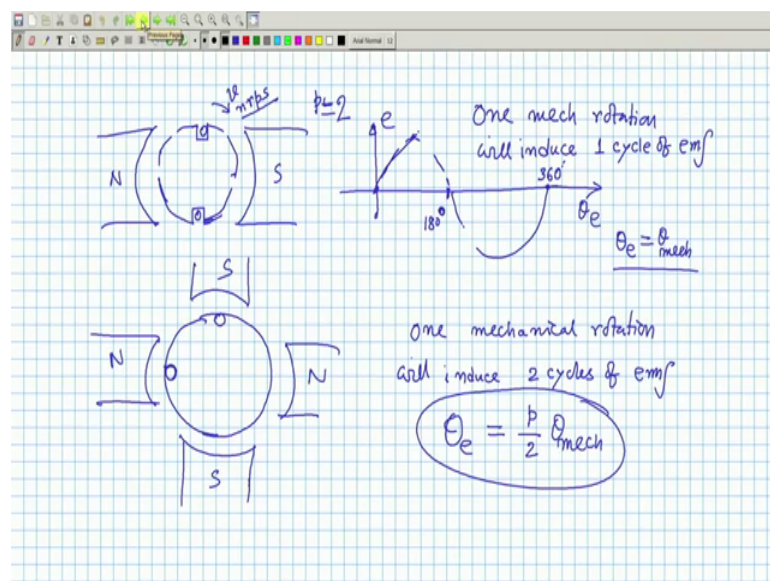


Electrical Machines - I
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 59
Armature Winding of D.C Machines - I

Welcome to lecture number 59 and we have been discussing about the DC machines, in our last class the diagrams were a little bit clumsy.

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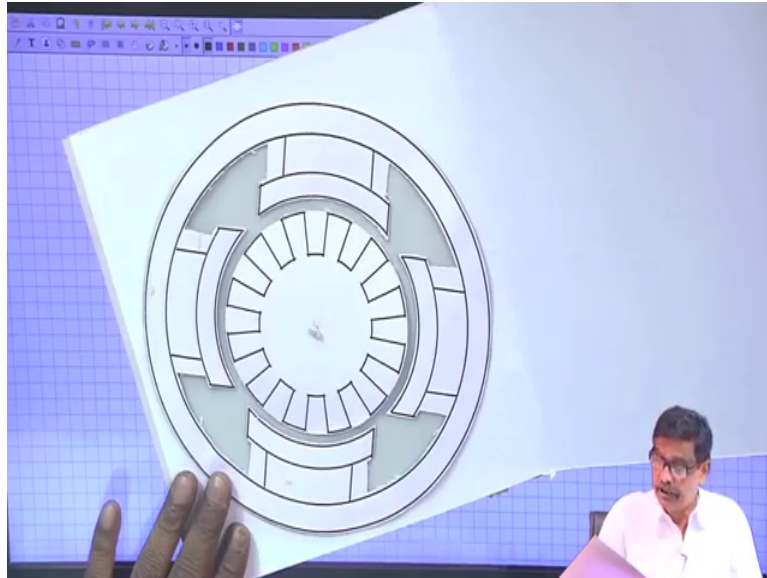


But nonetheless I explained to you that in a DC machine there will be a stator structure, which will have projected poles like this and it could be a 2 pole or multipolar stators this north south poles will be created by coils, which will be put around it these are called field coils and on the rotor side there will be an armature.

Only thing important thing I mentioned about this equation that, each coil has got 2 coil sides and if at any point of time this rotor will rotate, if one coil side of a coil is under the center of the north pole the other coil side must be under the center of the south pole so, as to maximize the induced emf. After all induced emf is $b l v$, velocity of the conductor will remain same and therefore, the nature of the induced voltage will be same as the nature of the b distribution along the air gap.

