Course Name: Design of Electric Motors

Professor Name: Dr. Prathap Reddy B

Department Name: Electronic Systems Engineering

Institute Name: Indian Institute of Science Bengaluru

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Title: Stator Winding Design-Double Layer Winding

Greetings to all. In this lecture, we will discuss the stator winding design with an example on full pitch double layer winding. Here, we will see how to select the coil pitch, number of coils, winding diagram in detail and with stubbing and arrow check approach. Let us consider an example 24 slot, 3 phase, 4 pole double layer winding with full pitch. We can see here 24 slots and with respect to the stator core and all slots are numbered 1 to 24. So, the winding design procedure will be same to make any type of winding.

So, we have to analyze the given data and then define the type of winding, whether it is double layer winding, full pitch winding or short pitch winding, those things. Then, select the number of turns per phase by utilizing the Faraday's law of voltage equation and select the copper gauge with respect to the current rating and then make the coils. After making the coils, let us say it is double layer winding, how many coils will come? Either it is 24 or 48. So, 24 coils we are considering means 24 coils we have to make.

After making the 24 coils with respect to the coil pitch, place all coils in a symmetrical manner and connect the coils with an additive polarity by utilizing the stubbing and arrow check approach. We can follow the arrow direction based upon that thing. We can connect the coils and verification of magnetic poles with right hand thumb rule principles and then winding check with respect to the body and with respect to the neutral phase to phase, is there any short or not? Finally, we can bring 6 terminals coming out with respect to the 3 phase machine. If it is m phase machine, 2 m number of terminals, we have to bring it out to make star and delta connections and test the machine with under the operating conditions. Let us consider the same 24 slot machine, 3 phase, 4 pole winding slots per pole per phase is equals to 2 and coil pitch is equals to 6 slots and coil sides are layers per each and every slot is nothing but 2.

That means, each slot we have to place 2 coil sides and number of total number of coils is equals to coil sides per slot into total number of slots by 2. It will give 24 coils. That means, first we have to make 24 coils in this fashion. We can see the coil here. This is

the coil and the number of slots per pole are coming 6, because it is a 24 slot machine and 4 pole.

That will give 6 slots per pole and phase spread for each and every phase 2 slots we have to accommodate. That is slots per pole per phase is equals to 2, based on that thing. 3 phases, first phase will be 2 slots, second phase will be 2 slots and third phase will be 2 slots under one particular pole. Now, we will place the coils. Before placing the coils, we have to make like this kind of coils.

We can see here, I am showing one coil. Like this 24 coils, we can make it. This is the one. So, each coil how many number of turns are there as per the given voltage and power ratings and the wire SWG, we have to select based upon the current. For this example, we require 24 coils like this manner.

It is a double layer and full pitch winding. This coil pitch will be 6 slots. So, after making like this 24 coils, one by one we have to place. Let us say this coil side, I will place in slot number 1 with respect to the reference. I am considering the starting point will be slot number 1.

So, I will place this coil side first. We can see here. So, the first coil side, I am placing in slot number 1. One by one, the conductors we have to insert in the slot here. In the empty slots, one by one we have to insert here and here.

So, the first coil we are inserting in first slot and seventh slot bottom side. Here, 7 dash represents seventh slot bottom side. We are placing the coil and without dash x represents the coil side. We are placing at the top side of the slot. So, the first coil we are placing slot 1 top side, slot 7 bottom side.

Second coil that is related to the first phase only because the coil span or coil belt or phase belt is equals to 2 slots based upon that thing. Second coil we are placing in slot number 2 top side and slot number 8 bottom side. We can see here how we are placing the coils. This is slot number 1 top side. This is slot number 7 bottom side, slot number 2 top side, slot number 8 bottom side.

So, like this 2 coils we have placed in the 4 slots. After placing these things, it is a double layer winding because of that reason instead of starting from other phases, we have to follow from the seventh slot because already bottom side we have filled the conductors. So, it is easy to fill the conductors at the top side. So, here I will place the next coil that we can see seventh and eighth slot top side we have placed like this 2 coils. We are placing one is at seventh slot top side, the other end of the coil is thirteenth slot bottom side such that in a sequence we can make the windings.

At the end, only we have to remove these 2 coil sides and place the conductors at the bottom side of first and second slot and then again we have to place back the first and second coil sides. So, in a single layer winding, we can come in any fashion, but in a double layer winding, first we have to place the bottom side conductors and then we have to place the top side conductors. We can see same manner here thirteenth and fourteenth slot top side and nineteenth and twentieth slot bottom side 2 coils we have placed. This coil side is placed in thirteenth slot top side, this coil side is placed on in nineteenth slot bottom side that is nineteen dash. Same manner another coil also we are inserting in fourteenth slot top side and twentieth slot bottom side.

