Fundamentals of Electric Vehicles: Technology and Economics
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Lecture 33
Mechanical Design – Part 1

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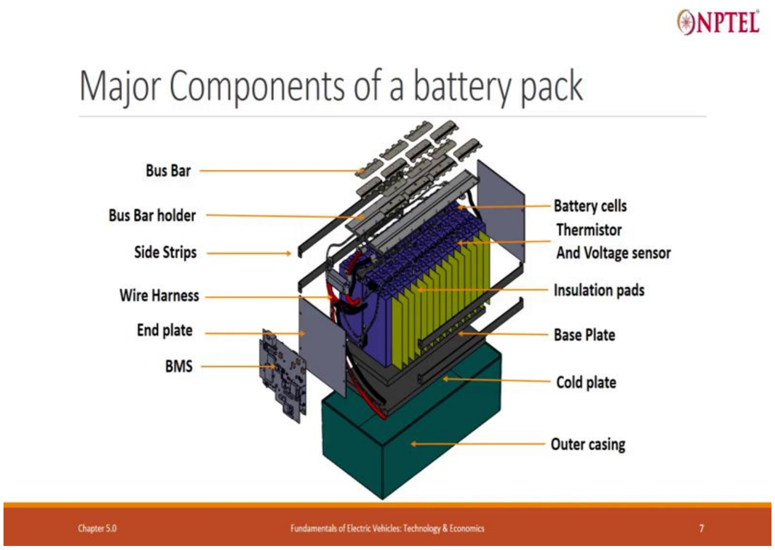

Next, I will show you a small battery pack and the major components of a battery pack. Either it is small or big, this component remains, remains unchanged. More or less, you will find all those components there. First one is battery cells. Now for a battery back, battery cell become a component. When we do series and parallel connection, generally cells are made of, outer casing is made of metal, except pouch cell, where it is made of some polymer. If you talk about cylindrical cell or if you talk about prismatic cells, in both the cases, the order casing is generally made up of metal.

In, in prismatic cells, that smaller cells which we use for cell phone, or in laptop also is made of polymer. But if you talk about EV application, most of the cells are made of metal. What happens, there are two terminals, positive and negative. One of the terminal, either positive or negative, mostly positive would be connected to the cell bodies, or directly embedded on the cell body itself. So, your cell is always at some potential.

Either it is positive or negative depending upon the terminal. So, when you are putting two cells in series, so there is always a chance that current can make a local loop. Current flow can make a local loop. To prevent that, we provide a insulation. Now, problem with the insulation is that generally insulation when we talk about the thermal conductivity is also very low, obviously industrial conductivity has to be low. But what we want, heat to be dissipated.

But if I am insulating a surface, that means, not much of the heat can escape. We want to prevent the charge movement, electrical charge movement, but not thermal. Sometimes it is also desirable to thermally isolate, in the case of events like thermal runaway or short circuits, where cell can get heated up. It should not impact other. Sometimes we require that also, but most of the time what we require is that, it should be able to dissipate the heat from the all the direction.

But generally that does not happens if we use insulin. But our primary purpose is, there should not be a local loop of current. There should not be a current leakage. So, we provide the insulation after every parallel cells. If I have four parallel cells, and then another four, in four parallel cells and these two are in series, I provide a insulation between these two. So that there should not be a leakage current.

Base plate, it is a responsible for holding the all the cells together. It is responsible for any external factors, like vibration beyond control, it still protect the cells. Side strips. Side strips help fixing together the end plates. These are the end plates here. This, this. Why end plate is required, I will talk later. It need to exert some pressure on the cell. So that bulging should not happen. It increases the life of the battery pack. End plates, just now I talked.

Why we require is basically to constraint the cell movement one thing, base plate, end plate and side strips, the basic function of all these three are constraint the cell, put some pressure over the cell surface so that, and that is uniformly distributed pressure, so that we can increase the life. We will talk it later, how to increase the life and why it is needed to put some pressure. And the side strip holds the end plates together with some pressure.

The cold plate, the cold plate is required to maintain the temperature within the optimum range. Bus bar holder. Now, we are putting the bus bar, now we are connecting in series and parallel. And that is done by bus bar. And then bus bar should not move, it has to be constant. If it is moving, that means there is a chance of short circuit. So, we provide a constant, that we say a bus bar holder. Now, the bus bar, bus bar is needed for series and parallel connection, to efficient flow of current. Efficient flow of energy.