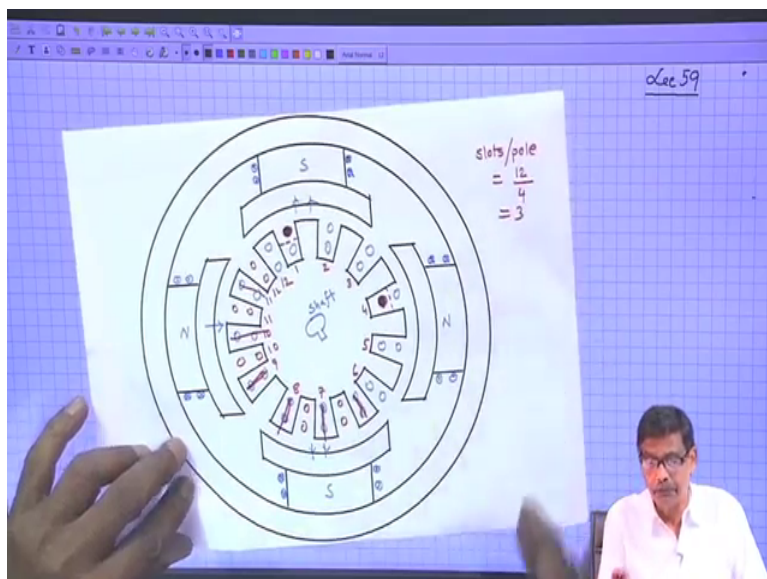
Now, today I will try to explain that in a much more clear diagrams, the situation will be like this diagram if you look at.

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So, if you see that these are the poles stator poles where there will be coils around it to create north south; north south and this armature it is slot and teeth slot teeth where the conductors will be placed and this whole thing has got a length perpendicular to the plane of the paper and this fellow will rotate and the conductors which will be placed here will be the armature winding ok.

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So, So, this is the thing and if you look at this diagram on a paper the same diagram I am telling, what is to be done is that this stator poles will be created by conductors placed around it is not and suppose this carries cross current and this carried dot current then this becomes a north pole.

Similarly there will be coils around the other poles as well and I want to create a south pole. So, the current distribution in this coil should be this cross this dot so, that lines of force will come out here lines of force will entail. So, this will become north south and then once again this will become north south, north I want to create.

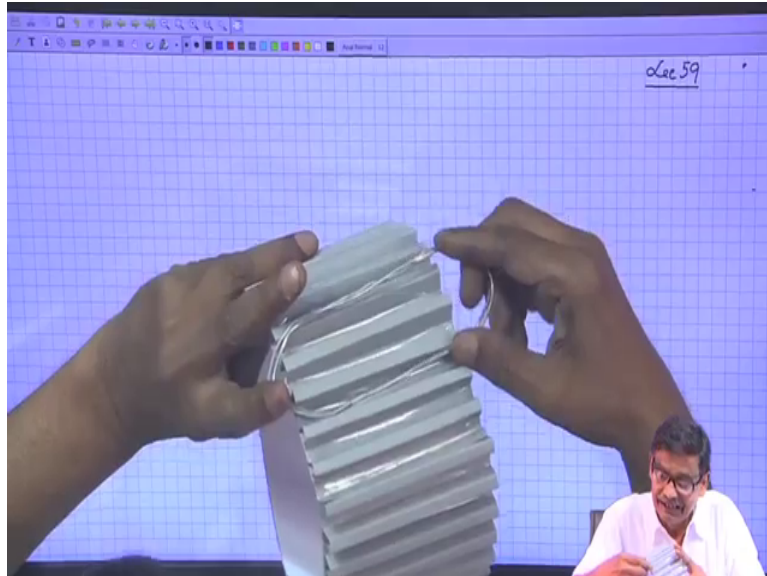
So, this will be cross cross dot dot and this is the another field coil identical all the coils are and they and I want to make it south pole therefore, this should be cross and this should be dot.

So, these coils which are wrapped around the projected poles are called the field coils. So, north south; north south 4 pole machine it will become, and the rotor is this one where there will be slots and there will be conductors placed. Conductors means coils will be placed and each coil has got 2 coil sides and this I will show like this.

So, these conductors will be placed in the slots of the rotor the this structure is rotor there will be a shaft here shaft with a key shaft perpendicular to the paper this is made of iron and these are called armature conductors like this ok.

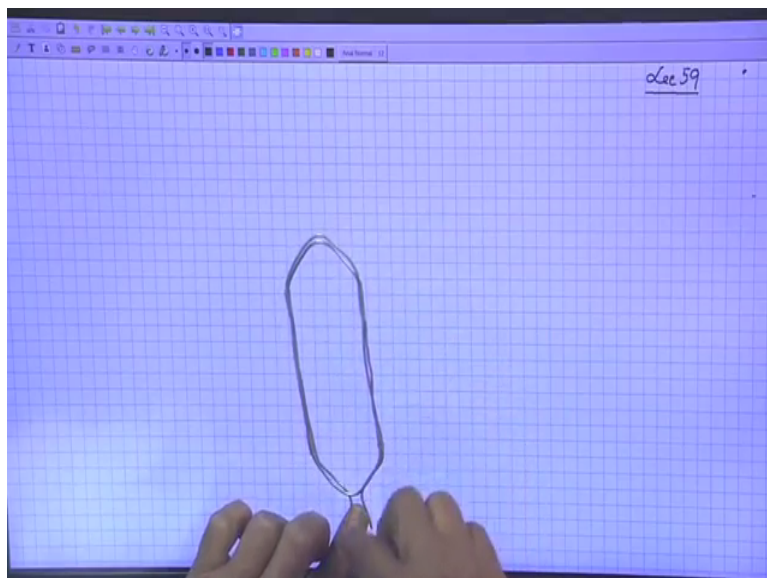
Now, I will tell you how this what is this coil is all about. If you see because in this diagram I cannot show the length of the machine. So, let me try to show it this way.

