Fundamentals of Electric Vehicles: Technology and Economics
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Lecture - 61
Engineering Considerations - Part 1

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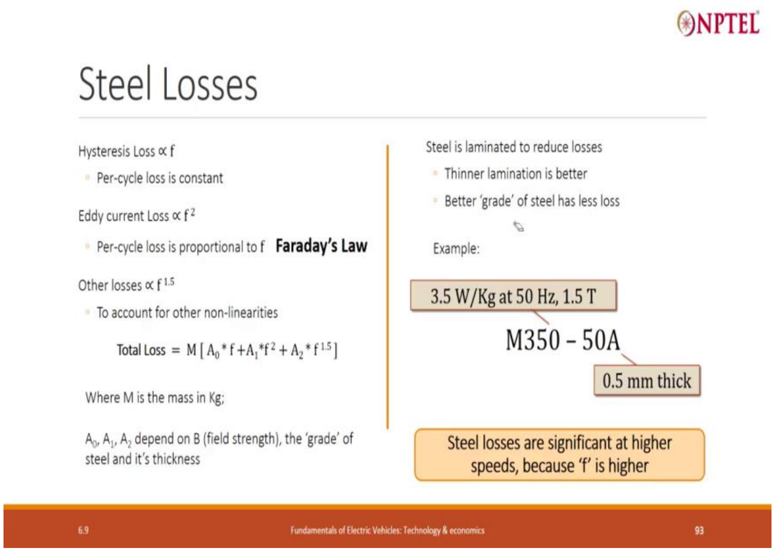

So we come to practically the last chapter after which I will also do a little bit of summing up of everything. Here I will be talking about a lot of seemingly unconnected things, all different standalone things which are all important considerations we should know and we should bear in mind when we design a motor.

So firstly, let me start with steel losses. We have already discussed steel losses. We have in particular, looked at what is called hysteresis, the area under the hysteresis curve is the amount of steel loss that we will get in one cycle.

So the per cycle loss due to hysteresis is a constant, which means the total loss is proportional to the frequency because frequency is the number of cycles per second. So at higher frequencies, which means at higher speeds, you will get more loss because the per cycle loss is a constant.

Now the eddy current loss is because of circulating currents, which are induced by the flux change which follows Faraday's law and Faraday's law tells us that the changing flux will create a voltage. And that voltage will result in a current that is circulating. We cannot change the voltage because it is coming from Faraday's law and is defined by the frequency. The per cycle loss is proportional to the frequency but the amount of current that is circulating because of the voltage can be reduced if we increase the resistance of the steel.

So if I have a block of steel, it is not writing, control-p. So if I have a block of steel and current is circulating, which I am calling as eddy current, the voltage that is causing this current comes from Faraday's law but the current that is resulting from it will depend upon the resistance that the steel path is offering.

And normally, the way to reduce that resistance is to slice it. And between the slice, there is a coating of insulating material, therefore the overall resistance comes down. The more the number of slices, higher the resistance, and therefore, lesser the current will be. And this is why you find that all the steel cores are made with thin sheets, which are stuck one on top of the other and those are called laminations.

So the per cycle loss itself is proportional the frequency and the total loss is frequency times the per cycle loss, therefore it is proportional to f squared. And then there are other different non-linearities in the behavior of the material. They can all be lumped together and added up as another term, which is somewhere between frequency to the power of 1 and frequency to the power of 2.

So by adding all of these losses, we will know what is the total loss. There is a coefficient with f, there is another coefficient, eddy current that is A1, and then for the other losses, f to the power of 1.5 there is another coefficient called A2. And all of these multiplied by the total mass of the steel in it will give us the total loss.

So now, these, these numbers A0, A1, A2, they depend upon on the one hand, the field strength which comes from the magnet and it also depends upon the grade of steel, and it depends upon the thickness of the steel. Already we discussed that the thickness, if it is thinner the resistance becomes more, so you will have less losses. So on all of these it will depend.

