Basic Electrical Technology
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Lecture - 23
DC Machine

Hello everybody, till now we had been studying about one very specific two port device and that was the transformer; transformer as you understand we discussed it quite early was one of the two port devices that we were supposed to discuss and it takes the electrical energy from one side called the primary and delivers the electrical energy on another port called the secondary and that is also the electrical energy and we modelled the transformers, studied its equivalent circuit and got to know how it operates the principles of the transformers and the various non-idealities which go up to make a practical transformer.

Today we shall begin our discussion of another two port device which is the DC machine. The DC machine is also a two port device like a transformer. However, it has one fundamental difference and that is the voltage or the effort on one side is related to the flow or the through variable of the other port. Likewise, the flow on the electrical side is related to the across variable or the potential variable or the effort variable on the port two side.

And another point to be noted is that in a DC machine one port is electrical in nature meaning the quantities that are going to be applied to one port are electrical quantities and the quantities that are applied in the other port are the mechanical quantities because it is in the mechanical domain mechanical rotational domain so torque and omega will be the effort and flow variables that is the potential and the through variables, potential of the kinetic variables and in the case of the electrical domain it will be voltage and the current as usual.

Hence, we are going to discuss another two-port device called the DC machine. There is going to be energy which gets energy which flows into the machine through one port and we will call that was port 1 and energy flows out through another port and that is called port 2.

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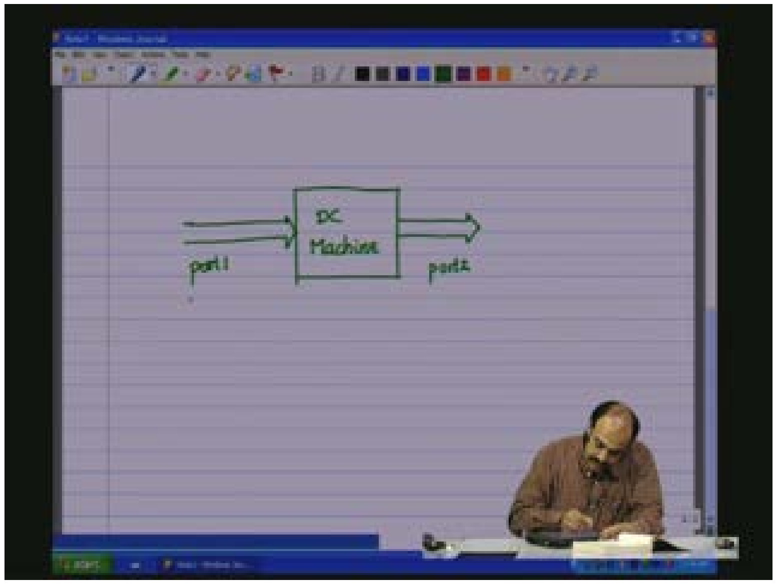

One port is electrical in nature meaning port 1 let us say is electrical domain, port 2 is in the mechanical domain mechanical rotational domain. This means the potential variable and the kinetic variable on the electrical side is the voltage e and the current i in amps, volts and amps, the product is going to be the watts and the potential variable on this side is torque in Newton meter and omega in radians per second. So this is volts (Refer Slide Time: 5:40), this is amps, this is torque in Newton meter and this is radian per second.

So e on one side, torque on the other side are the effort variables or potential variables, i on the electrical side, omega on the mechanical side are the flow or the kinetic variables; the product of effort to flow on each side is always going to be watts that is the power flow. Now, if the energy is flowing in this direction as shown which means from the electrical to the mechanical side then the same device is called a motor. If the energy is flowing from port 1 to port 2 that is the electrical energy is converted into mechanical energy and used for driving something then the DC machine is called the motor. The same instrument or the equipment can be used in a way wherein the energy flows from the mechanical to the electrical meaning something rotates the mechanical shaft of the machine and that is going to induce the electrical electrical side parameters and therefore the energy from the mechanical side can flow that is energy from the mechanical side can flow to the electrical side and such under such conditions the device is called a generator.

as the as the effort On the effort on the flows on the electrical side are DC values the motor and the generator both in the case of motor and the generator the machine is called a DC machine.

