Electrical Machines - I

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Lecture - 77
Power Flow Diagram, Rotational loss

Welcome to next lecture. And in our last lecture, I told you we were discussing motor operations.

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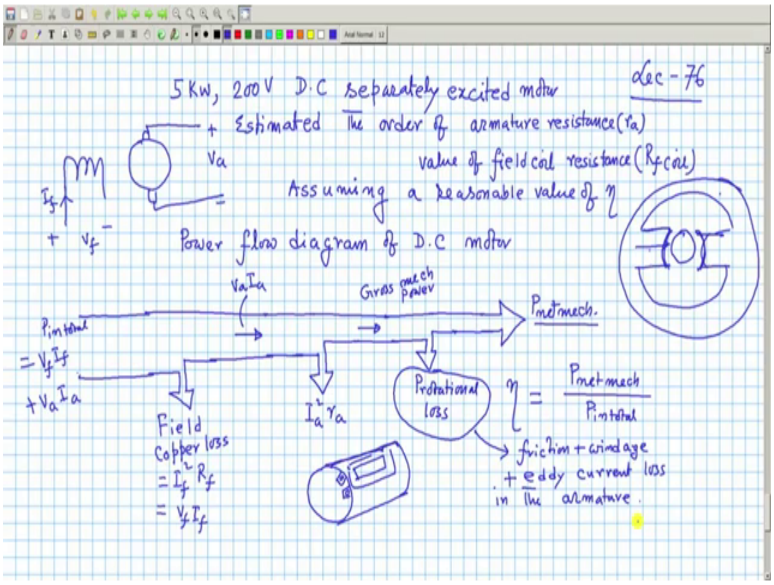

And suppose I took a DC machine name plate rating as 5 kilo watt, 200 Volt I have taken it will be 220 Volt may be for easy calculations. DC separately excited motor; DC separately excited motor. We were took this motor to explain the things.

And then we estimated the order of armature resistance, value of armature resistance, value of field coil resistance. Mind you it does not include external resistance, field coil resistance that is R f coil. These two things we estimated, these are very useful information, ok.

Based on based on what assuming a reasonable value of efficiency, value of efficiency of the machine, say 80 percent we assumed like that. So, it gives me a fair idea of the order of the resistance, order of the armature resistance will be; now we are sure what is law if it is 5 kilo Watt machine its order I am sure it will be 0.5 ohm or thing like that. Field coil resistance will be of the order of 100s ohm and so on for 5 kilo Watt machine. You can repeat this exercise for a 10 kilo Watt machine. You will find r a has to be still further low for higher rating. As an exercise I leave you.

Now, today first what I will do is this I will draw the first the power flow diagram of a DC machine, power flow diagram of DC motor. So, here is the input power, P input. P input will comprise of electrical power input will comprise of V f I f plus V a I a. Mind you this is the circuit diagram. This is V a and this is V f and this is I f. This is the total electrical input in the system.

From this a portion will be lost in the field circuit, field copper loss which will be equal to I f square into R f; R f total if you have connected an external resistance then it is to be taken into account. So, and that is also equal to V f, I f. So, V input is this plus this. So, here the power will be V a into I a, remaining power, power input to be armature.

Here this power out of this total power input a portion will be lost in what is called armature copper loss, I a square r a. Then if this power is subtracted then I will get here gross mechanical power developed; gross mechanical power from which if you subtract the rotational loss you will get the net mechanical power output P net mechanical.

Efficiency of the machine is P net mechanical divided by P in total; P in total that is what I assumed with it 80 percent, difference of these two is the loss and so on, anyway. So, this is, now the question is I will tell a few words about this rotational loss. What happens is this when a DC machine will be rotating there will be friction and windage loss, ok. Rotational loss comprises of friction plus windage against air it is running and there will be mechanical friction on the shaft and bearing that thing plus the eddy current loss in the armature.

See, in case of DC machine all currents are DC, is not, and that is why the field poles and the yoke structure are made of solid iron. I am sorry, solid iron it is made of. Generally, it is made of small machines it is just solid structure. This is yoke, these are the pole side, this is stator part, this is made of solid and here is the armature.

Now, there will be eddy current loss taking place in the iron of the armature. Why? Because if you see the rotor if it is suppose solid iron where slots are there you have put conductors to make armature conductor etcetera, but look at the iron body of the armature.

It is moving in a steady field here therefore, in the iron body you pick up any closed path, it will sometimes see maximum flux linked by this assumed closed path, sometimes 0 flex there will be there induced Voltage, Faraday's law AC Voltage, there is no commutator and rectifier here, I know what is the purpose. So, there will be eddy current pass available on the body of the iron and iron will become also hot. That is why the rotor or the armature of the DC machine you cannot use the solid iron. You have to use stampings, circular stampings in this case.

