Fundamentals of Electric Vehicles: Technology and Economics
Professor. Kaushal Kumar Jha
Centre for Battery Engineering and Electric Vehicles
Indian Institute of Technology, Madras
Lecture 12
Electric Design-Part - III

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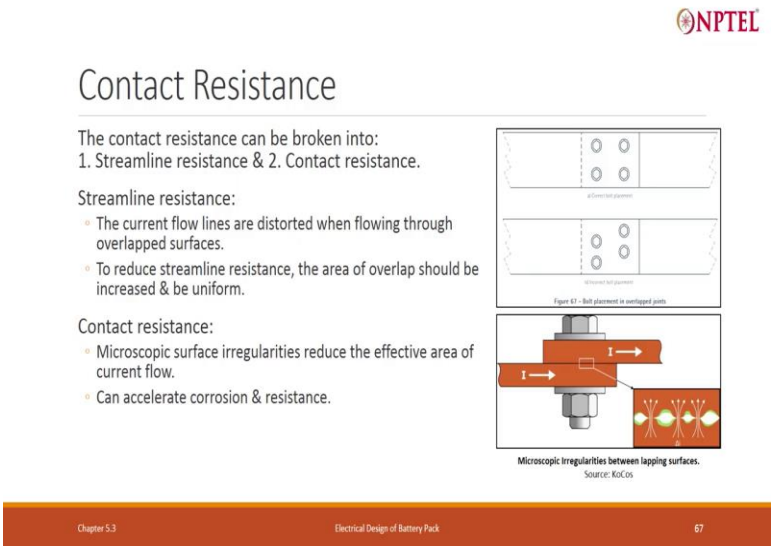

Now contact resistance, it plays very important role. The contact resistance can be divided into two parts; one is streamlined resistance and the second one is we say contact resistance. However, both are contact resistance only. What is streamline resistance, the current flow lines are distorted when flowing through overlap surface. If this one surface and if this is a another surface, now if current is flowing from this to this what will happen, the current has to jump to this and then it has to flow like this.

So, because of that there would be a resistance that we say it is streamlined resistant. It will jump like this and then it will start flowing on this one, this type of resistance we say streamline resistance. And then another resistance what we talk about is, if we need to reduce the streamlined resistance what we have to do, we have to increase the overlap, surface overlap. The easiest way of producing the streamlined resistance is to reduce this, so increase the surface overlap.

Now, second one is contact resistance, contact resistance why it happened, none of the surfaces are super smooth that means every atom or molecule on this is not attached to that. There is some

always microscopic projections and because of that there is not 100 percent contact, the contact is less. If contact is less what will happen, current density on those contacts should be increase, your resistance will also increase.

Because resistance is a function of cross sectional area and the length. Now, the cross sectionally, cross sectional area getting reduced because of the small projection, even it looks smooth, but if you look, look in a microscope, you see lot of projects and there, so only those projected parts get in contact.

So, what you have to do because what you have to do, you have to try to make as smooth as possible. What does it do, first of that its create resistance because of the temperature can increase. The second things it accelerated corrosion also, because of the elevated temperatures. Because of the current flowing only on the limited places, which is not visible to the naked eye. But as you see, as soon as you seen under microscope, you can see it very easy.

So, for streamlined resistance to decrease you need to increase the overlap surface. This contact resistance can happen because of the external effect also, like moisture ingress. The form of, the formation of oxide layer deposit of dirt, grease and all those things. Because of that also the contact resistance increases. So, we have to, whenever we are doing when whenever we are assembling or making, we need to keep the place as clean as possible, surfaces as smooth as possible, to minimize the possible contact resistance