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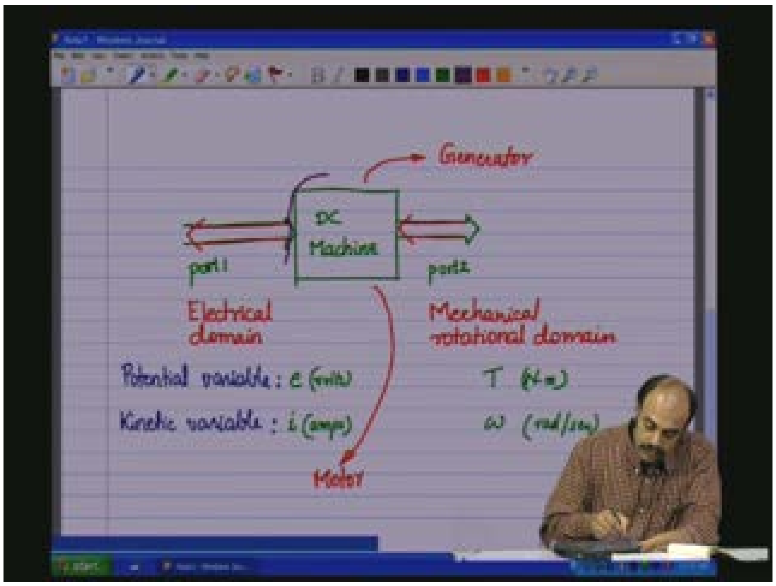

This is the machine that we are going to focus now and try to understand its principle of operation, the basics, the concepts what makes it happen, what makes it rotate, what makes it generate. First we consider the DC machine as a generator so we discuss the DC generator and the same machine will be later discussed as a motor that is a transverse energy from the electrical to the mechanical domain; most the principles that we study about the DC machine as a generator will also be applicable to the same machine which will be in the motoring mode. So these two functions of the DC machine we will try to focus in this class and the coming classes. but before that we need to know one or two small principles like we had the Faraday's law of electromagneticmagnetism in the case of the transformers which form the bases, here also of course we will be using Faraday's laws of electromagnetism because the energy is passing now through three domains. You see that the energy………. let us say if it is in the case of the generator, ultimately you will need to have the energy in the electrical domain, the energy emanates from the mechanical domain as far as this equipment is concerned and it passes through the electrical domain through an intermediary medium and that is the magnetic domain. So energy passes from the mechanical domain into the magnetic domain and from the magnetic domain to the electrical domain. Therefore, three domains are involved. And in the case of motor the energy emanates from the electrical domain and goes into the magnetic domain and then from the magnetic domain it goes into the mechanical domain and causes the mechanical movement that would be the green arrows indicate the motoring direction for the energy flow.

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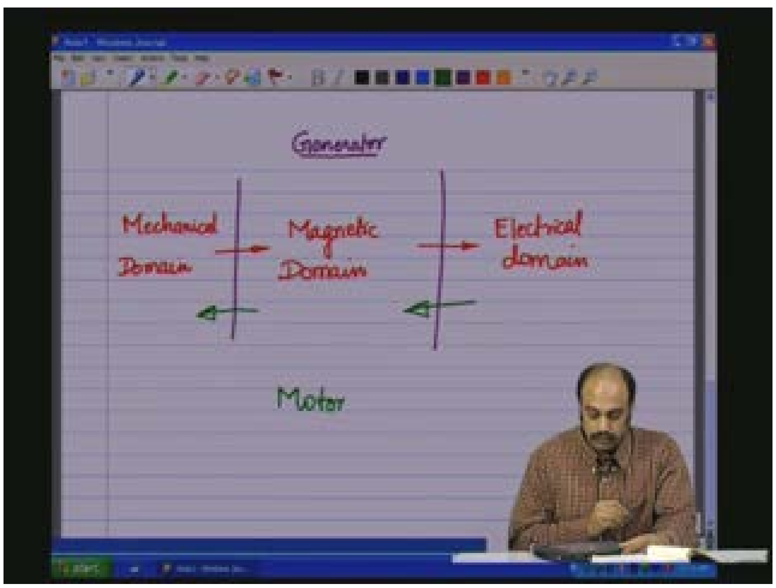

You see that electrical domain to the magnetic domain, magnetic domain to electrical domain the principles here are very similar to that of a transformer. All the transformer principles the Faraday's laws or the electromagnetics all those things are valid. There are few rules that we need to know form mechanical to magnetic domain and that is one is of course the Faraday's law and another is the lorentz force lorentz force. These two laws are applicable in this transformation of this domain.

