Electrical Machines - II
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Lecture – 17
Induced Voltage in a Coil in a Rotating Machine (Contd.)

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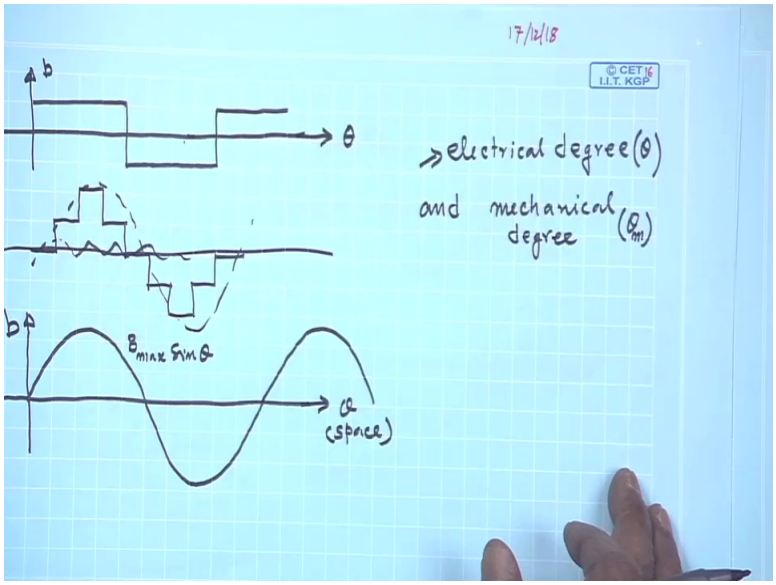

So, welcome to 17th-lecture ok. And we were discussing about the electrical degree and mechanical degree and what is the difference?

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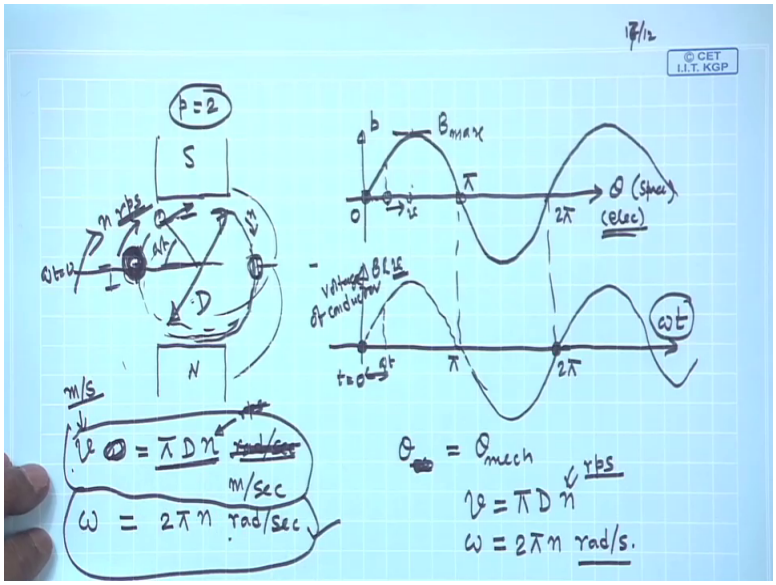

The whole idea is this that if it is a two-pole machine, your b distribution if it is sinusoidal. The fundamental component of that b distribution only we will consider, we will see that how this can be made more perfect a sinusoidal b distribution. But, assuming that b distribution is this a conductor if it is moving underneath this b distribution, then the induced voltage across it will be just same as this b distribution.

And this is the space angle mind you this theta is space angle and this is your omega t, what is omega? Omega is the speed of this rotor in radian per second, where from we started speed of the rotor is n rps which I can measure with a tachometer, so that is the mechanical speed anyway whatever it is.

But, a to calculate the induced voltage, I required the v not omega. And v I must therefore expressed in terms of diameter of the rotor if it is D v is equal to pi D n, but mind you n is in rps, it may be expressed in rpm, but rps. And the angular speed is in radian per second, which is 2 pi n radian per second.