Next we have to fill in this place. So, nineteenth and twentieth slot top side we are placing the coil sides and first and second slot bottom we have to place. That means, already we have placed this one and two right top side we have placed the conductors. In order to place the conductors at the bottom sides or coil sides at the bottom, we have to remove this one and two outside. Then we have to place one dash and two dash first coils related to the twentieth and nineteenth slot first.

Then we have to place the coil side related to the seventh slot and eighth slot at the top side. This is one and seven dash, two and eight dash right. Initially, we have placed one and two as a reference. At the end we have to bring these two coils out and then insert these two coil sides after placing the bottom side coil sides that is one dash and two dash these two things. Similarly, for B phase or second phase three and four top side the two coils one coil is placed at the top side of slot three and bottom side of slot number nine.

Next coil is placed in slot number four top side that is this one and slot number ten bottom side. Similarly, the slot number ninth top side and slot number fifteen bottom side same fashion ten and sixteen dash. Here coil pitch is decided based upon the full pitch winding one plus six is equals to seven and for example, nine plus six is equals to fifteen. So, ninth slot top conductor that is without any dash is connect we are placing in the other end is in fifteenth slot bottom side. So, the remaining conductor coil sides related to the B phase also placed in the machine.

We can see these four and these four all eight slots are filled with second phase conductors or second phase eight coils. Next C phase coils we can see here first coil related to the C phase is placed in fifth slot top side then eleventh slot bottom side. This is the let us say this is the coil related to the C phase or third phase. So, this starting will be placed in fifth slot and second coil side placed in eleventh slot. So, let us say we are placing in at this particular slot means that is five and next slot bottom side eleventh dash we have to keep and then from eleventh we have to start top side of the eleventh slot then that complete slot will be filled with coil sides.

So, with respect to the A phase we can see here eight coils earlier for single layer winding we have seen per phase four coils because of the double layer winding each phase has eight coils and total number of coils in the machine are twenty four that is twenty four coils that means forty eight number of terminals are there this papers wire end terminals we can see here in the machine forty eight number of terminals are there in the machine. So, how to connect this forty eight terminals for that we will follow the stubbing method with arrow representation. So, the number of coils per one stubbed winding with respect to double layer winding is equals to slots per pole per phase the number of stubbed windings for to make the complete machine winding are. So, for that M S into slots per pole per phase into pole pairs that will give twelve stubbed coils we have to make even though we have twenty four coils in the machine we will make twelve stubbed windings these twelve stubbed windings only we will make the connections by utilizing the arrow representation we can see here one stubbed winding first coil related to the A phase or first phase with respect to our reference second coil. So, the first coil is placed in slot one, top side and slot seven bottom side that is this one and slot two top side and slot eight bottom side these two coils we are making as one stubbed winding and it is a virtual representation for these two coils the starting will be one and ending will be one dash same physical representation for easy purpose we are representing as one stubbed winding as a virtual manner.

So, this stubbed winding starting will be one and ending will be eight dash this connection we have to make it with copper we have to join the seven dash coil side end terminal and second slot top side coil side starting terminal the ending terminal of first coil and starting terminal of second coil we have to connect the ending terminal is placed at the bottom side of slot number seven and starting terminal of second coil is placed in starting top side of the slot number two next the stubbed coil with respect to the second phase I am representing with B. So, the coils which are placed in slot number three top side slot number nine bottom side slot number four and slot number ten we are making as one stubbed winding starting will be three and ending will be ten dash similarly C phase one stubbed winding I am making and it is a combination of two actual coils we are making connection and we are making as one stubbed winding. So, total twelve stubbed windings we have to make from the twenty four coils two two coils we are joining each other in this fashion and we are making two coils equivalent as one stubbed winding. So, finally, we have twelve stubbed winding means twenty four terminals with twelve stubbed windings without stubbing twenty four coils and forty eight terminals are there. So, how to connect this twelve stubbed windings and twenty four terminals for that we will follow the arrow check representation for symmetrical and greater than three phase machines one arrow will be forward and one arrow will be backward direction for asymmetrical and two phase machines two arrows will be forward and two arrows will be backward direction and the number of arrows will vary with respect to the stubbing coils let us say twenty four stubbed coils are there twenty four arrows twelve stubbed

coils are there twelve arrows in this example we have twelve stubbed coils each stub winding consist of two coils two actual coils related to that particular phase winding.