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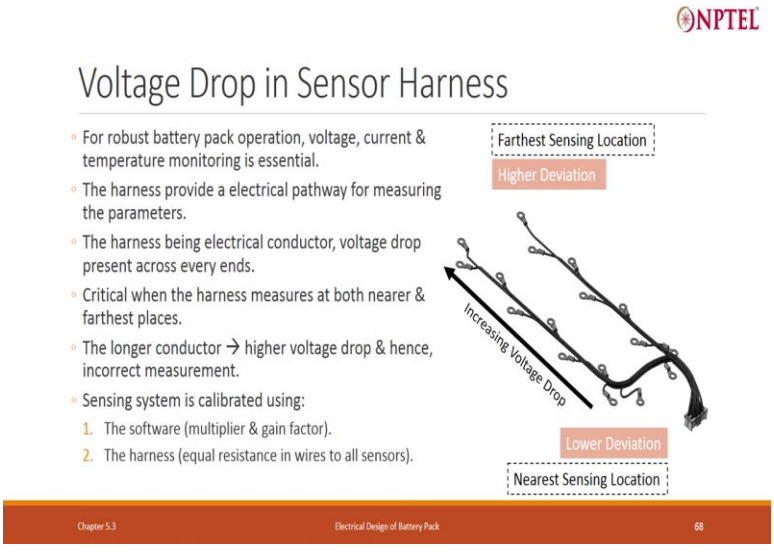

Now, the another thing which we are talking is similar to what we have talked, voltage drop in bus bar, the similar way there is a possibility of voltage drop in sensor harness also. What are the sensors harness, what are the sensor harness? Voltage sensors you have to put everywhere correct. Now, you have to put thermistor everywhere. Now, these would be connected by a wire to the BMS by (())(04:35) Management System.

Now, because of this, and the sensor should be at different location. So, you cannot have the same length, you will have a different length but can we still make that resistance equal, if it is, however the sensing currents are very low. It is in milli ampere or in micro ampere. It would not impact huge but it will still impact, maybe 1 millivolt, maybe 2 millivolt.

And when we recalibrate back to the voltage that voltage to the value this 1 millivolt, 2 millivolt impact. So, for robust battery pack operation voltage, current, and temperature monitoring is essential. Now, the harness provides electrical pathway for measuring these parameters either voltage or current or temperature. It is essentially a electrical conductor, similar to the bus bar only thing is that thickness, width, cross section is much, much less because the current flow is very low, micro ampere or milli ampere.

Student: (())(05:55) typically how many sensors would be there?

Professor: Typically in, how many sensors should be there in a battery pack? So, typically for the example what we have taken 2p, 16s will have 8 voltage sensor, 16s so we will have a 16 voltage sensors.

Student: (())(06:13)

Professor: Because we measure the cell for every parallel, measure the voltage for every parallel cell.

Student: In addition, your current.

Professor: And then we add up to find out what is the voltage, in addition to that will have a current, one current sensor is sufficient. We can have multiple but one current sensor is sufficient. However, voltage sensor has to be 16.

Student: And then the temperature sensor.

Professor: Then will have the temperature sensors. So, temperature sensors idly at least one should be for every cell but by experience or experimentation or simulation we know where would be the maximum temperatures. So, we try to tap only those points. However, if you look up on safety, we do not know which cell will go in thermal runaway. So, generally it is advisable to put the maximum thermal sensor, but then it costs.

Student: But there wireless sensors to avoid (())(7:13) resistance.

Professor: There are wireless sensors but then again it costs and then manage you have to manage the wireless sensor in the regular environment.

So, come back to this slide. So, critical when harness measures at both nearer and the further distance. In that case, we do not have the same length. We have a different length and that, that would be there, if my BMS is at one end of the battery pack, nearest cell will have the shortest length, the farthest cell will cell will have the longest length.

Student: (())(07:50).

Professor: You can do but again that would unnecessary increase your material cost. And any moving object is not desirable inside another moving object. The longest conductor will have high, higher voltage drop and hence incorrect measurement. Because when you recalibrate back to the parameter what it does, it does voltage and current sensing, but then you have already a program or a table from where after seeing that voltage and current it will give you back the either temperature or current or voltage.

