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

Lecture – 54
Introduction to D. C Machine

Welcome to our next topic in the Electrical Machines I lectures and we will start discussing about DC Machines.

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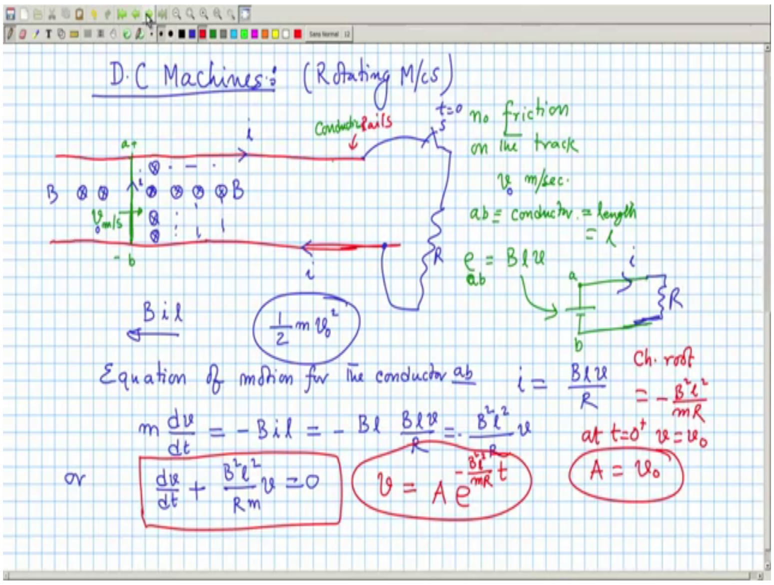

And DC machines and these are rotating machines you know rotating machines; rotating machines, machines I will often write like this. Now, before I start discussing with DC machines rotating, we try to understand how DC voltage can be generated? For example, after the discovery of Faradays in 1830s or so somewhere, which says that voltage induced in a coil is n d phi dt and if the coil is moved in a magnetic field which sinusoidally varies, then there will be induced voltage which will be also alternative in nature.

This was quite obvious but, nonetheless people started developing DC machines first and we will see that it is not so easy because, inherent voltage induced in a coil, when it is rotated in a magnetic field will be essentially alternating in nature. So, we have to do something extra to convert that AC voltage to DC, if this problem has been brought today that ok, you want to generate DC one solution perhaps many people will give that generate AC because, AC generation is so simple and connected rectifier get DC over.

But, in those days rectifiers were also not there at that time. So, it was DC machine people started thinking that large power I have to somehow before that of course, people knew about batteries DC voltages only we were used to at very small level of power batteries were there, 1.5 volt connect them in series get some voltage like that but, large voltages delivering large current 100s of voltages that was not there, then you know DC machines in any case was developed. So, to understand the basics of DC machine, we start with this discussion.

You imagine that I have a coil a conductor, this is a conductor and suppose these two red lines are rails ok, this is a conductor and these two are rails, it has wheels and it is putting. So, that this conductor can move this way that way, these are rails and let us imagine on the top of this arrangement, I have put a knot magnet all along this line length of the rails and below this I have put a South Pole magnet all along the track, that is from in the root top, if it is on the plane of the of my table, on the roof top there is a North Pole and on the floor there is a South Pole in between it is there, on the table top and there this table runs infinitely. Now, if that be the case then the direction of B, I must show cross from top to bottom. So, it will be say cross B ok.

So, B direction and it is all along this whole length and also along the breath everywhere it is B, flux density you know. So, this is the flux density B from top to bottom and this is the conductor. Now, let us imagine that this conductor is moving with a velocity say v meter per second, this conductor is moving with a velocity, v meter per second from left to right and let us imagine, let us assume that not imagine, let us assume that no friction, no friction on the track, no friction on the track and also air resistance, no friction on the track.

Therefore, to move this conductor at a constant velocity v meter per second, on a friction less track no air friction also, you require no force therefore, external force acting on the conductor will be 0 that is what Newton's told us, to move a thing in a frictional friction less environment at a constant velocity, you do not require any force.

If no force is acting on any body, then either it is at rest or it is moving at a constant velocity that is what we know. So, anyway to move the conductor at a constant velocity v meter per second, I do not require any external force to be acting, it will go on moving, under these assumptions ok, that is fine and suppose this side of the conductor I name it as a and this side I name it as b small b, the 2 ends of the conductor. As the conductor moves, there is v there is a velocity, these are at right angle.