Thermistor and voltage sensors. So, thermistor measures the temperature, login to BMS and then BMS takes action based upon the temperature. Similar way it also locks the voltage, because the voltage is wiring between some limit and with the voltage wiring, we know what is the charge and discharge condition of the battery. Wiring harness is required for again the efficient flow of energy and the efficient flow of signal, both in and out, bi-directional. BMS is the heart of system, which communicates with within the pack, temperature, voltage, current flow and outside, like motor and controller.

Drivers. The outer casing is again required to prevent from environmental conditions. If somewhere it is raining, water should not come inside. If it is dusty environment, dust should not go inside, because what happens, if water comes inside, you may find short circuit condition there. If the dust comes inside, the resistances of all the contacts, like bus bar is welded with, or screwed with cells. If the dust deposit happens here, resistance increases.

If resistance increases, what will happen, higher heat generation and the lower efficiency, energy flow, or the condition like crash, it should be able to protect inside domain cells, holder and all those things. So that is work of outer casing. So, all together, battery cells, thermistor and voltage sensor, insulation pad, base plate, cold plate, outer casing, bus bar, bus bar holder, side strip, wiring harness, end plates and BMS, this all things together forms a battery pack.

If the battery pack is bigger, this is, this is around 2 kilo watt battery pack. If battery pack is 20 kilo watt, the parts remain same. Part does not change. The length, width, thickness, rating would change.

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Any question till now? Which we will talk now. So, the question is that in battery pack, the cells are in series and in parallel. Yes, both are there, which we will talk now. There are mechanism.

Student: (())(9:03).

Professor: Yes. Question is, what causes battery to be discharged in the event of crash? So, actually we do not want to be, basically what we want, we want to put a mechanism during the crash situation my battery should be able to dissipate the energy as fast as possible. So, some high value of resistance in parallel path, which get connected by BMS command if such event is about to happen. So, what happens, that whatever the energy is stored because of charging gets at least dissipated immediately. Some people make it in 5 minutes, some people make it in 10 minutes.

Some where we do not put, for like a smaller pack like this, we do not put, what let suppose if bigger pack, 100 kilo watt battery pack is here. If there would be a fire hazard, or thermal runaway case, so at least in that case, whatever the energy is stored, electrical energy is stored, we do not have to worry if we are able to discharge it quickly. So only thing which we need to worry about that is that time is chemical energy. So, it is a choice of pack designer and requirement of the vehicle, different standards and this. But mostly it is resistive dissipation. In this pack, we have not shown that particular thing, but can be.

Student: (())(10:52).

Professor: Cooling can happen at any place, where you have exposed surface. In fact, in between cells also which you can put the cooling plate. It is all based on the requirement how much thermal energy or heat load is coming up in the battery pack. So, the question was, the base plate is, sorry, the cooling plate is always kept at the bottom, no. It can be kept at, kept at the proper location during the designing. And also depends upon what is the heat load of the battery pack, what is the environmental condition we are going on.

Student: (())(11:36).

Professor: It can happen at any time.

Student: (())(11:43).

Professor: No, but before thermal run, runaway lot of events happens. One of the, the very first event which you can measure easily is temperature starts rising up. It does not happen certainly at 35 degrees, it never happens. So, there is a threshold., 90 degree or 125 degree, or 150 degree or 200 degree. Like for NMC cells, it is approximately 150 plus degree. And beyond that, it is very difficult to control.

Student: (())(12:21).

Professor: Yeah. So now we have put here thermistor. So, it will detect if there is a temperature gradient which is beyond a specified limit. Let us suppose my temperature is rising up 10 degree C per second, however I have built it for only 2 degree C per second. This information will go to BMS. Now BMS will have all the processing capacity and it will detect where it is going. Then it will immediately shut off.

In many of the battery pack, it will start discharging the cells in such a way that other cells, so that my energy content of the pack become minimum at possible. Especially if you go to storage application in EV application, you have a fire suppressing system also. That gets activated. However, saying that now it is going to happen thermal runaway, it is very difficult. There is no clear-cut physical physics for that one till now, or physics has not been understood clearly till now.