So, what you can do, either you measure and then correspondingly corresponding gain, you put it into software or you try to equalize resistance in all wires. So, this is example of one of the voltage sensor. The current drawn through this wires are very low, micro ampere or milli ampere. However, while calibration is also in micro ampere and milli ampere only. So, even your resistance is changing by milli ohm or micro ohm that will impact there, during the, retrieving the value.

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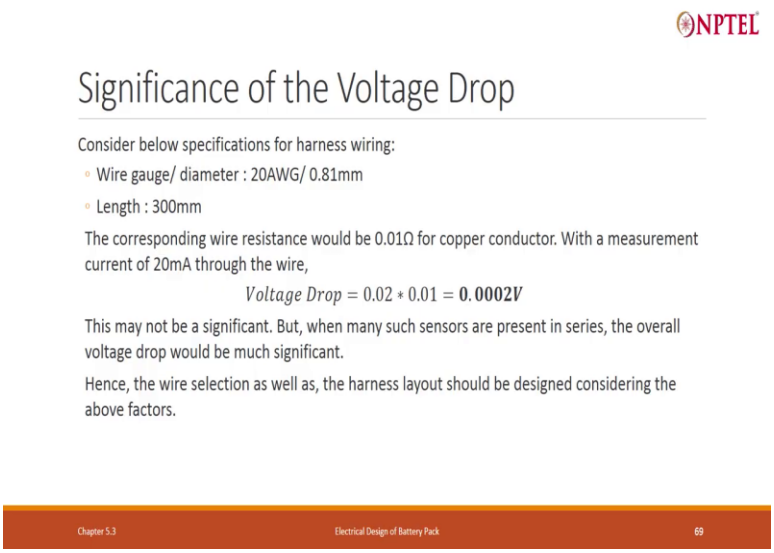

Now, significance of voltage drop. We try to solve example here. The wire gauge diameter is 20 AWG or 0.81 corresponding, diameter is 0.881 mm, length 300 mm. The corresponding wire resistance would be 0.1 ohm for the copper conductor. With a measurement current of 20 milli ampere through the wire, so 0.2 millivolt. Even though sensing current is 20 milli ampere, actually it should be 0.02 volt here, 20 milli ampere correct only, 20 milli ampere 0.02 volt into resistance will give you 0.2 millivolt. My sensing current is in milli ampere, my voltage drop is in millivolt.

But then when we are recalculating back, we are also talking about millivolt and microvolt only recalibrating in the sense, retrieving the voltage value. So, that is impact there. For low current it may not be significant, however for precision point of measurement it is becomes significant. Similar way for thermistor.

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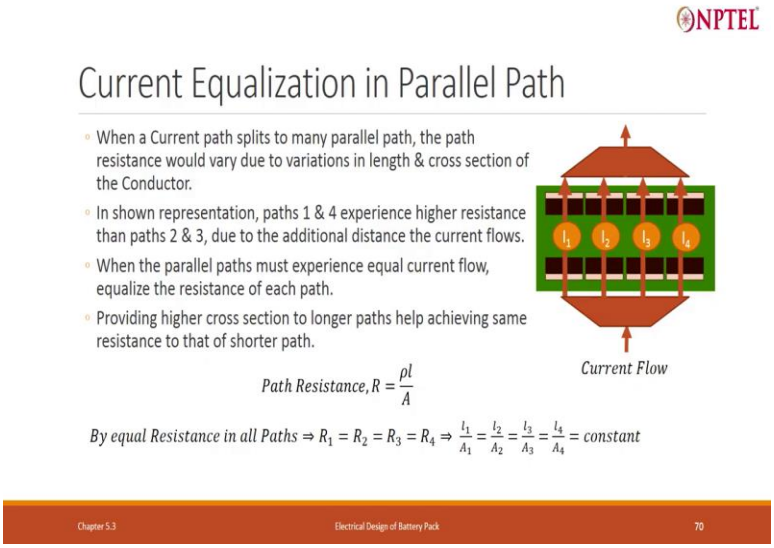