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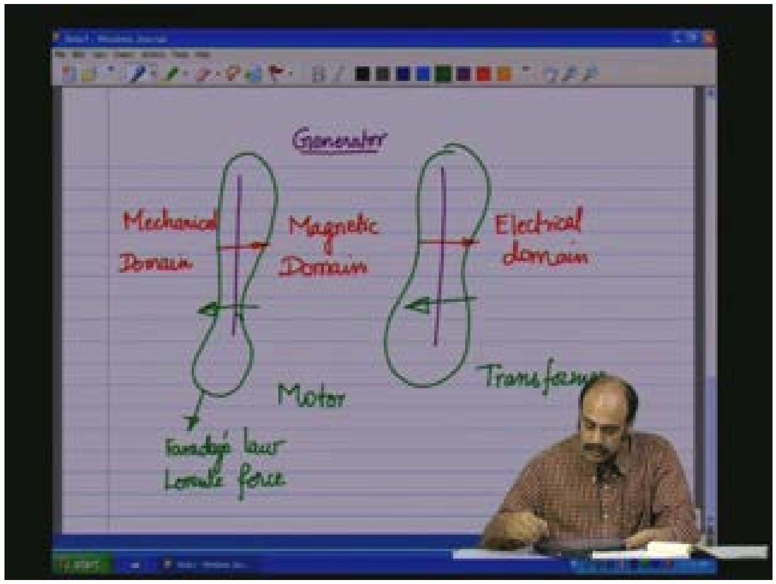

Now let us take let us take a piece of magnet and let us call it as north pole and somewhere there on the left side you will see the south pole for that piece of magnet. Let us take another piece of magnet and let me give it some space let us take another piece of magnet and place it at some distance in line with the north pole but the south pole facing the north pole and this has a north pole also of course because no magnetic element can be with an isolated pole so it has its own north and south poles. But we are interested in this that is until here (Refer Slide Time: 13:41).

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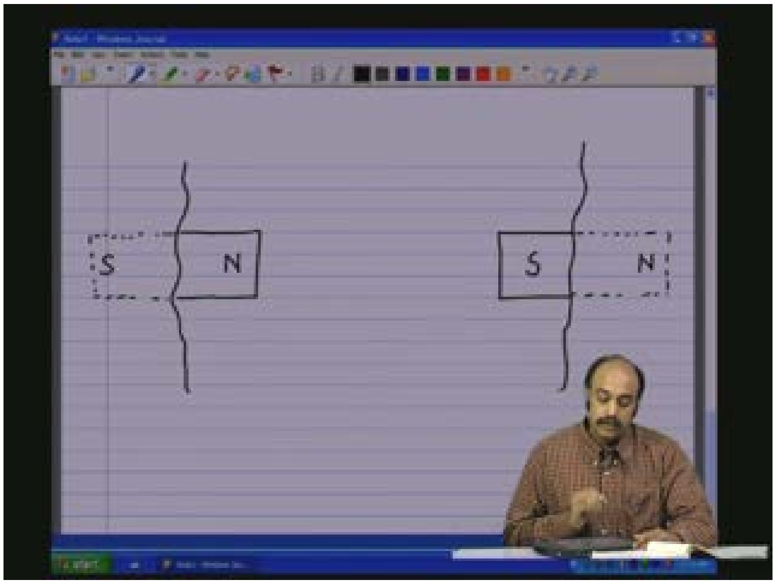

Now here if you see the magnetic lines of force this is at quite some distance it is not quite near it because this is much much further than the distances that we are indicating here so that this north pole does not have much interaction with the field lines which are occurring here.

Now if we take the field lines there is a flux from the north to the south, it starts going from north to the south, it is quite strong north to south. But in this direction in this direction the field in an orthogonal direction is zero. is zero Now in an arbitrary direction at an angle the field is going to exist but it is going to keep decreasing; let us say we take the we we draw a circle let me draw a circle as shown like that so we have a circle here (Refer Slide Time: 15:26) and if one travels along the periphery of the circle at this point the field is strong on positive at a point here the field this is at a point it is orthogonal to this north south axis and the field there is zero in that direction, at any other direction let us say at when when we are at a point here then the field field will field will be a bit reduced compared would be a bit reduced compared to the position on this because it is not directly in line and then if we take a point somewhere here the field will still further be reduced and still further if we take a point somewhere here the field is positive still but still further reduced and so on till it becomes zero at this point.