So, I can apply right hand rule like this here, they will be showing this. So, you see there is a b here into the paper. So, forefinger is b, there is a velocity thumb gives you velocity and this one middle finger, the end of the middle finger will give you the polarity of the induced voltage, that is a will be plus, b will be minus and magnitude of the induced voltage will be B l v, that is equal to potential of a with respect to b, that is how we write, a will be positive B l v.

So, and what is l, l is equal to length ab is equal to length, conductor length. So, this much induced voltage will be there and it will as it moves with a constant velocity therefore, this conductor becomes a seat of emf. So, I can say this conductor is like a battery here, a b and this magnitude of this battery voltage is like this, it will be DC because, always the magnetic field is into the paper I have never changed it.

And nothing will happen, although across the rail if you connect a voltmeter it will read B l v because, it makes contact with the these are also conducting rails, conducting material is not although no current can flow. Now, what I will do, I will connect between the rails a switch and l volt got the point. So, if you wish if you close the switch, this voltage which is a battery across it a resistance will be connected, is it not?

And we expect a current will flow like this, if the switch is closed, current path will be this is the source, it will go and come back. Let, the initial velocity be v naught, it was moving with a velocity v naught say meter per second and my target is to find out when I close the switch, how much will be the current and how long will the current flow things like that.

Now, look here the moment this conductor delivers power current here, current will also flow through this conductor, same current series. Now, we know that that a current carrying conductor placed in a magnetic field, we will experience a force and what is the magnitude of the force B i l, where is b? And you have to apply left hand rule B is here, i is this finger i and thumb will you give you the direction of the force.

So, B i l this much force will act in this direction, opposite to the direction of motion the moment you close the hence forth. So, shown so, long when the switch was opened as I told you, conductor was not experiencing any force whatsoever, it was just moving with constant velocity as per Newton's law but, the moment you close the switch although friction etcetera is not there, I immediately find that it will now experience a force in the opposite direction, is it not?

Therefore, this conductor ab is acted on by a force, if it is acted on by a force from right to left and it had a and a initial velocity of v naught, what do I expect? Conductor to decelerate because, no other force is there, velocity will go on decreasing but, if velocity goes on decreasing this voltage will go on decreasing, this current I will also go on decreasing.

Physically I am first telling and so in this way although there will be this resistance will be heated up, current is flowing i square R t but, can this how long it will sustain, it looks like that as time passes, after we have closed the switch at t equal to 0 suppose, as time passes the magnitude of the current will decrease, magnitude of the induced voltage decrease, velocity decreases and the time will come when, velocity will become 0 and all this game will be over, everything will be dead I mean, there will be no velocity of the conductor and things like that.

Now, what I am trying to tell that, when a conductor had a initial velocity v naught and without anybody assisting its motion and it is also not needed when the switch is open, see there was kinetic energy stored in the conductor, half m v naught square, is not? When the switch was opened, that kinetic energy was somehow important but, when you close the switch the energy is getting extracted from it is kinetic energy is dissipating here and that kinetic energy was finite therefore, finally, it will become 0, all the energy will be dissipated here.

So, these example if I mathematically analyze, we will enhance our this physical understanding in a much better way. For example, for physical reasons I know, velocity will become a function of time, the induced voltage e ab will become a function of time and so on. So, I must write down these two equation, equation of motion for the conductor ab.

What will be the equation of motion? Suppose, m is the mass so, m dv dt, it is velocity is always from left to right, must be equal to the force acting from left to right, from left to right what is the force acting? When the switch has been closed is minus B i l; B i l is acting in the opposite direction, this is the equation. So, it is a first order differential equation. Now, the question is what is i? I a very simple circuit, B l v over R, where R is the resistance so, I put that.

So, minus B l and then i is B l v by R, is it not? So, that it will become equal to B square, l square by R into v negative sign or I can write m dv dt, plus of B square, l square by R into v is equal to 0 and then divide both sides by m. So, that this equation will become, this m will come simply here, this is the equation which is a first order, constant coefficient, differential equation and I want to know what is velocity.