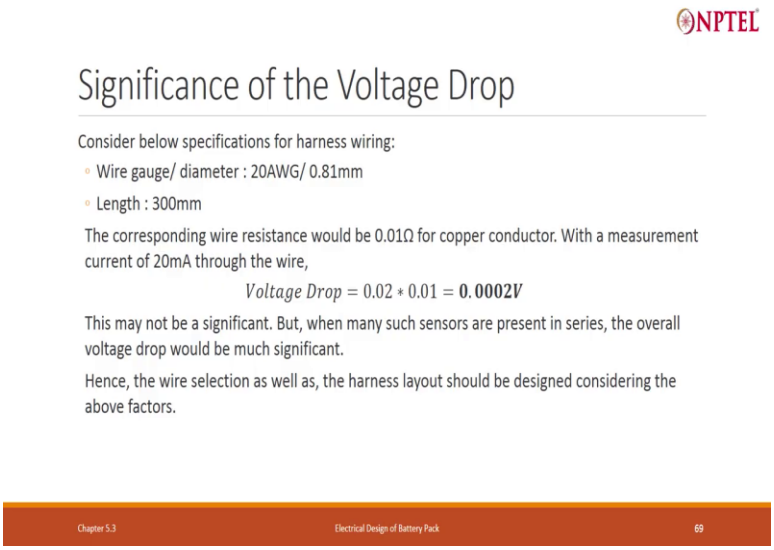

Before going to that, we would like to know about current equalization in parallel path, which we were talking initially. Now, if you talk about a BMF, it will have multiple switch, where we distribute the current equally. Why we distribute the current equally, because each one has a particular temperature limit. My temperature cannot exit more than 70 degree or 75 degree C. But then the corresponding current cannot be 8 ampere or 7 ampere. But if I have to draw.

Student: (())(12:07) So that 0.2 millivolt is acceptable or not acceptable.

Professor: It depends upon the precision of measurement what we are looking for. However, you always have a option to correct it through software gain, or by making the resistance equal in all

path. Which can be done otherwise also, not just by keeping all the length same, I can have thicker wire for a smaller length and can have

Student: For a longer length?

Professor: Like that way also that is what next…

Student: I just want found that it is only 0.12 ampere per mm square, density is very low. (())(12:55).

Professor: Yes, no that is what I am saying. It is all depends upon, what is the availability cost and then what you wanted to measure. Because when you talk about thermistor, thermistor also gives millivolt corresponding milli ampere current and then it recalibrate back again to the temperature. So, any error here in milli ampere would reflect back there also.

And the second thing generally we do the current sensing in all these cases, so may not impact much. But if there is something which is related to volt, like thermistor it is a voltage, how it gets converted into current, and then it senses, and then again converted back into the voltage, and then again converted back into temperature. Like right now, what we were discussing. Can we make equal assistance even in the case of wiring harness, yes, we can do, by increasing the thickness of the longer wire. But in that case, we have to use this different wires for different sensors.

Now, if you see here so we have the 4 gates here or 4 switches here or 4 paths here I1, I2, I3 and I4. Now, current is flowing here. What we ideally say that the current should be same in all the path. If it is not the same, what will happen, the sum path temperature would be higher than other path where resistance is more. But after seeing this you can easily say that I1 and I4 will have higher resistance because it has a longer path.

If you see here that I1 and I4 has a longer path than I2 and I3. So, if I do not consider thickness is remain same what will happen, I1 and I4 resistance is more. So, the current flow would be less then I2 and I3. I1 and I4 have the same resistance but more than I2 and I3, I2 and I3 has the same resistant but less than I4 and I1. So, what will happen here, the more current will flow through I2 and I3, less current will flow from I1 and I4.

