

Course Name: Design of Electric Motors

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Title: Stator Winding Design-Fractional Slot Double Layer Winding

Greetings to all, in this lecture we will discuss the stator winding design with an example on fractional slot windings. Here we will discuss the coil pitch and how to select the number of coils, how to make the connections using stubbing and arrow check representation and also complete winding design. We can see here fractional slot winding and 18 slot 3-phase 4-pole winding as an example and 18 slot stator core we can see here and slot numbers from 1 to 18 have represented and the slots per pole per phase small q is equals to capital Q divided by number of phases into number of poles that will give $3 \text{ by } 2$ because it is a fraction q value is equals to $3 \text{ by } 2$ that is the reason we are calling this type of winding is fractional slot winding. Next pole pitch is equals to $18 \text{ by } 4$, 18 slots divided by 4 poles it will give 4.5 and $9 \text{ by } 2$, $9 \text{ by } 2$ also a fraction and we have to distribute 4 and of slots under each and every pole. We can see here different color representation this is pole 1, pole 2, pole 3 and pole 4 under each pole 4 and of slots are accommodated.

So, in order to split or in order to share the slot into 2 parts we have to design the double layer winding for that thing and coil pitch is equals to 4.5 with respect to the pole pitch. If we want to design a full pitch winding coil pitch also should be 4.5 which is not possible we can select either 4 or 5.

So, if we will select the coil pitch is equals to 4 slots then it will be short pitch winding and if we will select coil pitch is equals to 5 then that type of winding is called over pitch winding. So, for this example I have considered coil pitch is equals to 4 slots and slots per pole per phase is a fraction. So, in order to make the winding double layer winding is required and slots the coil sites or layers per slot will be 2 and the number of coils with respect to the double layer winding is 18 and coils per phase is equals to 6 and total number of coils to make the winding is 18. The winding design procedure is same as the single layer winding and double layer winding. First we have to define the number of turns with respect to the Faraday's law of voltage equation then conductor gauge

selection with respect to the current for a given voltage for a given power rating and we have to make the 18 coils with respect to the given example like 18 slot 3 phase winding double layer.

So, 18 coils we have to make and coil pitch is 4 and after that we have to place the coils in respective slots and before placing the coils we have to place the slot liners we can see in this image the white color one to insulate the conductors from the stator core. And coil side separators between the 2 coil sides let us say here these are the 2 coil sides in between we have to place the coil side separator that is insulating papers we have to place and winding connections with respect to stubbing and arrow check approach and verification of the developed winding with respect to the right hand thumb rule for magnetic pole formation and placing the insulating papers and sticks to close the slot and end winding threading and varnishing to make the rigid and tight with respect to the winding and validation of complete machine at the rated operating conditions. Now first we have to place the coils one by one. So, with respect to the coil 1 this is one coil side this is second coil side with respect to the coil 1 like this 18 coils we have. So, first coil side we have to place in slot 1 and next coil side we have to place in slot 5.

Since it is a double layer winding we have to place one coil side at the top side other coil side at the bottom side as per the coil pitch $1 + 4 = 5$. So, one coil side we have to place at slot number 1 other coil side we have to place at slot number 5. slot number 2 we have to place the coil side in slot number 2 and slot number 6 this is second coil. We cannot place one more coil in the slot 1 because one end of slots we have to distribute for each and every phase right. So, if we will place one more coil here the C phase conductors we cannot accommodate it.

So, each coil phase spread will be one end of slots only. So, one coil side which are placed at the bottom side of the slot number 1 will go backward manner. Next slot number 6, but top side will place the coil and the next end will go to the slot number 10. We can see the next coil related to the A phase. Similarly, the fourth coil related to the A phase which is placed in slot number 10 and slot number 14, $10 + 4 = 14$.

So, 10th slot top side and 14th slot bottom side the conductor is placed and same fashion we will place the conductors or coil sides in slot number 11 and slot number 15. The last coil related to the A phase is placed in 15th slot top side and first slot bottom side. Here we have already placed the conductors at the top side of the slot right. So, in order to place the second coil side that is at the bottom side initially we have done the coil side at the top sides right. So, now, if in order to place the coil side at the bottom side we have to remove the coil side at the top side then place the coil side at the bottom side then we have to place the return conductor with respect to the first coil which is placed in slot 1 and 5.