So, velocity the solution of this equation is well known characteristic root of this equation is minus B square, l square by mR. So, it will be some constant A into e to the power minus B square, l square by mR into t, is it not? And there is no forcing function on the right hand side. So, that is the solution, this is the solution and I have to determine the A from boundary condition, see velocity of a mass cannot change instantaneously, when the switch was opened it is velocity was v naught, at t equal to 0 plus after we have closed the switch, velocity will be still be 0 because, of it is inertia therefore, at t equal to 0 plus, v is equal to v 0 only. So, this gives you A is equal to v 0, what is v 0? The velocity of the conductor when this was opened.

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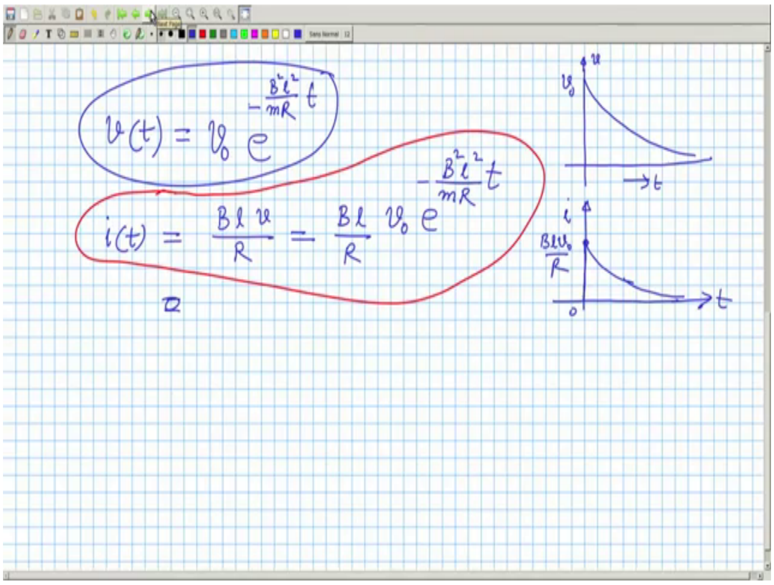

Therefore finally, what I get is this, that velocity of the conductor at any time t is v 0, into e to the power minus and you see it is equal to minus B square, l square by mR, that is minus B square, l square by mR into t, this is the thing and velocity will exponentially decay down to 0, as we were reasoning it physically so, that is xy. Then what is the expression and how current will change, i t is also very simple because, it is equal to B l v by R at any time current is this. So, I will put it here. So, it will be B l by R, then for v this one, that is v naught into e to the power minus of B square, l square by mR into t, this will be the thing, is it not? Correct. So, this is the, it is coming correctly dimensionally B l v is voltage by R. So, this is the explanation of the current.

So, both voltage and current if you sketch, we will decay down to 0, this was velocity of the conductor, this is time and this is the current. So, current in the circuit that t equal to 0, when you close the switch, this is coming correctly, that is B, this current value is B l v naught by R, then it also exponentially decay down to 0, this is time axis. So, this generator will not last long but, we have understood several things, one is a conductor moving in a magnetic field, it produces a unidirectional voltage, provided everything is not on the top, everything is below is South Pole, then when it moves that voltage magnitude of course, becomes a function of time.

Now, naturally the question is, if I want to make a sustainable generator not that after sometime everything will vanish, what should I do? That means, I want to get a constant voltage here, with some load being supplied that switch is closed and at that time I must maintain the velocity, see if I say that my velocity will remain v naught with the switch closed, then I must demand that there will be an opposing force coming in you must apply another force from left to right, to compensate for that opposing force. So, that once stay again net force will be given it will run at a constant velocity, got the idea? That is you must have a prime mover, which will push this conductor hard, the moment you want to extract power out of because of it is kinetic energy only, it was delivering power.

But, now the moment you demand that I want to get power in this resistance continuously, then rather make the velocity constant by compensating this opposing force from left to right, then nothing will be coming out from the kinetic energy to here, whoever is pushing that conductor at that force which is equal to B i l, it will do that one idea. So, in general there must be a this thing, external agency which will pushing it from left to right that is called prime mover ok.

So, this is a simple generator without any prime mover. In general therefore, to make the generator work, there must be a prime mover as I told and the equation of motion I will write next class but, before that let me in the same arrangement.