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See this is the actually this will be the rotor are you getting? This way and it is because the rotor windings is the most crucial in DC machine stator windings are very simple there will be 4 coils, if it is 4 pole machine and these coils are to be connected in series and ultimately 2 terminals will come out they are called field terminals, which is to be excited by some DC current creating north south north south poles but the armature winding is rather interesting.

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So, this is a coil which is diamond shaped like this, it is a coil like this and this coil has got 2 coils sides. If at any time these coil side will be under north pole the other will be under south pole. So, how this coil will be placed? It will be placed in its designated slot

like this here ok. That calculation we will do and it will have 2 terminals that is what I want to tell this is how the coils will be placed and these are 2 coil sides to make a coil you required 2 coil sides and these portions are over end portion of the coil.

The in this portion of the winding there will be no induce voltage because north and south will be all along the length of the machine there will be a north pole, south pole like that. Similarly this side also there will be and it is a multi turn coil. In fact, it is a 2 turn coil, it could be a 10 turn coil if you take a piece of wire make it like this on a wooden format this is to be made then it is to be placed in the designated slot you cannot place it arbitrarily of course.

Because I know that I have to be very careful to see that the coil span this degree in degree it should be 90 degree 180 degree electrical and mechanical angle last time I told which will ensure that if one coil side is under north pole the other coil side will be under south pole.

Only one relief is there that all coils are identical. If you know one coil the other coils will be placed in some other slots that is all with these 2 terminals start finish start finish like that I will put following certain grammar, certain logic which will fill up all the slots and we will be proceeding towards making an armature winding.

Armature winding is somewhat difficult to understand compared to AC machine windings. The reason I will tell you later because our goal will be here to produce DC. See what happens is this if you have a single coil like this, and this rotor is rotated under the influence of north south north south, then we know across the coil there will be AC voltage induced but I want to make it a make it a DC generator. So, how to make that AC voltage converted to constant value DC voltage to be generated?

So, what I have to do something extra after getting this AC voltage in all the coils there will be AC voltage induced each coils are identical same AC voltage will be induced only thing is the phase angle among the induced voltages will have some phase angle difference.

So, because of whatever is happening to this coil after some time same thing is going to happen to other coils but nonetheless the voltage will be of alternating time that is one thing.

Second thing is what we will do is this, we will have what is called double layer winding positively in DC machine. So, I will be using double layer winding what does that mean? It means that each coil for example, here let us calculate here how many slots are there; you can easily see there are 12 slots there are 4 poles then how many slots will be there per pole; it will be $12 \div 4 = 3$.

Therefore if I will use a different color suppose this is one coil side; coil I have already shown this is one coil side it goes and from where it will come out; because the angle between south and north pole is 180 degree electrical therefore, number of slots per pole will be 3 therefore, its return should be 1 2 3 after that its return will be that is its return will be here.

We will calculate this, this is one coil side this is another coil side that is it is a coil this red mark thing each one coil side will occupy the upper deck of a slot and its return coil side will occupy the lower deck of the slot that is in each slot there are 2 decks double layered winding it is called. Therefore, each slot we will house 2 coil sides belonging in general 2 different coils.

We will see how this will be nicely filled up that we will see later. In other words what I am trying to tell that in terms of this diagram, this is the coil this coil when I make it I will these 2 coil sides I do not make it planar in one plane what I will do is I will raise this coil side a little higher than this.

Are you getting? So, this is the coil side and its return will be a little lower there these 2 coil sides will not be in same plane. Then only if you place one coil here like this its return will be in the lower up deck of the slot and it is the starting coils side of this coil will be in the upper deck got the point hopefully.