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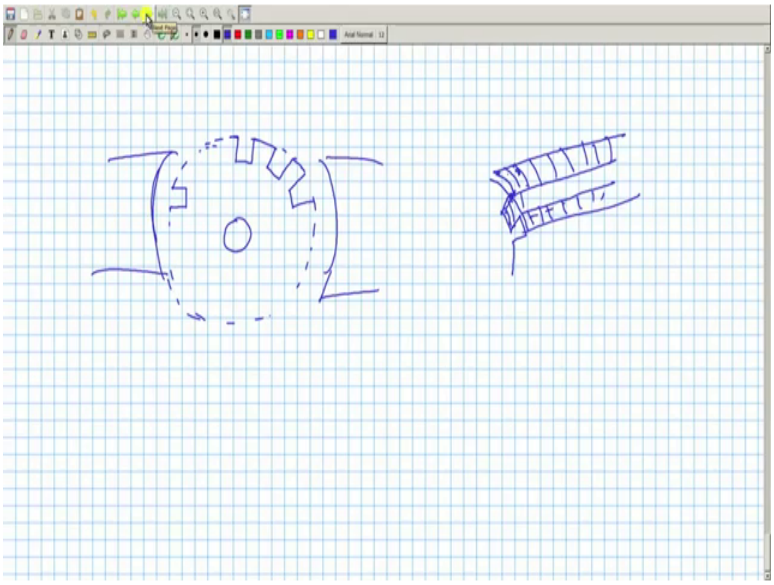

For example, it will be like this, suppose thin plate and it will be stampings will be, will look like slot teeth like that it goes on. I think you got, getting behind here it will be like this, all over the periphery. This is one plate and its thickness is few millimetres. And then you give a varnish coating to this plate, and then you stack many plates one above the other and you will get the height that becomes the length of the machine and this fellow will be rotating in the your steady field; field is steady therefore, eddy current loss will take place.

But this time it will be less. Why? Just like transformer you have reduced the path of the eddy path. So, they it will look like a plate here, this is one plate, this is the next plate aligned, so that slot aligned like that you get the length of the machine. These are the stampings. Are you getting? Iron stampings. Circular plates.

I think you have got the idea and several plates stacked together. And each plate of course, must be electrically insulated from the neighbouring plates. So, that you know each plate has its own electrical identity, and eddy current pass will now be reduced, these are few millimetres. So, there will be eddy current loss taking place in the armature.

If it is a separately excited machine and you are not changing the field current, strength of the eddy current I know it depends upon the frequency of the induced voltage frequency of the induced voltage ac induced voltage in the armature body will be p n by 2 like that. So, it will be proportional to frequency square, it will be proportional to the b max square those things are still valid here because after all AC voltage part only we are seeing. Therefore, to reduce eddy current loss. It directly depends upon the flux per pole because from that I can calculate b. If I do Fourier analysis I can calculate b max and so on.

But nonetheless, for a given field current if you are not touching the field current and suppose the speed of the machine is constant then the eddy current loss will practically remain constant. So, also frictional loss. Therefore, this part rotational loss consists of friction windage, not winding I am so sorry, it is windage, it is called windage loss. This is the scenario of the machine.

So, now, this understanding we will you have this information, so that we now understand motor operation in a better way. Therefore, suppose I now consider a separately excited motor. So, this is a thing.

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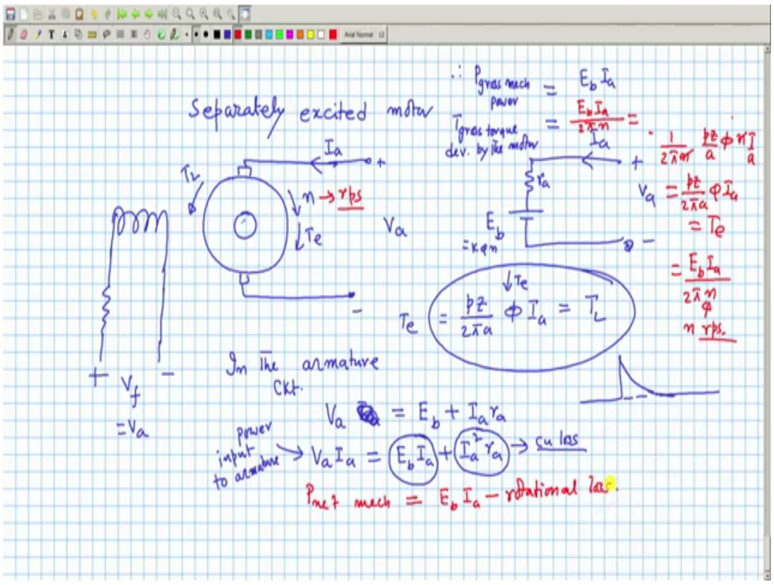

This is shaft, these are the brushes, armature and this is the field. Here is your V f, here is your V a, normally V f will be equal to V a, that is normal case. But since separately excited motor, what happens? You would like to vary the armature voltage separately that will come later. Now, as I told when you switch on the supply there is no back emf. So, some starting arrangement has to be made. We will discuss later. External resistance you connect to limit the current to it is rated value as the machine picks up speed, cut that resistance out.

