pretty much what I did. Prepare a spreadsheet for 2-wheeler IDC with the data that I have already given. Obtained the traction force, traction power, torque, every second and compute. This time, I am going to ask you to compute for R equal to 0.3, you cannot just copy the results that I have produced, you actually have to build this spreadsheet, this is an assignment that I am going to give you, you have to build it or take a little bit of work, it will take you 1 hour, 2 hour work, but you will find that you will be able to actually do this.

Now, I am going to change the drive cycle. Now assume that 100 seconds in the 1st 100 second in the drive cycle is exactly why what I defined for IDC. But after that it climbs a slope at 5 degrees for 10 seconds, climbs a slope, and then the vehicle is taken to 0 speed. Climbing it at a constant speed, I have taken it (())(26:53) speed, then the vehicle goes to 0 second, just like in IDC, so I have changed your drive cycle.

You add that in your spreadsheet, change that now, this extra, take a copy of the spreadsheet and add a few rows saying it is now climbing up had one more force the gradient force, nothing else changes. So, traction forces, the previous three plus gradient force and compute. This is a home assignment. If you do this, you will actually get a very good feel for everything we have done so far.

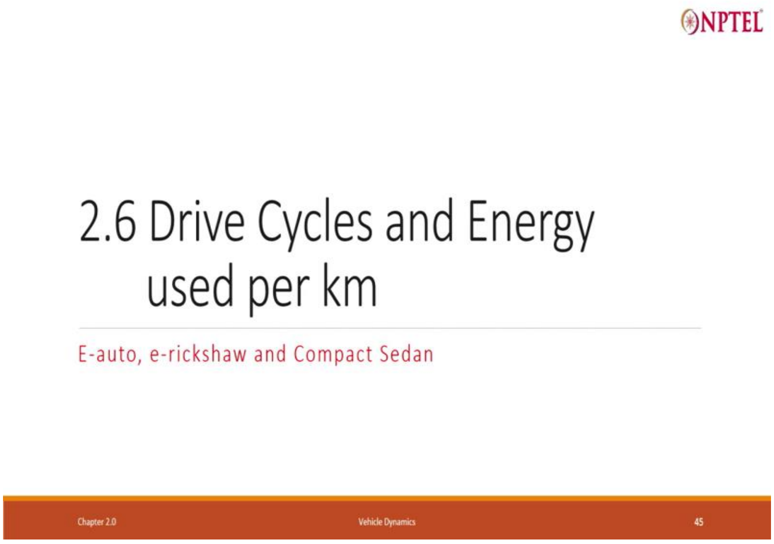
Because it includes all the forces acceleration force, the force due to drag, force due to slope, force due to rolling resistance, it tells you how to compute the total force, it tells you how to compute the torque. We have not talked too much about the torque but we will talk about torque some other time. It tells you what is energy, power consumed, every second energy consumed. Of course, assuming motor and controller and batteries to be idle, ideal if it is non-ideal we look at it.

(Refer Slide Time: 28:17)



Actually, to sum up a low-end-two-wheeler consumes only about 16 watt hour per kilometer without taking into account regeneration. As I told you with 50 percent regeneration is a very good result. So, it can travel 70 kilometer in 1 kilowatt hour. We will assume that 1.25-kilowatt hour is actual battery, we are only using 1 kilowatt hour of that. So it can actually give me 70 kilometer with regeneration. But if the regeneration is not that good, it will not give. But as I point out computation does not take into account every, assume that every element of the drive-cycle drive is ideal in efficiencies may add up to around 20 percent. And it does not take into account the auxiliary energy used. This is where I will stop.

(Refer Slide Time: 29:04)



But in the next class, I am going to talk about e-auto, e-cycle e-rickshaw and compact sedan, pretty much repeat what I have done today, but with slightly different numbers. But you will get a feel of these three vehicles also. Exactly the same drive-cycle may change or may not change. If changes will give the new drive-cycle and does not do that, this is what we will do in the next lecture. Very similar to what I just now did for 2-wheeler. Now I will do it for e-auto 1st, then for e-rickshaw and then for compact sedan. After that we will do the same thing for a small truck.