Let us proceed. So, in each slot so, this red mark coil is a coil this is one coil side multi turn coil it is there are several turns and upper deck will occupy that and lower deck will occupy that. For example, if I say ah the slots number suppose 1, 2, 3, 4 then 5, 6 oh I am sorry this is not this is a teeth 5, 6, 7, 8, 9, 10, 11, 12; is not? Number of slots per pole which will be equal to $12 \div 4 = 3$ something mistake 1 2.

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Student: (Refer Time: 14:32).

1, 2, 3, 4, 5, 6.

Student: 7 (Refer Time: 14:35).

Oh, here it will be 7; anyway like this I am it has been rightly pointed out it is the 8 should be here is not that is what that is the problem of this rotating diagram. This is this will be 10, this will be 11, this will be not there 12; like that it continues anyway slots per pole we will calculate. So, you please correct that, you have understood in these slots these conductors are to be placed.

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Lec 59

Double layer winding : Each coil will have two sides
Coil span = 180° (electrical)

Let no. of slots = $S = 16$
No. of poles = $P = 4$
Slots/pole = $\frac{16}{4} = 4 = \text{coil span} \equiv 180^\circ$ (elec)

Total number of coils = no. of slots = $S = 16$

Now, what I will tell you is this that, now we will be talking about double layer windings double layer winding ok. That is each slots conductors will be placed on slots each coil will have two sides and we will assume coil span is equal to 180 degree electrical and this I have to do in order to maximize the voltage that is what I explained in the last class.

Suppose let number of slots number of rotor slots that is we are talking about armature winding number of rotor slots b is equal to v ; I will denote it by capital S , suppose side by side I will go with numbers suppose it is 16 and let the number of poles number of poles is equal to P is equal to say 4 then slots per pole is equal to 16 by 4 is equal to 4 and that will be equal to coil span.

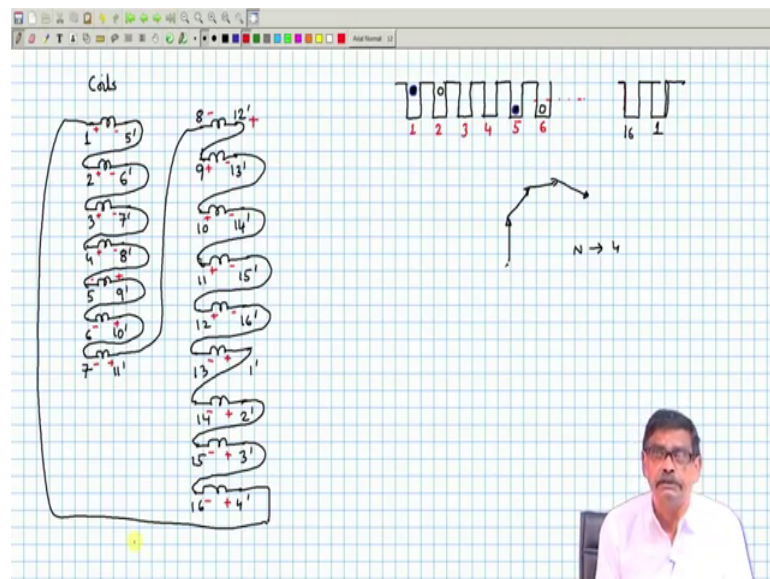
What does that mean; that is coil span is the difference between the 2 coil size of a coil in terms of slot number in terms of slot number like this 2 coil sides this will be placed in one slot and this will be placed in another slot they will be numbered take the difference of these two number and that has to be equal to 4 in this case. So, this is coil span and this is equivalent to 180 degree electrical or in this case 90 degree mechanical that is the thing.

Anyway this is the thing. So, I will draw the diagram in this way now, now follow me very carefully what I am doing. Suppose each slot will have 2 coil sides because it is a double layer winding therefore, total number of coils has to be equal to number of slots that is equal to S that will be called to 16; is not.

Because each coil requires 2 coil sides how many coil sides will be there; 32 because each slot will carry 2 coil sides therefore, number of coils will be half of the coil sides that is 16 itself. So, in general whatever is the number of slots that will be equal to the total number of coils I can put in the on the periphery of the rotor slots that is.