So what we know is that we laminate the steel in order to reduce the losses. The thinner it is, the better it is and if you use a better quality of steel, which is called the grade of steel then also you get lesser losses. So when I go and try to purchase steel laminations from a shop, there are different grades that are available. They will be denoted like this, M350 – 50A. What does it mean? That M stands for the grade of steel. It says that it will give me three and a half watts per kg under certain standard test conditions, which is 50 hertz and 1.5 Tesla. And the number 50A merely tells me that the thickness is 0.5 millimeters.

So I can have 270 dash 35A, M270 dash 35A. It means the grade is 270, it means I will get 2.7 watts per kilogram under standard test conditions and the thickness of the sheet is 0.35 millileters. So I can choose different grades of steel.

Student: What is the number 1.5 (())(05:51)?

Professor: A smaller number following the M is a better grade of steel and a smaller number before the A is thinner grade of steel, which is also better. And the selection of steel will become important if the motor is going to be running at high speeds because at higher speeds, the frequency is also higher.

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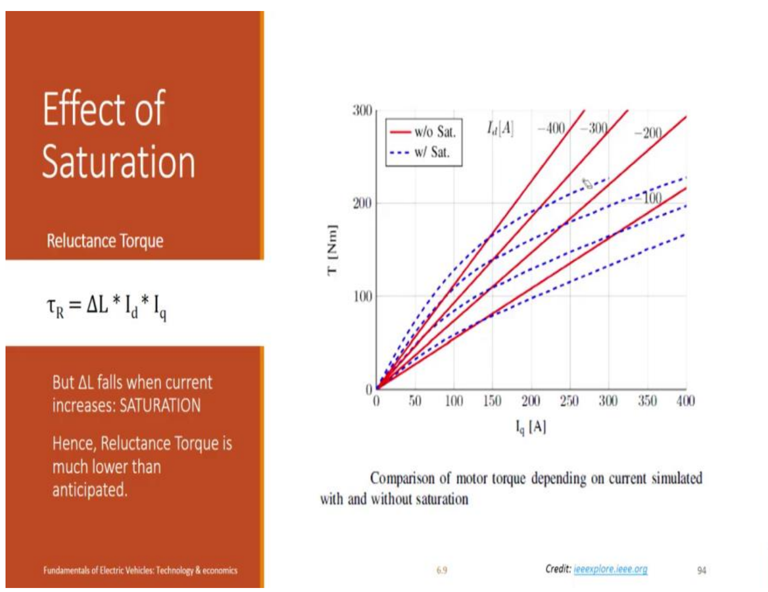

Next point we will discuss saturation. We already saw that the permeability of steel is not uniform. Initially, the permeability is very high which means you get a high inductance and after a while, the inductance saturates, it means it becomes a poor inductance. And we have also studied that reluctance torque is Ld minus Lq. The difference in inductance between the d-axis and the q-axis multiplied by Id and Iq.

So the reluctance torque that we get depends upon the inductance. If the inductance becomes poor, we get lesser reluctance torque and this effect will be particularly significant at higher torques because that is when saturation happens. So if we do not take into account saturation as a phenomenon then we will anticipate that we will get a lot of torque at higher currents due to reluctance but the actual torque will be much lower that what we have, we are expecting and this sort of shows.

For example, if you let us say, take 200 amperes of Iq at let us say, yeah, I am taking this 200 amperes and Id value is minus 400, let us assume. Id will be large when we are doing field weakening and that is when we are going at a high speed also. So then you will find that here, I am expecting according to my inductance that the torque I get will be at this level but because of saturation the torque that I get is only this much, significant drop. Fine?

So the impact of saturation is a drop in the reluctance torque and we should be very mindful of it if we are optimizing the motor for delivering high torque.