All 6 coils related to the 1 phase winding is done. We can see under each and every pole 1 and of slot is occupied by first phase whether it may be A or B or C depends upon the excitations. So, the A phase winding is done. Next in order to place the coils related to the next phase let us consider here we are placing the coils second slot bottom side at this particular place. So, 2 plus 4 is equals to 6 already 6th slot is filled with A phase conductors or first phase conductors.

So, which is not possible in this combination. So, 2 minus 4 we have to do that will give minus 2. So, minus 2 plus 18 slots will give 16 slot numbers. So, this second slot bottom side and 16 slot top side we have to connect that we will see at the end. Now, we will see whatever the conductors which are going forward manner.

We will place the conductors in next slot that is third slot and seventh slot are filled with 1 coil. And next seventh slot top side and eleventh slot bottom side we will place the conductors because if we will place the conductors at the bottom side of the third slot then 3 plus 4 is 7 already 1 conductor is placed in the seventh slot in a forward direction. And the next conductor should go in a backward manner otherwise the conductors related to the B phase completely placed in third slot and seventh slot both are coming in forward direction. If we will do in that manner the winding symmetry will not come with respect to the end ring for that reason leave the coils which has to be placed in second slot and third slot bottom side. At the end we will fill these two positions.

Now, we will go in forward direction the coil side which is placed at the top side of the seventh slot is connected to the eleventh slot which is placed at the bottom side. Next eighth slot top side and twelfth slot bottom side conductors are connected or coil sides we have placed in eighth slot top side and twelfth slot bottom side. Next coil we will place in twelfth slot top side and sixteenth slot bottom side. So, similarly the coil related to the next phase we will place in sixteenth slot top side and second slot bottom side we can see here. Similarly we have not filled this position, but now sixteenth slot to second slot bottom we are connecting and next seventeenth slot top side to third slot bottom side we are filling the coil or conductors.

All six coils related to the second phase winding also done. We can see each under each and every pole one and half slots are accommodated with respect to the second phase. So, the brown color one 3 3 coil sides placed in under each and every pole. Next we have to place the third winding coil sides right we can see here empty places 3 3 places are there in each and under each and every pole. So, the coil the first coil related to the third winding is 4 fourth slot top side and eighth slot bottom side and next coil fifth slot top side and ninth slot bottom side.

If we will consider this part that is fourth slot bottom side 4 plus 4 will come 8. So, already eighth slot top side is filled with B phase conductors or second phase conductors

because of that reason this empty portion or fourth slot bottom side will place the conductors in a reverse or backward manner that will filled at the end of the C phase winding. So, the next coil is placed in ninth slot top side and thirteenth slot bottom side we can see the ninth slot top side and thirteenth slot bottom side one. Next thirteenth slot top side and seventeenth slot bottom side same way 14 plus 4 will give 18 14th slot top side and 18th slot bottom side conductors are placed or coil sides are placed related to each and every coil. We can see the coil here one coil side is placed in 14th slot next coil side is placed in 18th slot bottom side.

So, the last coil related to the third phase or C phase windings are 18th slot top side that is this portion and fourth slot bottom side. So, for forward direction with respect to the fourth slot top side will be eighth slot top side that is not possible fourth slot bottom to eighth slot top side that is why we kept empty at the starting at the end 18th slot top side is connected to the fourth slot bottom side. Like this way the winding coils related to the third phase also placed in the respective slots. We can see the complete coil placements with respect to the all three phase windings under each and every pole one and of slots are accommodated each and every phase. So, the coils related to the A phase winding we can see here 6 coils are there because the total number of coils are 18.

So, 18 by 3 phases will give 6 coils. So, 6 coils related to the A phase have presented here. So, total 18 coils means 36 terminals we have. So, these 36 terminals we have to connect in such a fashion then we will get the 3 phase 4 pole winding for symmetrical operation. So, how to connect all these 18 coils with respect to 36 terminals? We have to follow the stubbing approach with arrow representation.

Stubbing approach is nothing, but virtual representation of these physical coils and we will follow or we will utilize the arrow representation to connect these 6 coils. Whatever the 6 coils related to each and every phase are there that 6 coils we will connect by utilizing the arrow representation. So, the number of coils per 1 stubbed winding we will calculate with respect to the slots per pole per phase that is 3 by 2. So, one virtual stubbed winding is equivalent of one and of windings. So, splitting this winding is not possible, once we have placed the coil.