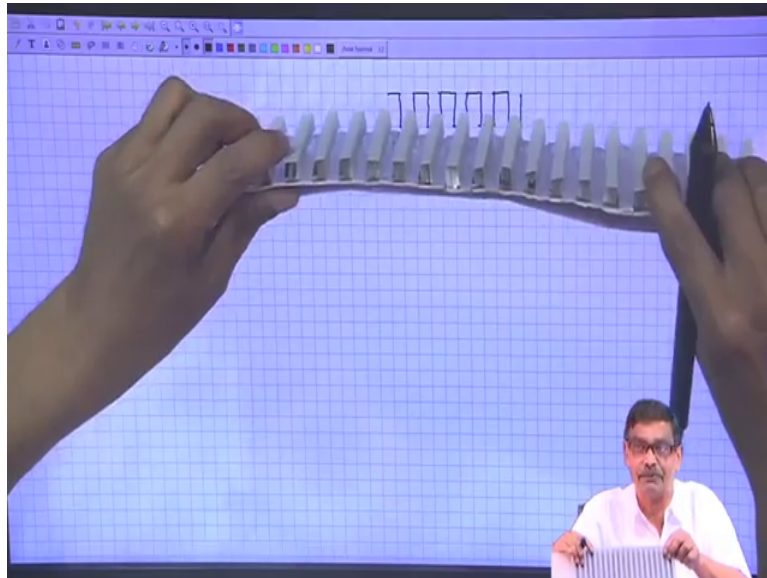
Now, how do I go about placing the coils like that; so, that calculations are simple if you follow me carefully what I want to.

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Now, suppose I want there are 16 coils 16 slots are there, in this diagram I want to tell you like this, these slots I will show like this slot and teeth in the developed diagram. This is the rotor periphery like that develop diagram means this diagram.

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Circular thing, you have unwinded it and you are showing it, this is perpendicular to the board like this, this diagram I have drawn hope you have understood.

Now, these slots I will number like 1 2 3 4 and dot dot dot it will be 16, and after that once again slot number 1 is not? Developed because it is after all circular once again one this is how slots will look like in the developed diagram.

Now, what I will do, I will take one coil. So, I will write here this is called winding table very simple otherwise if you please follow me at least for windings and this column I will write coils and each coil I will show like this.

Suppose I say that I will start; I will take one coil and I will in the upper deck this is the starting coil side and its returned first of all where its returned will be? Slots per pole is 4 therefore, it will be 1 plus 4 that is its return will be here. This will be the one coil one coil means this fellow I have put it and as I told you while manufacturing this will be slightly below and this will be slightly up so, that it will be nicely placed here.

So, this slot number is 5. So, out of 16 coils, I have put only one coil and slot number one I have put it. So, this coil side I will say it is 1, I start and its return is at 5 what all

we do is this that in the lower deck whichever coil sides will come, I will tell them as 5 dashed upper deck coil sides I will number with without any prime and lower deck. So, one 5 dashed is 1 coil whereas, it is 2 coil sides?

In slot number 1 and slot number 5. In slot number one it occupies the upper position of the slot there is a vacancy here, somebody will come here do not worry. So, everything will be filled up and in each slots there will be 2 coil sides. So, this is one coil it is over.

Now, what happens is this there will be 16 coils and all the 16 coils will be connected in series and the circuit will be closed. Now the next coil I will take and I will start like this next coil I will start from 2 and its returned will be in 6 dashed.

So, this is coil 1 this is over and it is multi turn coil mind you although I am showing one section and the second coil I will take which will start from 2 plus 4 and its return will be here that is in slot number 6. Although I have not connected the coil each coil will have 2 free terminals but this is how I will continue my waiting that is what I am telling.

So, 2 and it will be 6 dashed. So, I am writing it with red 2 6 dashed similarly third coil I will now not take much space because 16 coils I do not know whether I can show it but it can be done. So, so this is the thing or I will rather clean it what I am doing? So, coils I will do it nicely coils.

So, we have seen first coil symbolically, I am writing and it has got 2 terminals 1 5 dashed second coil it will start from slot number 2 to 6 dashed, 3 7 dashed number game it is all coils will have same span identical coils, then 4 8 dashed, 5 9 dashed, 6 10 dashed, 7 11 dashed ok. There will not be enough space. So, let me draw it here continue, I could draw it in this way.

Then 8 12 dashed, 9 13 dashed, 10 14 dashed, 11 15 dashed, 12 16 dashed, 13 17 dashed there is no 17 dashed what it should be; 1 dashed are you getting? 17 dashed I am writing, but there is no 17 dashed it has to be equal to 1 because with the circular 1 dashed.

So, I clean it you have understood whenever it will be exceeding 16, you have to write down this one 1 dashed, then 14 2 dashed and 15 3 dashed and this is 16 4 dashed 1, 2, 3,

4, 5, 6, 7, 8, 9, 10, 11, 12, 13 all the 16 coils I have taken. So, this is how I will fill up all these slots and in each slot each slot will house 2 coil sides.