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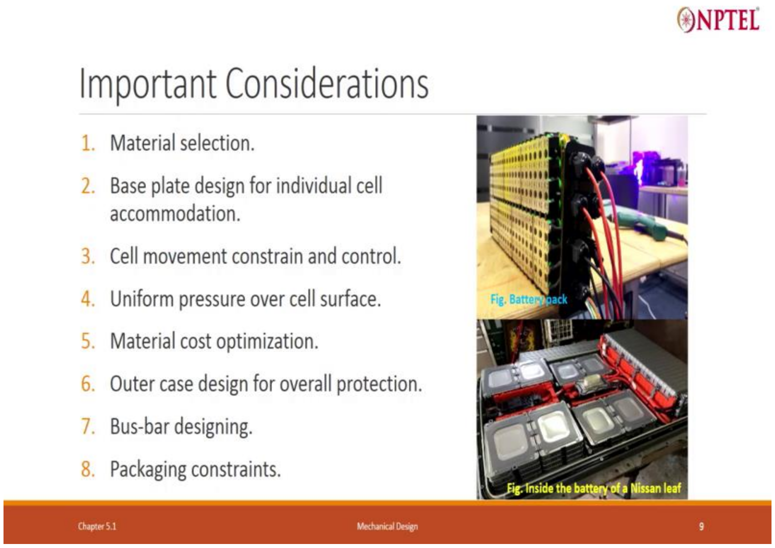

Now, we are going to start mechanical design. Till now it was a background for a battery pack design. Now, we are going to move ahead with the mechanical design. So, what are the important consideration for a mechanical design. In the right-side picture if you see here, battery pack and this one is the battery pack of Nissan Leaf. The most important part of a mechanical design is material selection, which material you should take. What are the criteria's for material?

It should cost us less, easily available, should have good to great strength, not hazardous type, not poisonous. So, we will talk in the next slide, what material selection, how do we do a material selection. So, second one is base plate design, over which we stack all the cells together. We accommodate the total cells. Then we also have to worry about cell movement. We do not want cell to move because that is the primitive block of a battery pack.

So, we constraint and control the movement of the cell. Uniform pressure all over the cell surfaces, that helps in prolonged life that increases the life of the cell. In chapter 4, when professor was talking about cells, he has also shown some pictures of how the cell get bulged during the charging and discharging. We do not want that bulge to happen, because that reduces the cell life drastically. Material cost optimization. I can have a material which is great in strength, but my pocket will not allow.

I have another material which has good strength and also fits in our budget. Then outer casing design, outer case design for overall protection. Bus bar design. Packaging constraint. Vehicle space is in premium. And it may not be a regular surface like a rectangle or cylinder. If you see the picture cell, here you see, it is a quite regular shape here. But If you see here, bottom one, this portion, this rectangle, again this is rectangle, but height is not same. It is a packaging constraint.

This is the space available. Now at the last row if you see, height is quite elevated. Within here, so within one pack, the profile is not same. It is different for different stacks of the cell. And why that has happened, because people who love to go for a rectangular or cuboid type of shape. It is easy to construct. It is because of the packaging constraint, because that is the only space available in the vehicle. Because again vehicle has to take care of lot other things.

It has to package motors, controllers, auxiliary systems, wiring harness, cables, seating arrangement. Who buy the vehicle, the person like me and you or some human. What they need, if I am sitting, I should be relaxed. So, that becomes always first priority. And after that, whatever space is available, that is allocated to the sub systems, like battery pack, motors, controllers, auxiliary system. So, the packaging constraints, within the packaging constraint, I need to make my battery pack.

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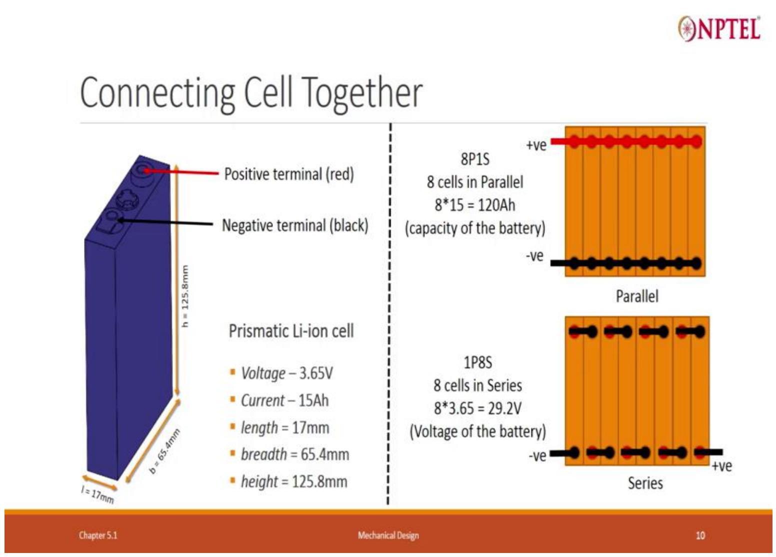

Let us move ahead and let us start making the pack. So, the cell is the building block for any battery pack. I am showing you a picture of 15 Ah cell. The voltage is 3.65 volt for this individual cell. Current rating is 15 Ah. The length of this cell is 17 mm. Why I am putting length of this cell because we are going to stack this cell.