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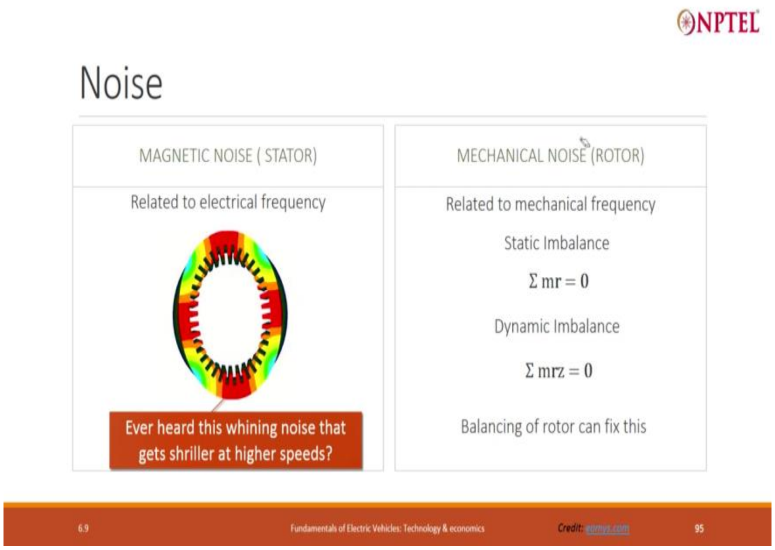

The other thing that is a common problem which anybody will complain to you about after you make a motor is the noise. We do not like an engine which is noisy, we do not like a motor that is noisy and to understand what is noise, we have to see what is the source of it.

Noise can come from the stator and that is called magnetic noise. The rotating magneto-motive force because of the AC currents that are circulating causes a wavy circulation of the magnetic field and that magnetic field will distort the structure of the stator and at a rapid rate, it is getting distorted here distorted there in all directions and that will cause a certain noise.

I do not know if anyone of you have stood near a transformer on the roadside. You will hear a low hum, hmmm. Have you heard it? That is 50 hertz, the frequency of the AC. All the laminations are vibrating at 50 hertz.

And a motor, particularly a motor running at high speed, the frequency will be much higher. So in a lot of these science fiction movies you will find some robotic arm is moving like this and inside there is actually a motor running at very high speed and then some planetary gears are reducing the rpm and the normal sound effect that they give is a very shrill sound, [shrill sound] that is the way it will go. That high frequency is because of the frequency of the motor's rotating magnetic field.

This is the magnetic noise and it comes from the stator. There is also another noise which comes from the rotor, which is mechanically rotating part and if the rotor is not well-balanced then you get a mechanical, mechanically induced noise which is also related to the frequency, the mechanical frequency. And as you know, the electrical frequency and mechanical frequency are related by a ratio which is nothing but the number of pole pairs. Mechanical frequency multiplied by the p, the number of pole pairs is the electrical frequency.

And imbalance can be of two types, what is called static imbalance and there is something else called dynamic imbalance. Many people use these words loosely without really understanding what they mean and what the difference between them is. But very broadly speaking, if you can balance the rotor, both statically and dynamically you will reduce the mechanical noise.

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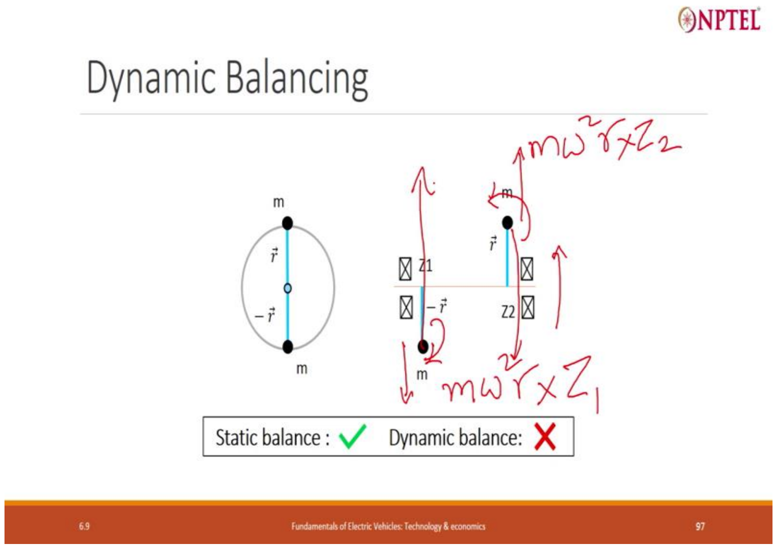

And let us understand a little bit what this mechanical balancing is all about. I am looking at rotor. This is the cross-sectional view and if it is everywhere else uniform but there is an extra weight here and an extra weight here, so if I have a rotor like this which is otherwise very, very firm and well-balanced but there is a weight over here and a weight over here, if I simply leave it, this weight will tend to bring this down. And finally, it will overshoot, oscillate, and come to rest in such a way that the two masses are symmetric with respect to the vertical.