Now, starting current is large, but the as the machine picks up speed because armature circuit is like this, this is back emf, this is supply, this is your I a. This armature current will shoot up to a large value then it will gradually decay. Now, the question is finally, where it will decay down and settle.

The answer to this is very simple the machine will finally, settle down to such a speed such that enough current will be drawn from the armature supply which will make p z by 2 pi a into phi into I a is equal to load torque, is not. If machine starts rotating this way, mechanical load torque will be this way, and electromagnetic torque is this way. This is the expression of the electromagnetic torque.

Machine will finally, run to such a speed at such a speed that the electromagnetic torque is equal to load torque steady state operation. Let us consider this steady state operation only, that is if load torque is 0 I a will be 0 finally, because current we have seen it will shoot up, then it will decay, if absolutely machine is under no load even there is no eddy current and frictional losses then the final armature current will be 0 and ah it will run at a constant speed without drawing any current; that means, E b will as speed was increasing will become V a, so that no current is drawn. Anyway, but that is an idealistic situation. So, E b is K phi n mind you and it will settle down to this speed. So, this is the thing.

Now, I will also I told you about the power flow diagram this one, is not. This is the gross mechanical power developed, we found out the expression of the torque from considering b i l in our earlier lectures. Now, I can also get that from simply arguing that in the armature circuit, I will write this was the next page. In the armature circuit this is I a, suppose steady state current drawn is I a, back emf is E b in the armature circuit. The KVL equation is V a into I a input; power to the armature. Sorry, KVL equation is V a is equal to E b plus I a r a neglect brush drop etcetera, ok.

Now, multiply both sides by I a. What is this? V a into I a. This is what? Power input to the armature and that will become equal to E b I a plus I a square r a very nice. It tells you that total power inputted to the armature, armature draws this total power. A portion is lost as copper loss and this must be then equal to the gross power developed, gross mechanical power developed.

So, we say that therefore, I say P gross mechanical power is equal to E b into I a. Then, the gross torque developed t gross torque developed by the machine, developed by the motor [noised] will be equal to; I will use red colour E b I a by 2 pi n, if n is in rps, power by angular speed gives you torque. Now, you see this E b I can write it as p z by 2 pi a into phi into I a, is not; E b is K phi sorry K phi n, K phi n is E b into I a by.

Student: (Refer Time: 22:00).

Um.

Student: (Refer Time: 22:02) omega n.

Omega; n is in rps.

Student: (Refer Time: 22:11) differentiate when (Refer Time: 22:13) omega, right.

I will just correct it, yeah. This is the total power converted to mechanical thing. So, E b into I a is that. That divided by angular speed in radian per second will give you the torque developed. Now, what I am telling. So, this is equal to 1 over 2 pi n, I will keep it. E b is how much? E b is p z by a into phi.

Student: Into n.

Into n and then I a is there, it is correct now. So, now, you see this then becomes n goes p z by 2 pi a phi into I a. This is the electromagnetic torque developed by the machine which I got it earlier in directly calculating the torque. Considered each conductor, they are carrying current I a by a, b i l all sigma are integrated. So, this is a thing. So, to calculate the torque gross torque developed. You can use this formula as well. So, torque is basically E b into I a by 2 pi n, but do not make mistake n should be in rps that is the thing.

So, we now know that in a DC machine if you a steadily if it is operating it is it will be like this clear. And then the net mechanical power of course, we have to subtract from this is the rotational loss. So, P net mechanical will be this E b into I a minus the rotational loss. This is how we have to calculate [FL]. Now, I will tell you some simplified way of calculating the operating point of a DC machine. Now, the if I want to sketch the this is the, this circuit diagram is always necessary. This is the thing.