So, if I have something known as the MOSFET let us suppose. So, my MOSFET what I have designed is for equal current because why equal current, because again the temperature would go there by, I square R, R is the internal resistance or junction resistance of the MOSFET. So, if I have to divide 30 ampere equally, so I will divide 7.5 ampere in all the path. But if in this path it is going 10 ampere, I2 and I3 it is going 10 ampere because of the less resistance and I1 and I4 it is going 5 ampere. What will happen, my this two MOSFET's I2 and I4 would reach to the elevated temperature much faster than I1 and I4.

So, what will happen, if my design criteria is 70 degree C or 80 degree C or 90 degree C it will reach there and it will try to go further. So, what will happen that MOSFET will fail. Once that MOSFET is fail, now these two paths are closed, all the current will pass through I1 and I4 ultimately it will fail I4 and I1 and I4 also. So, I have designed it for same resistance in, I wanted to design it for same resistance for all the paths. However, it has not happened, how can we do that?

When parallel paths must experience equal current flow, we must have the equal resistance in those paths, parallel path. How can we do that? What is resistance, path resistance? R is nothing but rho l by A. Now, rho is constant for all the path, what is not constant is l and l, is also same, no l is not same. However, what we were assuming A is same. If we vary the cross-sectional area depending on the length, then my current can be equalized because resistance can be equalized.

For that what we have do, rho is, rho is constant for all the path. What is changing, what we can change, l and A. So, for my all paths l1 by A1 should be equal to l2 by A2 should be equal to l3 by A3 and should be equal to l4 by A4. So, it is becomes a simple ratio. So, whenever my l is more, I have to provide more cross-sectional area. If my l is less, I have to reduce the cross sectional area there and this is how in most of the electronics, this is how it has been, it is being done to equalize the current, to equalize the current means, you have to equalize the resistance.

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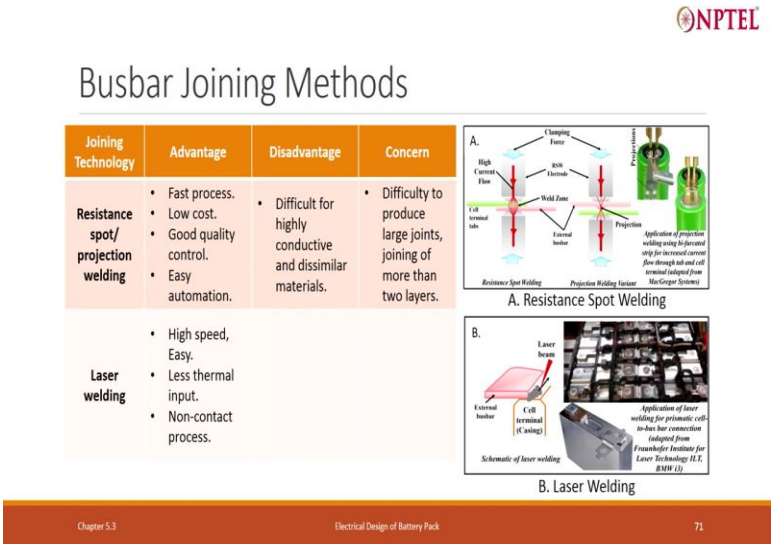

So, especially in electronic circuit if you see or even in the regular circuit, if I have, it is also depends upon limitation. So, I may not have a switch which can take this 100 amperes or 30 ampere see if I have to divide in multiple switch. So, some portion of current should go, equal portion of current in go in that.

So that is where we provide the several path, but then resistance of all the paths should be equal. Now, next we will be talking about bus bar joining method. How do we join bus bar to the cells. So, there is a mechanical joint, simple mechanical joint threaded where you put the nut and bolts and then tight it. But most of the time in battery pack you weld the bus bar because you will not have the option of providing the threaded screw and bolts. nut and bolt.