So if, no matter in which angle you leave it, it will rotate and oscillate and finally, come to rest in that position. Such a wheel is said to be statically imbalanced. It is of course dynamically also imbalanced. Now to correct it, if I move it like this. Now, no matter which angle I keep it, it will remain in that angle, it will not rotate because the two ms are creating equal and opposite moments. It will not rotate by itself.

But what happens when this whole thing is set rotating is that this mass will experience a centrifugal force m omega squared r and it will create a moment about this point, the distance is Z2, the axial distance. And this one will experience a centrifugal force same m omega squared r multiplied by Z1. So there is a moment in this direction which is proportional to Z1, which is a small number and there is a moment in this direction which is proportional to Z2, which is a large number. So there is an imbalance moment load.

It will cause the entire shaft to rotate like that within the varying clearances. But within half a revolution, the situation is reversed. This mass has moved here and this mass have moved there and it will have an opposite moment. So what will happen is in the shaft, during the course of its revolution, it is banging this way, this way, this way in different directions and taking up all the little clearances in the bearing and that will cause a noise. So let me erase is this.

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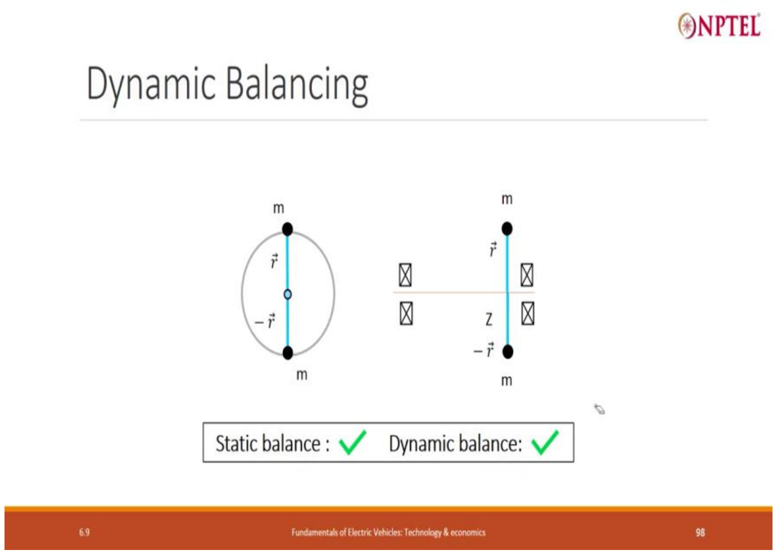

So this rotor, though it is statically well-balanced, when it starts rotating it will generate noise because of the imbalanced moments. And so, we say it is dynamically imbalanced. To correct it if I were to align the masses in such a way that they are at the same distance axially but in opposite directions, now it is both statically balanced and dynamically balanced.

Of course, in a real rotor when we want to balance it, we cannot be moving the masses like that. We can either add the masses or we can remove masses and this addition, firstly, what we do is we will do static balancing by adding or removing mass at any one place.

And after it is statically balanced, we will rotate it, measure the vibration which is coming only due to the dynamic imbalance and to compensate that we will add a pair of masses equal and opposite directions or we will remove a pair of masses in equal and opposite directions. This is how balancing is done.

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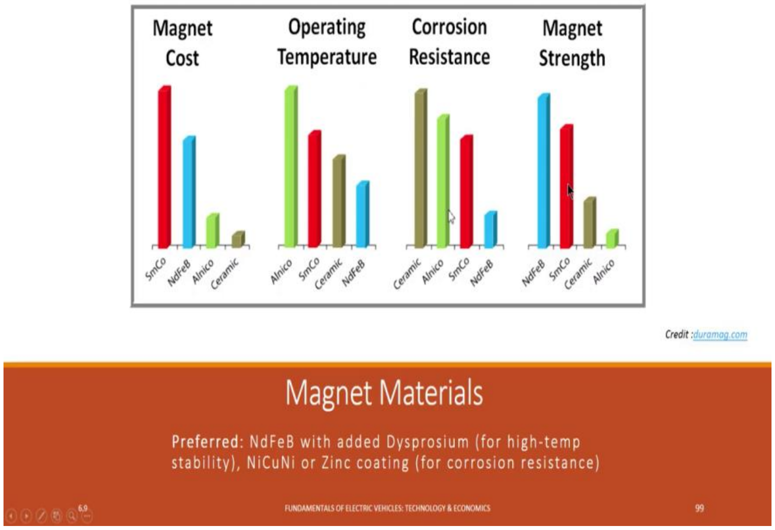