So, first stubbed winding I am representing with arrow in this fashion that is s one we can see here next s two with respect to the next stubbed winding here we can see s two then s three with respect to the c phase these two coils the coil side which is placed in slot number five top and slot number eleven bottom side slot number six top side and slot number twelve bottom side these two five and eleven dash and six and twelve dash these two coils we are connecting with external connection and we are making as one stubbed winding that arrow will be in this fashion arrow will be forward one arrow forward one arrow backward and again one arrow forward same fashion one is forward backward like this fashion we can represent twelve arrows each and every place we can see s one is forward direction s two will be backward direction like that manner by utilizing these arrows we will connect the stubbed windings to make the symmetrical three phase winding these are the four poles let us consider first six slots are forming one pole and next six slots are forming second pole like that six slots the conductors related to excited currents it is forming the four poles that we have to verify after making the winding connections. Let us consider the stubbed windings related to the a phase or four windings are there we can see here this is seven or sorry first and eight dash then seven and fourteen dash and thirteen and twentieth dash nineteen and two dash. So, this is the actual winding and we are representing as a virtual manner one stubbed winding, but that stubbed winding has the terminals information same as the physical winding we will follow this arrow check approach to make the connections we have to walk through the along the arrow direction let us say this arrow is in this direction next arrow is in this direction we have to follow this head to this tile next arrow tile not only this s one to s four s one to s seven or s one to s ten also we can connect we can see the first connection s one arrow head is this one in this fashion and s four arrow head is in this direction. So, this connection we are making now and next thing with respect to the s seven s four head is connected to the s seven tile point the same thing we can see s four arrow head point is this one then s seven arrow is like this fashion this is the tile point. So, this is the head point of s four.

So, we are connecting this connection same fashion we have to follow the arrows only four arrows are there with respect to the a phase s one s four s seven and s ten. So, with respect to this arrow in this direction s four will be in this fashion s seven is like this s seven is in this manner. So, we are just following the arrows. So, this is starting of a and this is ending of a that four arrows we can see here that particular connections this is starting of a phase and this is ending of a phase same manner we can connect the b phase and c phase connections this b and this is c let us say I am starting from this arrow and next arrow is like this. So, this head point I am connecting here and tile point we have

connected this head I am following the next arrow tile the next arrow head I am connecting to the next arrow tile in this fashion we can connect.

So, we are just following the arrow direction to make the winding connections. So, this connections we have to make with copper like we can make the soldering to make the rigid connection between the two coils. So, with respect to the terminal let us say this is some number x this is some number y. So, these two terminals we have to connect with copper with soldering proper soldering this is c phase here also same manner I am considering this is starting point s 3 same arrows one will be forward one will be backward. So, here with respect to the arrow representation we will connect the coils.

So, from this point head we are connecting to the tile these two points and then from this point head to connected to this tile point and from here to here and then as per the arrow we are coming out with the connections this is c dash. So, the final three phase connections we can see in this fashion all these three phase things this is at 0 degrees b phase at 120 degrees with respect to two poles c phase at 240 degrees or I can say b phase at 240 degrees c phase at 120 degrees we have to change the representation that is it as per the physical winding displacement all three windings are displaced by 120 degrees depends upon the phase sequence it will rotate either clockwise or anticlockwise that we have to verify and then we can change this terminal as b and this terminal as c if requires. And we will discuss now how to make the stubbing each stubbed winding consist of two coils in method one we are making the stubbing after placing the all coils inside the machine let us say these are the four terminals we have placed inside the machine these two coils and we are making this connection after placing all coils. So, stubbing is done after placing all coils that is method one whereas, the method two and method three the stubbing we will do before placing the coils inside the machine let us take this is coil one and this is coil two which has to be placed in slot number one top side slot number seven bottom side same fashion other slots. So, these two coils outside will connect in series and then two terminals only we will take that means, stubbing we are doing before placing the windings here coil pitch is same in both coil six and six whereas, in the method three the coil pitch with respect to the outer coil side is seven with respect to the inner coils coil sides is five.

So, one coil will be over pitched other coil will be short pitched, but the resultant pitch seven plus five by two will be six the copper will be same in all three type of stubbing approaches to minimize the connections. So, without after placing the windings this connection we have to do externally by following stubbing method two and stubbing method three the connections will be minimized the number of terminals to connect will be minimized where the stubbed winding consist of only one coil which is a representation of coil one and coil two based on that thing we can connect the different windings. With this I am concluding this lecture in this lecture we have discussed the

winding design with respect to double layer full pitch winding how to make the connections and how to develop the winding diagram etcetera. Thank you.