Then I told that if the conductor, suppose the starting point is here and it is moving in this direction. So, in this axis omega t is the position of the rotor, suppose here it was omega t equal to 0. So, at any time t it comes this is at any time t, this is the position of the conductor at any time t so, this is omega t, it is this time. At that time what will be the voltage B l v at this time, B l v. And when it cross pi by 2, it has reached maximum voltage. Once again 0 voltage conductor comes here, because there is no B.

And then it reverses its polarity, and a complete cycle of EMF will be obtained, when the conductor returns back here. And there is no distinction really between electrical and mechanical angle, when the number of poles of the machine is 2.

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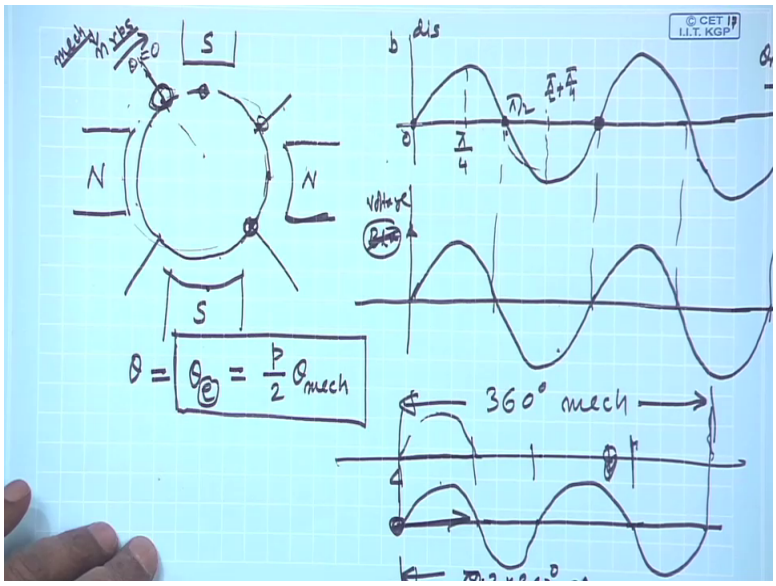

Now, let us see what happens, if it is a four-pole machine, suppose I will first draw the rotor, otherwise I am sketching the rotor so badly. So, this is the thing. Suppose, this is South Pole, we know how to create a four-pole structure. By not using projected poles only; by passing some current through the coils housed in stator ok, those I am not repeating. So, suppose effectively, it comes to this some South, North, South, North.

Please go through the earlier lectures, where I have indicated how a rotor or stator irons can be magnetized such that four-poles will be created using two coils you recall that. But, anyway just for understanding this, I will do like that.

Therefore, one quarter of this will be under the influence of North Pole. Next quarter will be under the influence of the South Pole. And next quarter will be under the influence of North Pole. And this is once again under the influence of North Pole. And these lines are the neutral position, where from North to South transition is taking place. Here the flux density will be 0 fundamental component of flux density.

Now, you will see if the first let us not draw anything, but let us argue like this you have a conductor, which is moving with a speed n rps. And that n rps is mechanical thing, we know only mechanical speed we are used to. I can use a tachometer. Tachometer records the mechanical speed in real term, so much rotations so many rotations per second and so on.

And suppose the conductor is moving with n rps, n is in mechanical; mechanical speed. Of course, one may question, we have not yet come to know what is electrical about it. So, what is the point of telling mechanical or electrical. Let us try to understand now that is why I will not do first any maths. Let us see this conductor is moving with some rps mechanical rps. Now, when this conductor in this position and it is moving in the clockwise direction voltage is 0. Then it will have peak value, when it comes under the centre of the South Pole, because I have assume the distribution to be sinusoidal in nature. Suppose, I am measuring theta is equal to 0 here.

So, your b distribution will be this one. Now, it will become maximum here, then when it when the conductor comes here, voltage will be 0, indicating this point. It will be maximum, when it comes here. But, in the opposite sense, because it is now under North Pole same conductor, once again 0 here. Then once again, it will have maximum here, 0 here, maximum here. So, this is the thing, so this is b distribution.

Now, you see when the conductor moves a pair of poles that is it starts from here reaches maximum, reaches 0 in one polarity of the voltage, then it reaches maximum and reaches 0 in the negative cycle that is the conductor has crossed only a mechanical angle of 180 degree. And a complete cycle of EMF is available that is the thing.