The next topic is about selecting a magnet. Very broadly, we can say that there are, we have 4 choices. The ceramic magnet is also called a ferrite magnet; there is something called alnico, aluminum and nickel and cobalt, it is an alloy; then there is something called samarium-cobalt, and then there is NdFeB, the common rare-earth magnet that we have been discussing so far; neodymium, iron and boron.

Now, which magnet to select is not a very simple answer. As you can see there are different criteria by which we can compare. On cost terms, samarium-cobalt is very expensive, it is only used in missiles and things like that where cost is not a constraint. NdFeB comes next in cost; alnico is much less expensive and ferrite magnets are the least expensive.

When it comes to temperature stability, alnico is very good, the samarium-cobalt comes next, ceramic ferrite is also fairly good, the poorest is the NdFeB. On corrosion resistance, ceramic is very good because ceramic is nothing but the ferrite magnet is just made of rust, it is already corroded material, we cannot corrode anymore. Alnico comes next, samarium-cobalt comes after that and the poorest is NdFeB.

And yet, we always talk about NdFeB because in terms of magnet strength, NdFeB is the best. The value of B in Tesla that I can get with NdFeB is unmatched by any of the other magnets and the ferrite magnet is even better than alnico but where alnico scores over a ferrite magnet, ceramic magnet is in the temperature. So given this, which magnet should we go with, becomes a complicated question to answer.

In general, for electric vehicles, I am not talking about missiles and things like that. For electric vehicles, the choice is NdFeB and we add another even more expensive and rarer-earth called dysprosium in very small quantities to improve the temperature stability of the magnet. And to improve the corrosion resistance, we usually give it some protective coating, it can be a simple zinc coating or there is what is called nickel-copper-nickel coating. We provide a coating.

So the NdFeB is very good in magnet strength. To improve the corrosion resistance, we provide the coating and to improve its temperature rating, we provide dysprosium in addition to neodymium. And overall, we get a magnet which is better than the others. This is the normal choice.

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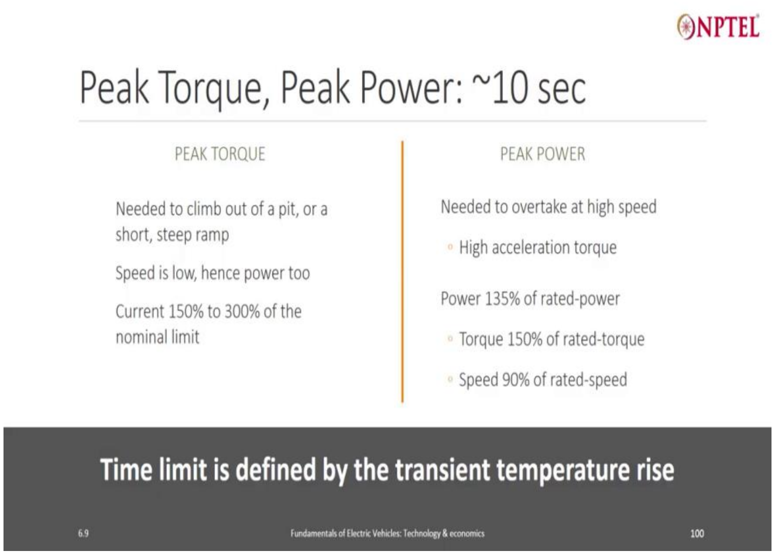

The other topic I want to address. When you look at any motor catalog, they will say that there is a certain rated torque, rated speed, rated power and we have seen all of that. They will also mention something called peak torque and peak power. Why do you need peak torque? Why do you need peak power? You need it for a very short durations.