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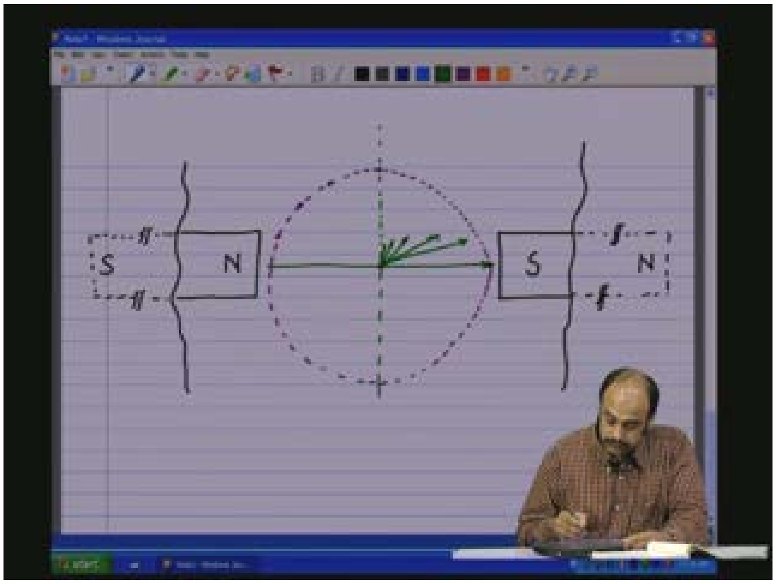

And then further if I take a consider a point on this circle circumference here in that direction the field starts becoming negative because if we consider a point here with a respect to that point the field is going to the point not away from the point and therefore corresponding to this point the field direction is negative and it is shown by this negative arrow (Refer Slide Time: 17:33). And as it as this point started in the circumference as this point starts travelling like this this would be going in this fashion with increasing field gradually till it becomes maximum and negative at this point.

So you see that there is a the field goes in this fashion in a sinusoidal fashion here. Now with a maximum when it is at the north pole negative maximum when the position is at when a point is at the south pole, zero at both the orthogonal points. So when the point starts moving at this point we see again the mirror image of this and then when this starts moving again towards the orthogonal axis you see the field decreasing field starts decreasing until it is zero at the orthogonal axis and as the point further continues it becomes positive that is this is the positive direction, this is zero, this is the positive direction so field again changes direction and you see that radially there is different amplitudes till it reaches the positive maximum when the point has again reached this point.

So you see that if we if there is a point which is situated on the circumference of the circle starting from the north pole the point located near the north pole if the field is moving away from the point it is we are putting putting it on the right side of this axis and the field is on the uh on the south pole the field is entering the point and then that is considered as negative. So a point which moves around the circumference like that starts with the field which is positive and then keeps decreasing as the point is moving along the axis there decreasing in this sense till it becomes zero and then it goes negative in this portion of the segment keeps going so on till the field is negative maximum till it is negative maximum as shown here nearest to the south pole point and as the point traverses along the circumference towards again the orthogonal axis this traverses the amplitude starts reducing further again till it becomes zero when it is at the when the point is at the orthogonal point and then this goes again in this direction changes direction and becomes positive max when the field again goes to this point. This is how the field would look like when a point traverses on the circumference as shown here when we place a north and south pole. So this would be the zero of the field phasor the field vectors. So this would be the picture of the field vector field vector spatial picture.

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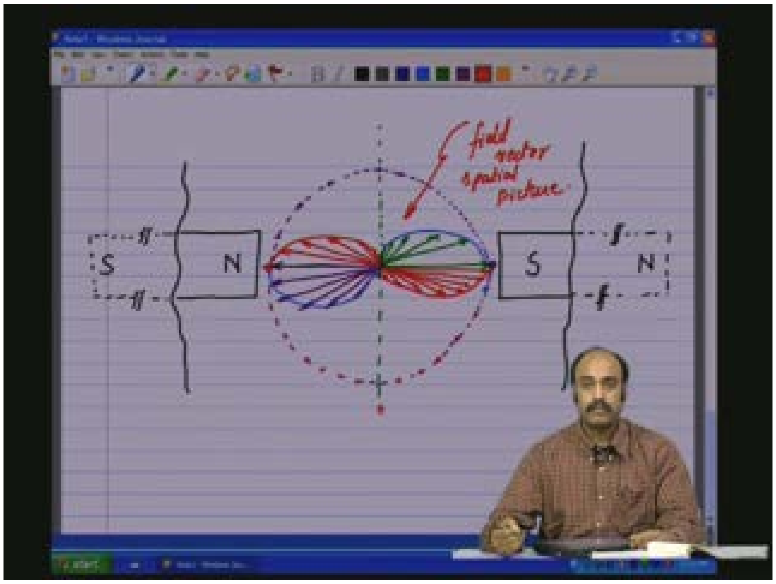

Now let us have a north pole and a south pole and let me have a conductor with some as such there is no such current in the conductor let us let us say that there is a field which is existing from north to south in this direction. Now this is a conductor. Now this conductor if it is stationary the field that is linking the conductor is also constant, there is no d phi by dt so as there is no d phi by dt there is no induced voltage in the conductor and therefore there is no current flow in the conductor.