So, 3 by 2 number of coils to make one stubbed winding is not possible because of that reason we will make the stubbing in different manner that we will see and number of stubbed coils to complete the windings also will change. As per the 3 by 2 ratio for each and every stubbed winding has one and of coil, we have to split each coil into half and half, so which is not possible. So, with respect to that 9 stubbed windings are required. So, 9 stubbed windings representation is not possible with respect to the splitting of each winding. So, for that reason we will make the stubbed windings few stubbed windings with one coil and few stubbed windings with 2 coils.

We have 6 coils per phase. So, these 6 coils we will represent as 4 sets like first set will be one coil, second set will be combination of 2 coils, third set also will be one winding and fourth set will be 2 coils like this manner. So, 2 stubbed windings consist of 2 coils and 2 stubbed windings consist of one-one coil respectively that we can see here. Total number of stubbed windings required for each and every phase will be 4 and with that number we will get total 12 stubbed winding with respect to 3 phase machine. So, the stubbed winding representation for the first 2 coils that is placed in first slot and fifth slot and second slot top side and sixth slot bottom side we can represent in this fashion. It is stubbed winding 1 that is represented as A 1.

It is the virtual representation of these 2 coils starting will be 1 and ending will be 1 dash. Stubbed winding is nothing, but virtual representation of the physical windings. These are the 2 physical windings or 2 physical coils that we are representing with one virtual stubbed winding and same fashion second stubbed winding consist of only one coil because we cannot split this winding into 2 parts and one and half one and half we cannot make it because of that reason the complete coil will be one stubbed winding. So, earlier stubbed winding 1 consist of 2 coils, stubbed winding 2 consist of only one coil because of one coil in this stubbed winding I represented with dashed line and same fashion next stubbed winding consist of 2 coils that is 10th to 14th one coil 11th to 15 slots second coil. So, these 2 coils I am representing with one stubbed winding.

So, the fourth stubbed winding related to A phase is this one the coil which is placed in 15th slot and first slot top side. So, A phase has 4 stubbed windings that 4 stubbed windings we can see here A1, A2, A3, A4 and with respect to the radial view we can see here first stubbed winding is representing starting of first coil that is one ending of second coil is 6 dash and second stubbed winding starting will be 6 ending will be 10 dash and third stubbed winding starting will be 10 ending will be 15 dash for this one 15 and 1 dash. So, we have to connect this 4 stubbed windings to complete the A phase winding and similarly B phase stubbed winding representation we can see here this is the virtual representation of first stubbed winding and second stubbed winding third one and fourth. So, B phase also has 4 stubbed windings each stubbed winding consist of one or two coils. So, the first B1 stubbed winding consist of one coil and B2 stubbed winding consist of two coils those two coils are placed in slot number 7 and slot number 11 bottom side slot number 8 and slot number 12 bottom side these two coils were joining externally and we are making one stubbed winding earlier also in order to make the stubbed winding with respect to A1 this connection we have to do externally by utilizing the copper same way for A3 also.

This is the stubbed winding with respect to the B3 stubbed winding with respect to the B4 we can see here the connection for this coil and this coil we have to do manually by utilizing the copper same fashion for C phase winding also we can make the stubbing C1 consist of two coils which are stubbed or connected by utilizing the copper wire second

stubbed winding in C phase consist of only one coil third stubbed winding consist of two coils those two coils are placed in slot number 13 and 17 dash 14 and 18 dash then fourth stubbed winding consist of only one coil we can see here in a fractional slot winding each and the number of stubbed coils are coming 9, but with respect to the 3 by 2 slots per pole per phase or 3 by 2 number of coils per one stubbed winding which is not possible because of that reason. So, one stubbed winding we have done with two coils other stubbed winding we have realized with one coil. So, that cumulatively both stubbed coils has three windings. Now, arrow representation we will discuss with respect to the connections. So, the stubbed winding one has arrow in forward direction for symmetrical and 3 phase greater than 3 phase machines one arrow will be forward and one arrow will be backward direction and for asymmetrical and 2 phase machines two arrows will go forward and two arrows will come backward direction.