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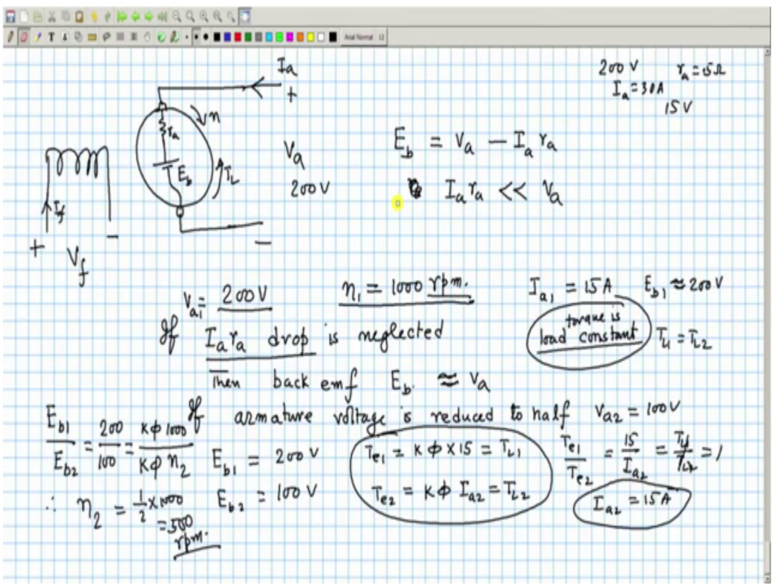

Suppose, the machine is running steadily with this armature speed there is load torque also acting in the opposite direction is present and ah the conductors are carrying the current, and the current you always show in this way armature circuit, ok. Now, inside the armature it is r a and back emf which is K phi n, and you can solve a host of problems without any difficulty provided you know the order of r a and things like that, but I want to tell you one thing.

This back emf; next lecture I will draw this pitch torque characteristics etcetera, but today at least whatever time is left. I will tell that E b is equal to applied voltage minus I a into r a, is not. That is what we have seen. And we know r a, I a r a drop is much much smaller than your supply Voltage. Why? That also we have seen.

Suppose for example, in the earlier machine supply voltage was 200 Volt, rated current was 30 ampere and r a was say 0.5 ohm. So, what will be the voltage drop I a r a drop? It is only 5 Volt, 15 Volt is not and your supply voltage is 200 Volt. Sometimes to get quick results we also neglect this I a r a because I a r a drop is much smaller compared to the armature voltage you have to get quickly the results.

For example, if I say this you listen carefully suppose you apply 200 Volt and you find the machine is running at say 1000 rpm, I have written rpm, clear. What I am telling if I a r a drop is neglected, so that quickly I get the results. Then I will say that then you get several interesting simplification, then back emf that is E b will be always equal to supply voltage as if back emf is fixed by supply Voltage. Are you getting this point? So, suppose 200 Volt is the supply machine is running at 1000 rpm and suppose the machine is drawing a current this is n 1, this is V a, V a 1; n 1 1000 rpm and I a 1 is supposed 15 ampere that means, machine is loaded, ok. Then what is E b 1 with r a drop neglected? E b 1 is also equal to 200 Volt.

Now, suppose I say that if armature Voltage, this is E b, E b 1 armature voltage is reduced by half, reduced to half that is V a 2 is made equal to 100 Volt, suppose I say. Then what will be the new speed and what should be the new armature current? And I say that load torque constant. Then what I will say E b 1 is equal to 200 Volt I know. What is E b 2? It has to be 100 Volt because I a r a drop neglected 100 Volt. Initially, machine was running steadily. What was the electromagnetic torque? It was equal to K phi into 15 ampere and that was equal to the load torque, steadily it was running.

In the second case the electromagnetic torque developed by the machine will be K phi, I have not changed field current, whatever is there I have not changed that. Only thing armature voltage I have reduced from 200 Volt to 100 Volt then I will say electromagnetic torque now developed armature current I do not know. And that is equal to T L 2, but I am telling load torque is constant is not T L 1 is equal to T L 2.

Then what you should do is this. E b 1, you should write down these two equations, one is torque equation and one is the back emf equation, and take their ratios that is what all you have to do while solving the DC machine problems. So, E b motor problems, E b 1 by E b 2 is 200 by 100 which I know is some K phi into initial speed that is 1000 divide by K phi the new unknown speed n 2 therefore, n 2 the new speed will be half of 1000 that is 500 rpm.

And to calculate the new current you take the ratio of these two equations T e 1 is equal to T e 2 is equal to 15 by I a 2 which is equal to T L 1 by T L 1, T L 2 I am telling same, so it is one. Therefore, you see I a 2 will remain same as 15 ampere, but speed will be half.

In other words what I am saying sometimes if you are told that neglect that small armature resistance drop then the problem becomes very easy back emf is decided by supply in Voltage. That is the one thing. So, there will be two cases initial operating point, at some speed it is running, some armature current it is drawing and some back emfs. Here we take the ratios. Similarly, another equation, torque equation you write for steady operation of the machine in the two cases. Take the ratios of this back emf equations and the torque equations. And there will be unknowns which can be easily computed.

So, I stop here today and we will continue with this; considering r a also in our next lecture. So, I indicated simply that if r a can be assumed to be neglected I a r a drop, then calculations are much simpler.

Thank you.