So let us say you are in a small pit, one of your, your let us say in a 2-wheeler and 1 wheel is inside a pit. Then to just get out of it, you need a lot of torque for a couple of seconds. Once the wheel gets out of it we will immediately reduce the throttle otherwise it will just go revving up very fast. But for the short period if you do not get that extra pull, you will not be able to get out of the pit.

Or let us say I am luggage truck cargo, small cargo truck. I have gone somewhere into a basement parking where they have, they are loading stuff and now, I want to come back to the road and take it somewhere. At the place where I am exiting the parking lot, there is a steep ramp which I have to climb. I just need to climb out of it in some 5 seconds. But during that 5-second period, I require a lot of torque because I am fully loaded with luggage and I have to just get out it.

So these are the kind of situations where I need a peak torque but the speed in these cases is very low, and since torque into speed is the power, the power is also low. But the current which is what delivers the torque will be one and half times or even 3 times the normal rated current. If I continue like that for too long, it will become very hot and it will exceed the temperature limit. But for a short period it is alright.

Likewise, if I am going at a fairly high speed and I want to overtake somebody, then I need an additional acceleration torque. I am already overcoming my rolling resistance and my air drag; let us assume I am going on a level road because it is difficult to overtake on a hilly terrain at a high speed and I want to overtake somebody. Then for a short period, for a few seconds I need an extra acceleration torque to get past the vehicle in front of me. At that time I need extra torque when I am already at a high speed.

So I will have to deliver more power as well as torque. The torque let us say is one and a half times and I am already at about 90 percent of the speed, then 150 percent of the torque multiplied by 90 percent of the speed will be 135 percent of the rated power and that will be the peak power.

The reason why we cannot persist with those operating conditions for too long is because the temperature will sharply start rising and before it reaches dangerous levels, I have to bring down the current otherwise there will be a thermal meltdown. But for a short period, it is okay and that is defined normally as the peak torque or the peak power.

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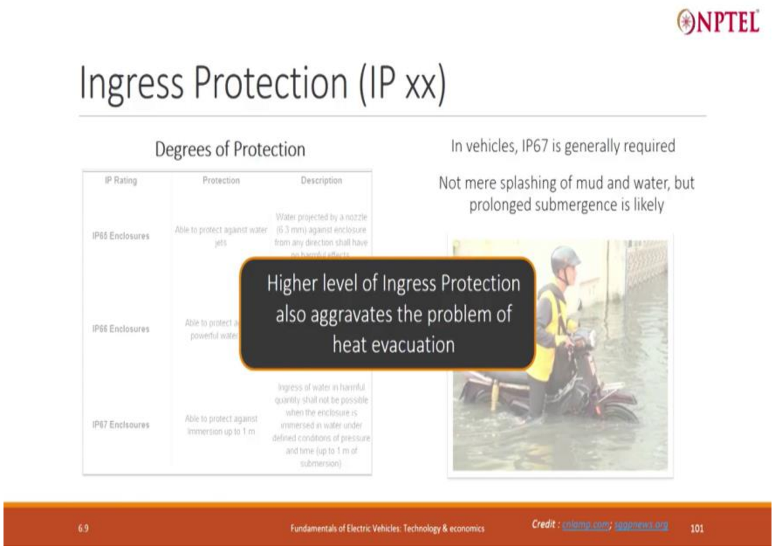

And the final topic I will cover now is what is called ingress protection. The motor as well as the controller will be exposed to environment where there is dust, mud, we will be going in muddy water, slush, there will be rain spray and when I even take it to a mechanic for servicing, he is going to apply powerful jets of water on it. And when I am washing at home, maybe I will use a garden hose and apply water to clean it. So it has to be able to withstand all of that.

So there are different levels of protection that are defined. IP stands for Ingress Protection and it will be normally followed by 2 numbers, 2 digits. So there is IP65, IP66, IP67. So IP65 means I can use my gardening water hose and with by partially blocking it with my finger, whatever strong jet of water I can get, it will withstand that.