In earlier case, when the conductor has moved to by 360 degree mechanical, your EMF has also produced to one cycle of EMF. But, here you can see when the conductor moves 360 degree mechanical when the conductor has moved 360 degree mechanical, two cycles of EMF will be consumed that is what I want to tell.

If I sketch this as theta mechanical b distribution, then what should I write theta equal to 0 here. Here how much should I write, b was 0 here we have moved only 45 degree, this is pi by 4 under this siding is that this is pi by 2, we have already moved by 90 degree mechanical degree. And got pi by 2 not pi, if this axis you indicate by theta mechanical angle, the angle the way we understand geometry.

If you go on measuring like this, what I am telling? When this will be 2 pi, here you have got so pi by 4. So, pi by 2 plus another pi by 4, and this will be like that I can indicate. The question is so but your conductor does not know all these things, it only knows whatever b is there above it that will be the voltage. So, conductor will also generate the

voltage like this, so this is voltage B l v voltage, do not write B l v now. So, this is the voltage of a single conductor and this angle is theta electrical.

Therefore, we can easily see the theta electrical will be p by 2 theta mechanical. So, time has come to distinguish between these two angles, when it is a multi-polar machine. If p equal to 2, theta electrical is equal to theta mechanical. And theta electrical as I told you, I will indicate simply by theta ok. So, theta theta electrical is p by 2 theta mechanical that is over 360 degree mechanical angle.

We have now brought in another two poles squeezed, same mechanical angle 360 degree in terms of mechanical angle. Suppose, this is 360 degree mechanical, what essentially I have done is I have divided this 360 mechanical in four zones 1, 2, 3 equal zones I am so sorry. So, one becomes North Pole, South, North, South like that.

So, I have brought in another two-poles. South North in two two-pole, it was not like that only 360 degree mechanical. 180 was consumed by South Pole, another 180 degree was used by North Pole. But, here 360 degree, 90 degree mechanical angle was under the influence of South Pole. Next 90 degree under the influence of North Pole, then another South Pole, another north pole that is over the same 360 degree mechanical. I have now squeezed a pair of poles North-South, South-North, South-North.

And therefore, any conductor moving it a does does not mind whatever you have done, but conductor moving he will only see oh I was now under South Pole sinusoidal. So, my voltage I will make this one, then in this half it will be like this, then in this half it will be like this and in this half it will be like this. So, as the conductor moves by 360 degree mechanical the electrical angle moved electrical voltage that we will get, it has made two cycles that is 720 degree. So, this angle is 7 2 into 360 degree electrical understood.

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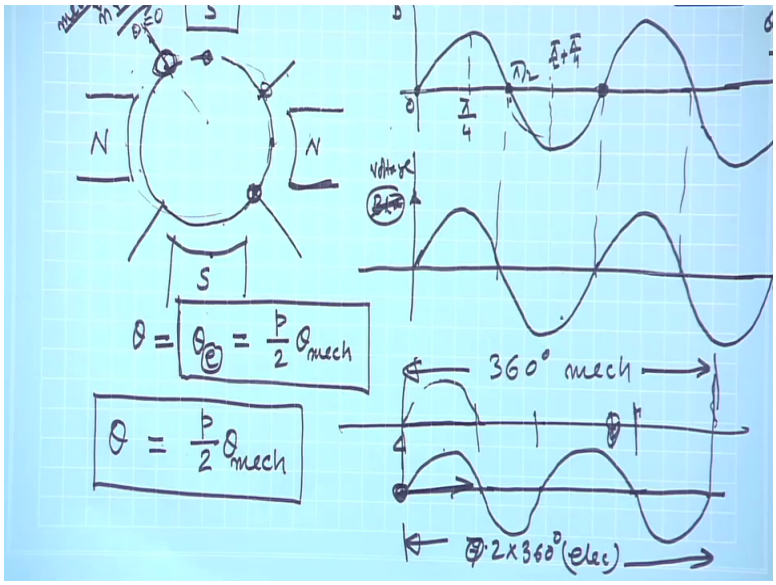

So, this is very important. Electrical angle is equal to p by 2 theta mechanical and one should not forget. If it is a six-pole machine, it will be 3 times the mechanical. Three cycles of EMF will be generated, when the conductor moves mechanical angle of 360 degree round. So, this is the very important thing. Therefore, it looks like that it is necessary to distinguish between electrical and mechanical angle, space angle, so what we will do is this?