Breadth 65.4 and height is approximately 126 mm. Let us go back to MPNS theory, M parallel n series. So, if I am putting everything in parallel, everything in parallel, all positive terminals connected together, all negative terminals connected together. What it does? It increases the Ah. So that many times, the number, number in parallel that many times Ah will get added up. So, here 8 cells are in parallel. Now each cell capacity is 15 Ah.

So, this 8P 1S configuration. What would be the current rating? 120 Ah, 8, 15 plus 15 plus 15, 8 times. So, that is nothing but 8 into 15, so 120 Ah. We say capacity of the battery also. What would be the voltage now? Voltage is 3.65 volt only. Because we have connected all the cells in parallel. Next move, the second configuration is series configuration, where every alternate cell positive or negative terminal is connected. You see, positive, negative, positive and negative. And this side, again positive and negative.

So, this configuration is known as series configuration. In series configuration, what happens? Voltage adds up. Now, what I am saying, one parallel. Because I am taking only one cell, in parallel. Others, next cell is in series. Again, next cell is in series. So, what happens here? Voltage adds up. Voltage add up means, my one cell voltage is 3.65 volt. Now I have put 8 cells in series. So, 3.65 plus 3.65 up to 8 times. So, I can simply put it, 8 into 3.65. This is 29.2 volt. Now, let us see if I have put 8P 8S.

So, what would be the current capacity? When I talk about current capacity, it is 1. So, what would be the current capacity and what would be the voltage if I put 8P 8S? So, if I put 8P 8S, 8P gives me 120 Ah. And 8S gives me 29.2 volt. So, the norm at, if I consider this as a pack, so norm at pack is 29.2 volt rated at 120 Ah. Multiply this to 120 into 29.2 for sake of calculation, take 30 volt. It is a 3.6 kilo watt hour pack. You multiply voltage with current rating, it will give you the capacity, pack capacity.

It is a 3.6 kilo watt hour battery pack, where my current rating is 120 Ah. Whenever I talk about current rating, it is at 1 C. And my voltage is 29.2 volt. So, I can make any voltage any Ah of the multiple of this particular cell. If I have other cell which is 10 Ah, again 3.6, and if I need 40 Ah battery pack, so I have to put 4 cells in parallel. If I need, if I put higher capacity cells, then number of parallel cell come down, if I have to maintain the same Ah. Yes, the cell in chapter 4, when Professor was talking about the cells, he was talking about 3 Ah, 8 Ah, 14 Ah, 15 Ah, 13 Ah, 50 Ah, 55 Ah, 24 Ah.

This all are form factor. However, except cylindrical cells, not all cylindrical cells, but most of the cylindrical cells has, is tender shape or form factor. If you move ahead other than cylindrical cells, let suppose for prismatic cells, or pouch cells, every manufacturer has their own form factor. So, and obviously it is not a continuous increment, like 1 Ah, 1.1 Ah, 1.2 Ah, no, there are certain Ah cells available. You can have 15 Ah cells which is available, you can have 24 Ah cells, you can have 50 Ah cells, you can have 55 Ah cells, you can have 60 Ah cells.

Student: (())(26:10).

Professor: Yes, corresponding. There is, that is what I said, form factors is not constant. For this particular, that is why I am giving you all the dimensions as well as voltage, as well as current. This one particular form factor. I change the cells. Let suppose I bring the cylindrical cells. The question is, that do we have the same form factor for all the cells, no. Form factor is generally tender shaped for cylindrical cells. But for pouch cells and prismatic cells, every manufacturer has its own form factor.

So, depending upon the requirement, you need to select a manufacturer, form factor and then you need to see who has this form factor. If you have, let suppose 5 giga watt hour capacity requirement, or 1 giga watt hour capacity requirement, a manufacturer would be happy to align with your form factor. But let suppose you want 100 kilo watt battery pack, or 1 mega watt hour battery pack, because in that case, you have to utilize what is available form factor.

So, form factor is very important. So, the based upon your packaging constraints, the capacity requirements, energy requirement, you have to select out of available things. And or, you can make your own form factor, you can demand your own form factor if your requirement is very large, because cell manufacturing process is very costly affair. If you see in the chapter 4, material is 30–35 percent. The cell manufacturing is 30 to 35 percent.

And the pack, with this all mechanical things what we are talking now and what would be talking add up around 30 – 35 percent. So, one third of the cost of a cell or a battery pack is basically cell form factor or manufacturability. So, what most of the people demand, they make a form factor to that requirement. And if you have a very low requirement, then you have to select out of that. If you have a very high requirement, you can enforce your form factor.