So, what are the methods for that one, we weld basically. So, there is a resistance welding, spot welding we say it. Very fast process keep on putting the two terminals, provide the current and it will keep on welding by heating effect, very low cost, good quality control. In fact, whatever in automotive you see it is a mostly spot welding.

Easily can be automated, you have to just move, put a moving table and then this comes goes, comes goes, like that way. Difficult for highly conductivity, conductive material and dissimilar materials. If there are copper and aluminium you have to weld it becomes difficult there or it is a very highly conductive you do not have any resistance because of resistance only the heat

temperature elevated and then melting takes place and both the things get joined. You can see into the picture.

In this you cannot produce very large joints. It is a very small dotted type of joint, very small, small joints, continuous joint and continuous dots. You cannot put the 10mm by 10mm joints with this. Temperature rise is measurable means not very significant that is why, because you do not want the temperature rise to be very high. Otherwise, your cell will get damaged. However, what happens in arc welding arc, welding we heat to very high temperature. So, that we cannot do it here in battery pack, especially when you are joining the bus bar.

Now, the next one is laser welding. In laser welding what we do, we put the bus bar over that and then we heat the bus bar through laser and that here is very localized it because your energy concentration is at very small area. So, the only localized heating happened and because of localized heating that particular portion get welded. It could be with continuous laser, it could be will pulse laser and the laser capacity depends upon the thickness of the weldment.

Again, it is a very high speed, EG less thermal input even in spot welding it is heats up it takes time, it is a very fast that much of energy can come quickly localized melting happens, and then welds get attached. Non-contact process, here in spot welding I have to touch both the things press. Here the laser beam can come from somewhere else and can weld your thing. Automation high automation, high initial cost. Because laser is very harmful to the people. So, you mostly you have to go for automation process, manual process does not work.

Because of the safety concern additional high (())(23:16) because it has a very high energy, concentrated energy. So, because of any reason it should not fall on you or anything else. In high reflective material what will happen, it will reflect back. You try to reduce the reflection; means you try to use the less reflective material for joining this process.

How does this contact points, the contact points for welding you always need to have a contact point, correct. How do you ensure that this contact points are attached with this here, this, so you may have to use some jigs and fixtures that, that contact points is in touch with each other with the proper pressure.

So, you have to need, you may need some jigs and fixtures. So, that is why need good joint fit up, which can intimate contact. There is a other method also ultrasonic welding, which we use

when my thickness is very, very low, like foil type of terminals when we have. So, that time we use ultrasonic welding.

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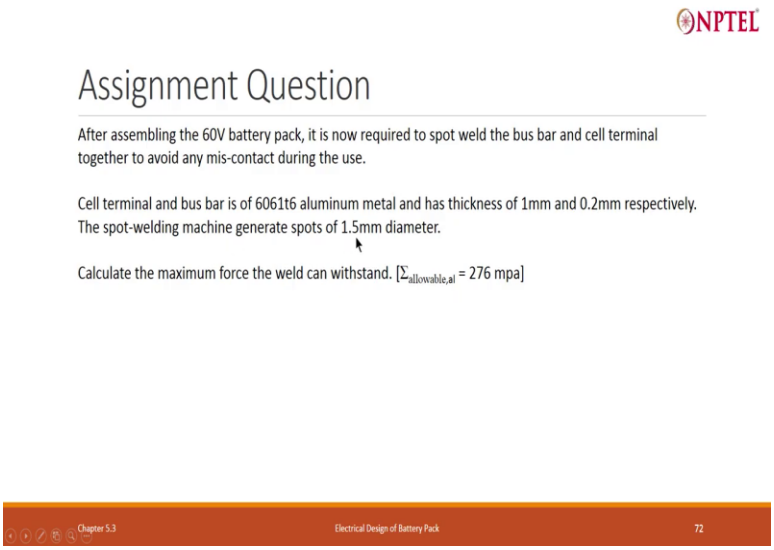

Now, after doing all the things one assignment question. After assembling the 60 volt battery pack, now it is now require to spot weld the bus bar and cell terminal together to avoid any miss contact during the use. Cell terminal and bus bar is of 6061T6 aluminium material and has a thickness of 1 mm and 0.2 mm respectively. The spot welding machine generates spots of 1.5 mm diameter. Calculate the maximum force the weld can withstand.