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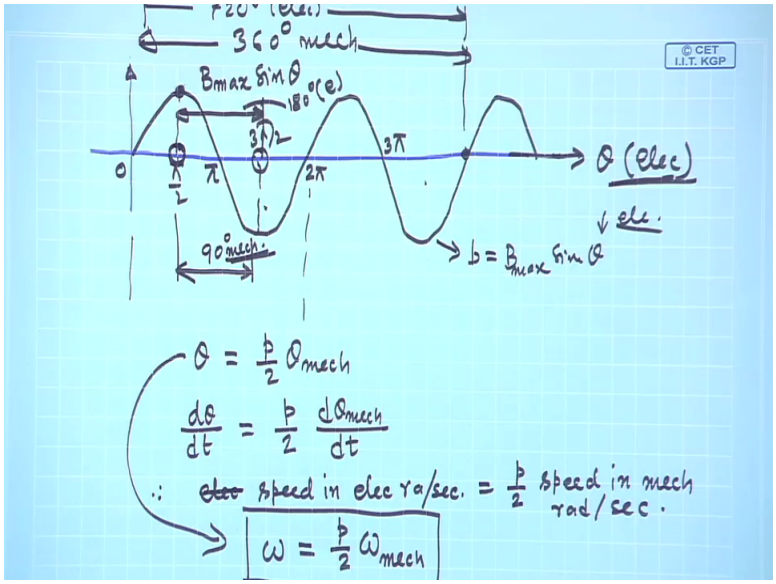

Suppose, I will say that this is a four-pole; four-pole machine 1, 2, 3, 4, this is 360 degree mechanical no doubt. But, in electrical angle if theta is in electrical that is how I should describe its sine wave, so that it will fit in, I will write it as B max sin theta and this theta as I told without any suffix means electrical angle, so B max sin theta.

And there I will indicate like this 0, pi, 2 pi, 3 pi, this is pi by 2 and so on, this is 3 pi by 2 is that clear. So, whenever you show the b distribution, because you do not know whether it is a four-pole machine or two-pole machine, so it is better did this will be giving you a true picture and you will say b distribution, in terms of electrical degree I know.

So, if it is a four-pole machine, you know this is 720 degree. If it is a six-pole machine, it will be 3 into 360 degree mechanical. So, I can always switch over, if I like that is coil, you are telling in this that they therefore if theta is a you have understood the point I hope and it is essential to understand.

Now, if you differentiate this with respect to time, you will get angular velocity d theta d t to be equal to p by 2 d theta mechanical by d t or I will say that electrical speed in electrical radian per second will be equal to p by 2 speed in mechanical radian per second or in other words what I am telling this omega. Theta is in electrical without any suffix will be equal to p by 2 omega mechanical, this is just comes from this. So, electrical speed is always greater than mechanical speed of the machine ok.

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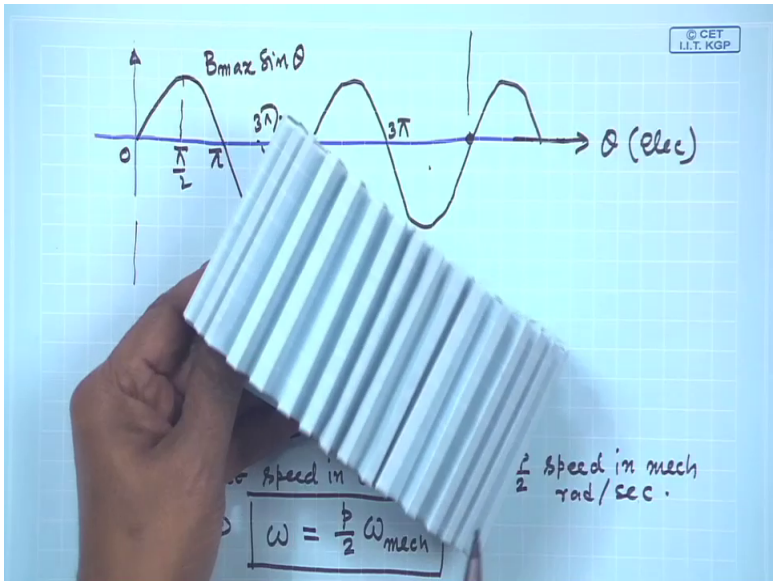

Therefore, while placing the a coil in this slots like this as I told you, you place one conductor so this is 360 degree mechanical 360 degree mechanical here is a slot here is number of slots are there. Now, if it is at this point you try to understand, if it is a two-pole machine, then half of the slots will be under North Pole and the remaining half will be under South Pole.