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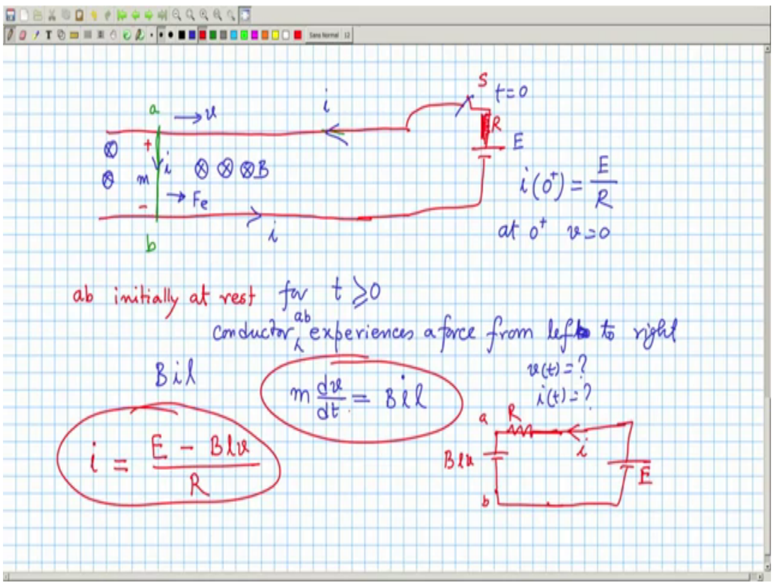

Let me just study another thing this was my rail suppose, this was the rail and you know this was my conductor and suppose this time what I decide is that, this conductor in the rails was resting of length l. Now, what I will do, it was at rest ab initially at rest, at rest. Now, what I do I connect a battery here, through the rails with a switch. So, when the switch is open nothing happens it remains stationary and there is of course, B as usual, I am just drawing 2 lines but, it otherwise invading all the areas between the rails B, flux density.

If you now close the switch and the conductor was stationary, it is velocity cannot change instantaneously, at least at t equal to 0 you close and I am pretty sure that i 0 plus will be equal to this battery voltage is suppose E, E by R it has to be because, at t equal to 0 plus v is still 0, conductor was not moving at t equal to 0 plus because it has got mass, it is velocity cannot change. So, at t equal to 0 plus current will be like this and what will be the direction of the current, it will be like this i, i and i. So, i at 0 plus is there, the moment this is current and it is placed in a magnetic field, it will experience a force, which I can get from left hand rule that is B and this is i hello [FL].

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Hello [FL].

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[FL]. So, you see this is B, this is i it is correct. So, this is B, this is direction of i. So, thumb will give you direction of velocity force, this is called electromagnetic force experienced by the conductor and the conductor in absence of any frictional force we will try to accelerate, it is velocity will now start increasing, earlier it was 0 at t equal to 0 you have closed the switch, then from t equal to 0 onwards, the conductor will start moving and the reduction of the force is from left to right.

So, for t greater than 0, conductor experiences conductor ab, experiences a force from left to right left to sorry from left to right and what is the value of the force B i l what else, they have got thing starts moving I can write down the dynamic equation. What will be the dynamic equation? M dv dt is equal to the force from left to right I will velocities this way increasing. So, this must be equal to B i l no negative side this time because, this is accelerating it ok, B i l. So, this is one equation, what is our target? What is the velocity as a function of time is what? And i as a function of time is what?

Now, the this is 1 equation. So, I must have 2 equations to get v and i, what will be the next equation. Next equation is, what will be the expression of i? Expression of i at any time t, see the moment this happens it is starts moving, we have just discussed a conductor moving in a magnetic field, will have a induced voltage B l v. So, for this conductor moving from left to right with velocity v meter per second must have a induced velocity and the what will be the polarity of this induced velocity, this is what we are saying B, v and l.

Therefore, this whole circuit will now be equal to a induced voltage here between a and b, that is B l v and this thing your switch here and please I will connect also a resistance here, otherwise there will be short circuit suppose with a resistance this source is. Or suppose this resistance is the resistance of the conductor either way. So, there is a resistance here and there is your battery voltage here and current direction is this therefore, I must say that current is E battery voltage, minus this B l v divided by R. So, I have got 2 equations, if you want to find out v eliminate I from this put it here, you will get a one first order differential equations solve for v, then use the other equation to get the current and this we will continue in the next class.

Thank you.