IP66 means I can take it to a service center where he is using a very pressurized water in a targeted way. He is hitting the water jet at different places and if it hits on my motor, on my controller it will withstand that, it will not get damaged. IP67 is in even more extreme condition where it should be able to withstand submergence in 1 meter depth of water for a reasonable period of time. Not forever, it is not like a submarine but submergence for several minutes it must be able to withstand and that is the worst.

Usually we require IP67. Why do we require IP67 when we are not building a submarine? Because this likely to be a very common scenario in our cities. So in all these conditions if you want the motor and the controller to survive, they have to be built with IP67 protection.

IP67 really means that you have prevented all ways in which air, dust, water anything can enter and that will also mean that your challenge of evacuating the heat will be more. So your thermal design will become more complicated when you have IP67.

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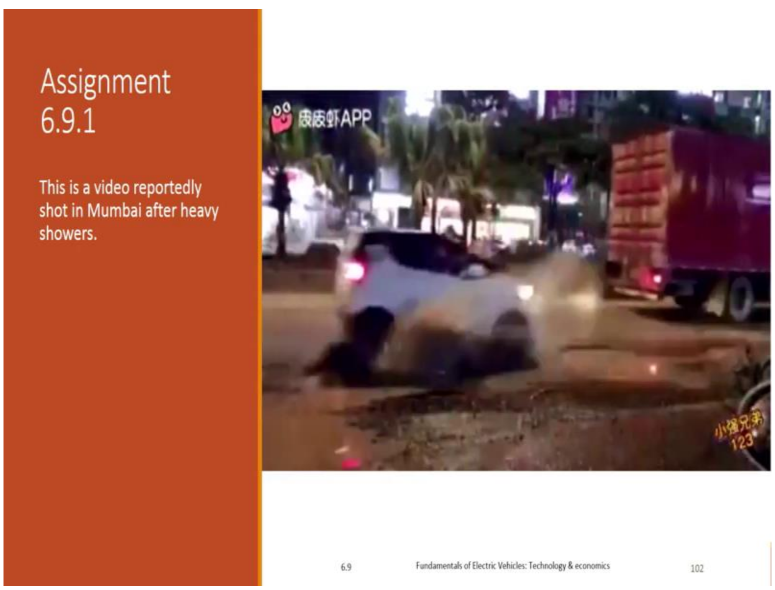

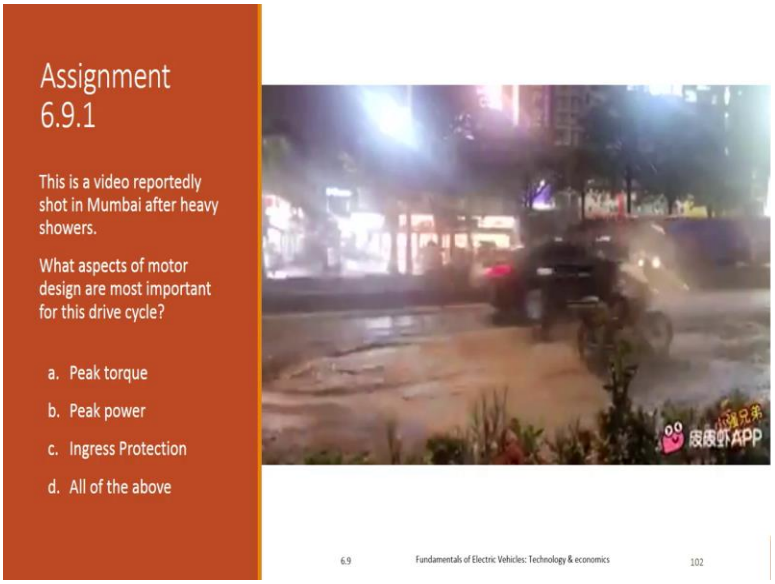

I will conclude with just giving you an assignment. It is a fun assignment. It is a video that was apparently shot somewhere in Mumbai after some rains. The audio is not clear but you can make out what is happening. People are trying to overtake on the fast lane without realizing that the road there is damaged.

So they are coming at a fairly high speed and then suddenly, they are jolted by the bumps that they are seeing. So the question is, what aspects of motor design are most important in this drive cycle? Peak torque, peak power, ingress protection, all of the above. More than one answer may also be correct. You can choose two answers if you want, whatever. So think through this. Thank you