Because depending upon the weld strength you have to go for higher number of spots or lower number of a spots or higher thickness of the spot, higher die of the spot or low die of the spot. Sigma allowable has been given, its a capital sigma it is a small sigma is supposed to be that is 276 mega pascal.

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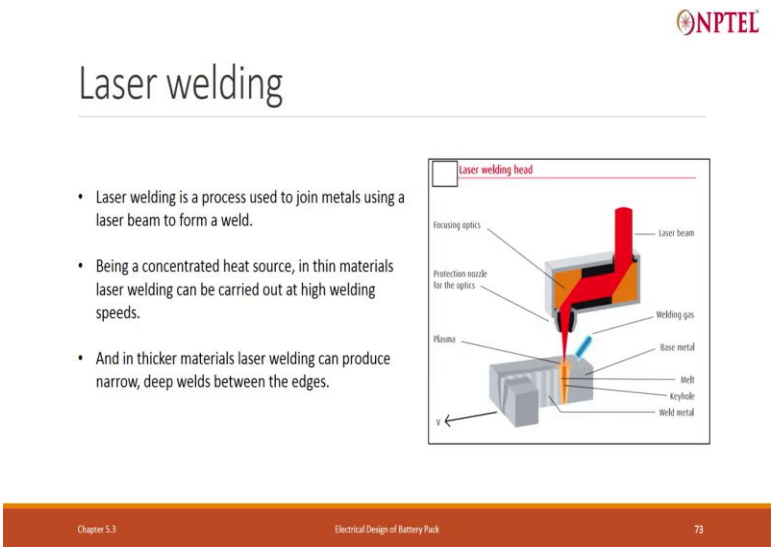

Now, what happens in laser building. If the material thickness becomes very big, so either we provide a keyhole, a small hole so that at that particular place the material thickness or bus bar thickness is low and so that it can penetrate, the heat can penetrate and get welded. Or if thickness is small enough, which can be heated by laser then we do not have to do the keyhole type of function.

Student: (())(26:26)

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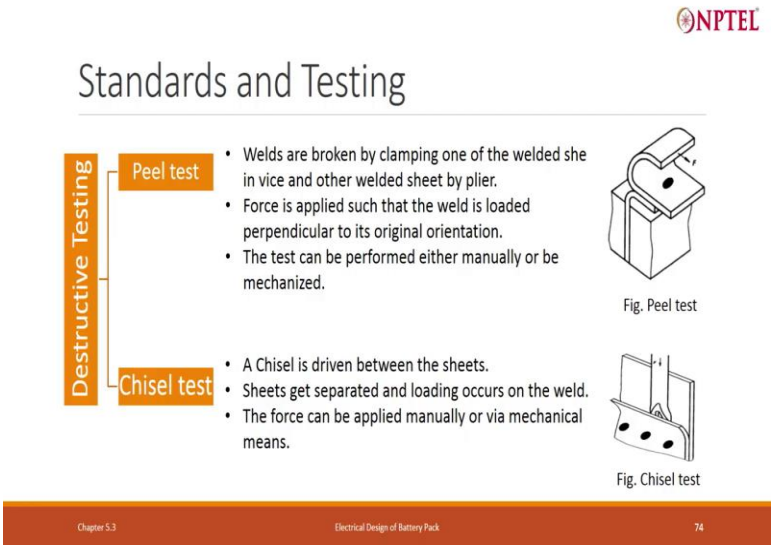

So, how do we test the welding, peel test and chisel test. Now, you have two weldment, you chisel with a force or you try to peel it and you can see the strength by providing the proper instrument there. So, this helps in mechanical consideration that even in this vibration, even in this loading my weldment will be still working. It would not get change. So, either you peel or you chisel in both the things you provide a external force, on that external force you need to measure and that would be the strength of the weldment.