For example, slot number 1 will house coil number 1 start and coil number 13 returns like that. So, this can be done then what I am telling this diagram is not the actual coils, I mean actually I know how they are disposed in space that is fine but so far there is electrical to understand how they are connected I have just drawn each coil represented like this.

Now, what I will do is this all these coils I am telling I will connect them in series. So, all the coils I will connect them in series; got the point? This connection now I now do because all the coil each coil has got 2 terminals available to me and I will connect them in series and not only in series all the coils and I will close it like this, that is all the coils in series and the coils are closed on to itself.

Now, here one may raise objections that is there are 16 coils which are put like this, where are the coils gone; this is these are the coils we can put on this and each coil is identical they are displaced from one another this is coil 1, coil 2 will be like this, coil 3 and you have connected with piece of wires in series this coil next coil and so, on and everything will be rotating under north south magnetic field and each one of them will become a seat of emf; is not.

So, and I have connected all the coils in series knowing fully well that each will become a seat of emf these are no dead terminals there is induced emf here in this coil.

Next coil will also have induced emf and so, on if you go on adding. So, when you connect them in series what you are doing; you are adding these voltages here, this voltage, this voltage, this voltage and so, on. Now the big question is if that is the case and if you close will not there be a circulating current.

The answer is no; because of the fact the polarity of the induced voltages in the coils will be such that the addition of all the voltages AC voltages there mind you, I have not told anything about how to convert it to DC till now but I know there will be source of AC voltage here like that and if you add all the voltages the sum of the voltages will be 0.

The reason is very simple. If first coil voltage is this he is represented by a phasor like this, second coil voltage will be lagging this by some angle β , third coil by this one like that if you go and you will end up with coming here to the same coil after you have traversed all the 16 voltages.

Therefore, resultant voltage acting in this closed coil which are closed each one of them is seat of emf then they some of the induced voltages will become 0. So, we need not fear there will be a circulating current although I know pretty well that each one of them has become a (Refer Time: 33:36)of emf [FL].

Let us also try to see that I told you there are how many slots under north pole. There will be 4 slots under south pole; there will be 4 slots; machine will be running. At a given time if you freeze if you take a snapshot, it is expected that 4 slots will be under the influence of the north pole and next 4 slot will be under the influence of the south pole and so on.

So, suppose this coil size 1 2 3 4 are under the influence of the north pole and the direction of rotation is such that they become plus; these 4 coils; these sides become plus. Obviously, the other will be under south pole and they will become minus; is not? Instantaneous voltage I am telling.

Then the next 4 slots 5 6 7 8 will be under the influence of the south pole they are starting and the polarity of this induced voltage will be reversed minus, plus, minus, plus, minus, plus and minus plus why not; and then the next 4 will be under the influence of the north pole and this will be plus, minus, plus, minus, plus, minus and plus minus and the other one other 4; 13, 14, 15, 16 will be under south pole and this will be once again minus, plus, minus, plus, minus, pluss, minus, plus.

So, if you start from this point traverse all the emfs you will be seeing as many plus. So, many emf in the opposition acting end up with a zero voltage between if you start from here traverse all the coils come back here zero voltage although there will be induced voltage across this. So, how did I put this plus minus; let it be very clear. Coils are identical they will be moving at some high speed no doubt fine.

And there are 16 slots are there, suppose it is expected then under the influence of this north pole at a given time it is expected there will be 4 slots under north pole these 4

slots under south pole 4 slots. If you take a snapshot instantaneous snapshot under that condition what I am telling, coil sides are there under the either under the influence of north pole or south pole.

Now, the question is let us assume that 1 2 3 4 is under the influence of north pole and direction of rotation is such that I apply right hand rule and come to the conclusion that then the coil sides 1 2 3 4 they are plus then about 5 dashed, 6 dashed, 7 dashed, 8 dashed time certain they has to be minus they must be under south pole because coil span is 180 degree electrical ok.

Then the next 4 slots will be under the influence of the south pole direction of rotation remain same. So, polarity of the induced voltage reverses and so, on. So, I stop here today to conclude that the armature windings I am discussing I am of a DC machine which is not complete.

I told you there will be several coils are to be placed in slots and all the coils are first to be connected in series and circuit is to be closed questions still remains that is fine; there will be no circulating current but my goal is to how to get DC so, that we will try to further explore in the next class.

Thank you.