The number of arrows depends upon the number of stubbing coils here number of stubbing coils are 12. So, 12 arrows will come one arrow will go forward manner other arrow will come backward manner because it is a symmetrical 3 phase machine. So, the first stubbed winding arrow direction we can see here second stubbed winding arrow will be backward direction third stubbed winding arrow will be forward that is with respect to the C 1 fourth stubbed winding fifth six seven like that up to twelfth stubbed winding we can see based upon the arrow direction we will connect the coils to complete the winding diagram. These are the poles visualization under each and every pole four and half slots will be there that is 4.5 slots and the current with respect to this poles will be in same direction and flux loops also in the same direction and here north pole this is south this is north pole and this is south pole.

Now, we will make the connections these are the just virtual representation of the poles at the end after making the winding connections by applying the right hand thumb rule we can visualize the number of poles. Here the arrow representation for stubbed winding one is in forward direction arrow representation for S 4 is in backward direction we can see this is the virtual representation of terminal 1 and terminal 6 the coils which are placed in slot 1 and slot 6 bottom side second stubbed winding consist of only one coil which is placed in sixth slot and tenth slot bottom side here arrow will be backward that is S 4 here arrow will be forward that is S 1 and here S 7 we can see this is the arrow here it is S 10 in backward direction that will be in this direction. So, with respect to this arrows we will make the connections. First connection we can see here the starting point will be this one.

So, arrow S 1 is in this direction. So, we are coming in this direction and then S 1 arrow head is connected to the S 4 arrow tile. So, from here to here connection is there. So, that connection is nothing but this one here S 4 tile point we can see here arrow point is here. Next S 4 arrow starting point or head point of S 4 is connected to the tile point of S 7 this

is tile point is nothing but this one. So, the connection is this thing we can see the connection initially S 1 headed to S 4 tile S 4 headed to S 7 tile S 7 headed to S 10 tile.

So, this is ending point of A phase this is starting point of A phase we have to make the connections in this fashion with respect to the arrows. Arrows I am representing here this is S 7 S 4 which are presented here already for better visualization I am drawing again this is S 10. We can see the connection simply I am connecting one head of the arrow to other tile of arrow here arrow direction is here this is the connection is in this fashion. So, this head is connected to the tile point of the next arrow this head is connected to the tile point of next arrow that is this connection at the end this is the final terminal with respect to the A phase this is starting and this is ending terminal. So, with respect to the arrow representation we can connect the coil in a simplified manner.

So, at the end we can see this is the starting point will be first coil which is placed at the top side of slot 1 and the ending will be 15th coil which is placed at the 15th slot top side this coil because we are taking the end connection from here. So, these two are connected these two are connected here these two this is starting and this is ending A dash same way B phase and C phase connections we can see here B phase is starting from arrow S 5 here this arrow is in this direction. So, we are starting from the tile point of S 5 and then S 5 head is connected to the S 8 tile point that is this one S 8 tile point then this connection is done then S 8 head should be connected to the S 11 is this one S 11 tile point. So, these two has to be connected then S 11 tile head point is this one that has to be connected to S 2 tile point.

Arrow is in this direction now. So, with respect to this arrow head is connected to the next arrow tile and arrow head we are taking out this is terminal B dash and it is B same fashion the four arrows related to the C phase we can see here this is arrow 1 and arrow 2 and arrow 3 and arrow 4. So, with respect to the S 3 arrow where this is the head is connected to the tile of next stubbed winding and head of the second arrow that is S 6 is this one head of the S 6 is connected to the tail of the S 9 and head of the S 9 is connected to the tail of the next coil that is next stubbed winding S 12. So, head related to the twelfth coil is coming out that is C dash. So, these are the final connections related to the A phase B phase and C phase. So, from these three terminals we can give the excitations the other three terminals we can make it either star if it is delta manner we have to connect all six terminals in delta manner and we can excite the machine with three phase supply and end winding threading and varnishing has to be done after making the winding before doing the varnishing and threading we have to verify the coil placements by utilizing the right hand thumb rule and current excitation should be 120 degree displaced consider any instant let us say A is positive current B phase having the positive current C phase having the negative current.

So, with respect to this instant whether four poles are forming symmetrically or not we have to verify once the symmetrical poles are forming then we can do the varnishing and threading etcetera and we can bring all six terminals out and we can assemble the complete machine then we can test at the operating conditions with this I am concluding this lecture in this lecture we have discussed the fractional slot winding design and developed winding diagram by utilizing the arrow check approach. Thank you.