So, if you have placed one conductor in this slot, it is return conductor if it is under the centre of the North Pole, it is return conductor should be placed under the centre of the South Pole, so that the maximum voltage will be induced. But, if it is a four-pole machine, if you place one conductor in this slot which is under North Pole, but the return conductor should be placed return conductor must be placed at 90 degree mechanical degree apart why, because that will then indicate electrical angle 180 degree and you are ensure it will be under South Pole.

Next opposite pole. Therefore, this is the thing that if you place a conductor, let it be a four-pole machine. So, if it is a four-pole machine, this is 360 degree mechanical. But, electrically 360 degree mechanical, which means 720 degree electrical one and the same thing.

Now, if you place a conductor here if you want to place coil, you want to make a coil plus if you must ensure that if this coil is placed comes under the plus B max, it is return must be under minus B max that is how this separation should be. Now, what should be the separation angle for maximum voltage, in terms of electrical degree it should be 180 degree electrical. But, in terms of mechanical degree, this angle is only how much 45 degree for not 45 90 degree half of this. So, this is 90 degree mechanical got the point.

Therefore, over in a rotating machine like this 360 degree mechanical is fixed. Now, depending upon whether it is a two-pole machine or four-pole machine or six-pole machine, you know over this 360 degree all the poles are to be accommodated. If it is a two-pole machine, 180 degree mechanical will be under North Pole, 180 degree mechanical will be under South Pole. If it is a four-pole machine, only a first 90 degree will be under North Pole, next 90 degree under South Pole, next 90 under North Pole, next will be another 90 degree.

Now, in such an environment, if a conductor is allowed to move with certain speed be meter per second, then as it completes one rotation, he will cross successively South-

Pole, North-Pole, South-Pole, North-Pole, before it comes back to its original position. Therefore, two cycles of EMF will be produced which is equal to 720 degree, when we sketch a voltage waveform.

Therefore, a conductor moves by 360 degree mechanical essentially means that you have moved the conductor electrically by 720 degree and two cycles of EMF will be produced. If it is a six-pole machine, then one-sixth that is 360 degree by 6 is 60 degree 60 degree mechanical first 60 degree mechanical say under South Pole, next 60 will be under North Pole, next 60 will be under South Pole, North Pole, South Pole. So, there will be three pair of poles, p by 2 will be 3.

Therefore, three cycles of EMF will be produced as the conductor makes a one complete mechanical revolution. What is mechanical degree? T he mechanical degree we understand in geometry that is the mechanical degree, you can measure with a protector things like that. But, when we it comes to the generation of AC EMF, we immediately understand that the cycle of number of cycles of EMF, which will be produced as the conductor moves around the periphery of the rotor surface, a several cycles of EMF may be produced. One cycle of EMF generally 360 degree, so 360 degree electrical.

Therefore, if it is a two-pole machine, no question of distinguishing between electrical and mechanical degree. But, if it is multi-polar machine, I must remember that so as to correct, so that I can write down correctly the expression. So, when I write b is equal to B max sin theta, this theta is in electrical. So, I will sketch it electrical like this and conductor will move with a velocity v.

Now, what I am going to do is I am going to find out most important step that after understanding the distinction between these two, I will try to calculate the expression mathematically. Now, I am doing a little bit of mathematics to find out the expression of the rms voltage induced across a coil that is what I will try to do.