Student: (())(27:27)

Professor: Yes.

Student: After testing I cannot use the (())(27:32)

Professor: Yes, so that is why some, these are destructive tests.

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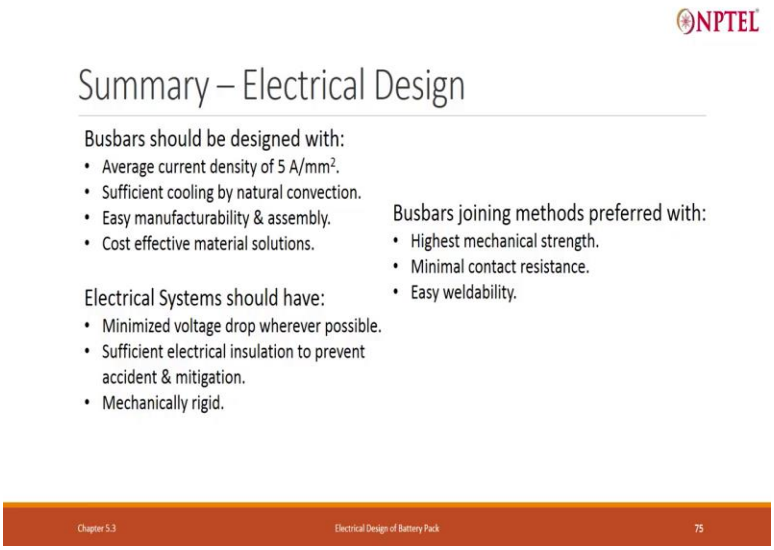

5.4 BMS Design for Electric Vehicle

Kaushal Kumar Jha Kaushal@tenet.res.in
Indian Institute of Technology, Madras

So, the summarize, we will summarize this section. Bus bar design should be designed with average current. Generally, we say 5 ampere per mm square, average current density. We should design in such a way that there should be sufficient cooling by natural convection. So, that we do not have to use any external means. Should be easily manufacturable and the assembly also, assembly should be easy. So, that would save in the production cost. Then materials should be cost effective. The and most widely material used for bus bar designing is copper and aluminium.

Now a days, aluminium is picking up. A electrical system either bus bar or cable should have the minimum voltage drop whenever possible. And how come we have a minimum voltage drop, by having minimum resistance, either it is due to contact resistance or because of the length or because of material resistivity or because of the elevated temperature, we should, we should try to reduce the resistance and thus automatically voltage drop would be reduced. Sufficient electrical insulation to prevent accidents and mitigation.

It is a very important, when we are talking about low voltage it does not make much different. But however, whenever we are going for higher voltage, more than a 10020 volt DC it is place significant role in the safety and any accidental touch. It should be mechanically strong enough to sustain the vibration, thermal inducing stresses. Bus bar joining methods, how do we join. For lower cost, lower thickness we preferably go for spot welding. However, where fully automation is required, laser welding would be a good substitute. It is a fast and very localized heating, so does not impact thermally cells or other components.

So, in next class, we will start BMS design for the electric vehicle. Anything thing, any questions? So, what essentially in this chapter, in this section we have understood. What is electrical design, so electrical design is basically the current flow path, either you take bus bar or you take cables. We try to reduce the resistance of any form by selecting a proper material by reducing the contacts and streamline resistances.

Then we also need to consider the mechanical and thermal stability and the our ultimate aim is always to reduce the voltage drop and that can happen by reducing the resistance. And then there are several ways we can reduce the resistance by selecting material by providing sufficient cross-sectional area. So, any question? So, next class we will go for the BMS design and with that we will complete, this chapter.