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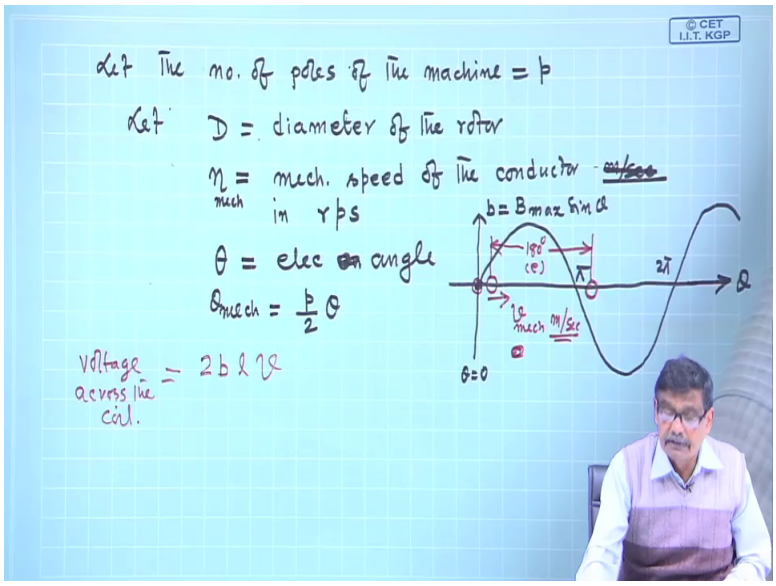

So, the problem definition is let it be a p polar machine. Let the number of poles of the machine be p ok. And let me write more formally D is equal to diameter of the rotor diameter of the rotor ok. And let small n be the mechanical speed; mechanical speed of the conductor in metre per second. So, this is mechanical speed, how much metres it goes or no mechanical speed of the conductor I am sorry in rps, how many rotations it makes which I can measure mechanical speed so, n mechanical.

And I will indicate theta to be the electrical angle. And theta mechanical, if necessary this may not be necessary is p by 2 into theta angle ok. And the problem is like this b distribution is given. And I will write it as B max sin theta. If I have chosen to measure theta from 0 crossing and going towards positive, this is entirely my business. So, I have considered this to be theta equal to 0. And this theta as I told you, it is theta electrical without any suffix. So, this is pi, this is 2 pi, and this is theta. And y axis is b is equal to in electrical angle this is the thing.

And now I will tell that a conductor single conductor is moving with a speed v mechanical is equal to so much meter per second ok. But, in a single conductor I know what to do. But, I want to use a coil, so coil I told if this is one coil side, I must make sure the other coil side will be 180 degree electrical apart. Then so the coil span is 180 degree electrical apart it has to be always, so that is very convenient to say. No matter

whether six-pole, four-pole, eight-poles coil span different in their positions in space must be always 180 degree electrical, why because then only the induced voltage.

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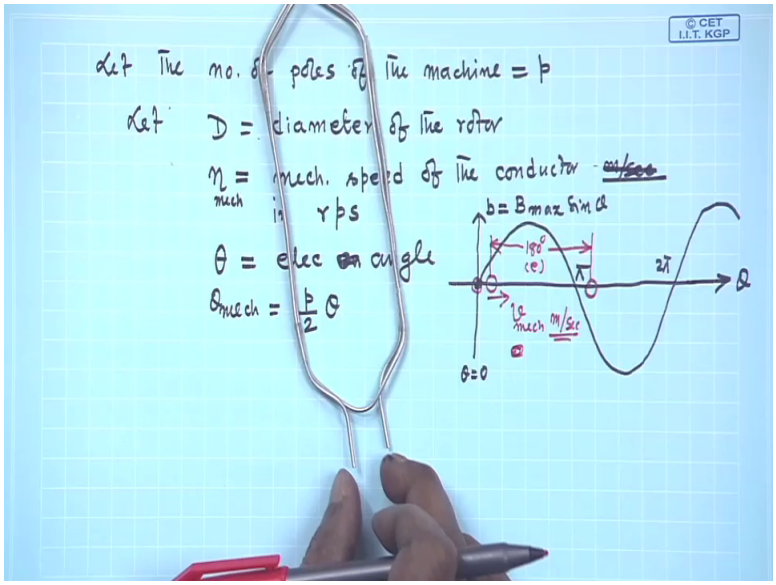

So, if this coil side is under the centre of North Pole at any time, this fellow must be under the centre of South Pole, so that you will get maximum voltage between these two point as 2 b l v voltage across the coil ok, we will continue with this 5 minutes. So, we will continue with this in the next class.