If the field is changing, if the amplitude of the flux here, amplitude of the flux phi here is changing then there is a d phi by dt and this results in an induced emf in the conductor which will result in a current flow through the conductor in a specific direction. Therefore, what is essential is a changing field for a current for a voltage to be induced in the conductor and thereby a current to flow in the conductor.

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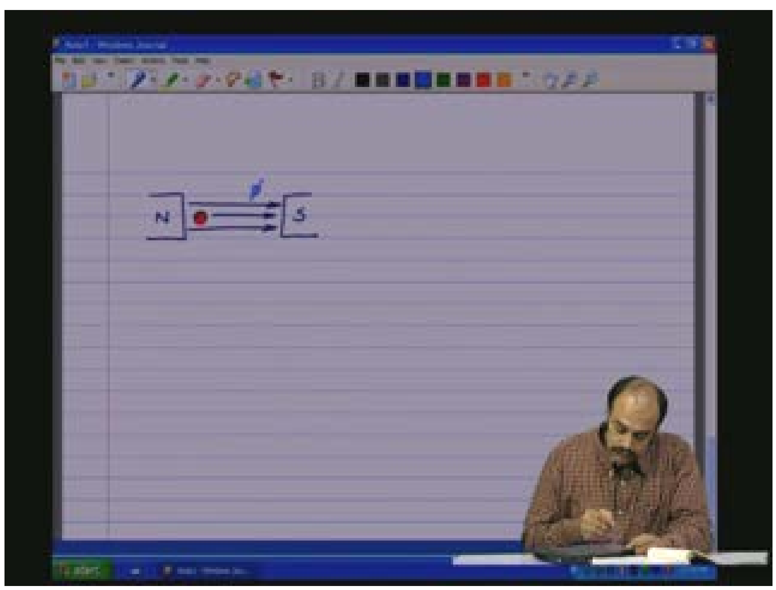

There are two ways in which to produce a changing field as far as the conductor is consider considered concerned. Let us say the conductor is fixed at a point. Now the flux phi here can change with respect to time; flux is the function of time, then amplitude here changes and therefore d phi by dt is finite not zero which will induce a voltage across the conductor and thereby a current to flow. The other way is to have flux fixed, flux is fixed, the flux amplitude is fixed; you have a permanent manner north and south pole and therefore the distant the distance between them is also fixed and therefore the flux phi is fixed.

Under such condition the only way that you can have a change in flux is of the conductor moves. If the conductor moves let us say to this position (Refer Slide Time: 25:35) then the flux at that position which is at a radial angle is going to be lesser and if it is moves still further the flux is going to be lesser, if it is at the orthogonal axis the flux there is going to be zero and let us say it continues to move. So the flux amplitude that is going to cut the conductor is going to keep changing as the conductor moves along the circle. so that is Therefore, the moving to the conductor is going to give you the d phi by dt which is going to induce a voltage and thereby a current to flow. This is the other method in which induced emf can also be produced in the conductor.

In the case of DC machines the flux here is kept constant by means of the fixed permanent magnets let us say or something that produce constant flux and thereby the only way that you can produce an induced emf in this conductor is by moving the conductor along the periphery which means that this conductor is going to see varying amplitudes of the flux at different amplitudes different points on the circumference of the circle and therefore a d phi by dt and therefore an induced emf and therefore a current to flow through the conductor. This comes by from the Faraday's laws of electromagnetism where you know that the induced emf which is equal to Nd phi by dt.

An alternative expression in terms of the conductor length can also be derived which is………. let us just modify the……………. and then we have this, these are the magnets and then of course there is the conductor, so this conductor is positioned like this and then you have all the flux lines linking the north and the south poles.

Now if this conductor is having a length L and then there is a cross section area A c and therefore flux by A c is going to be the magnetic flux density B and then if the conductor is moving at some speed let us say V is the velocity in meters per second at which the conductor is moving cutting across the flux then the voltage induced is also given by B the flux density which is a constant of course in this case because phi is a constant, A c is a constant, L L is a constant again because this length of the conductor and B which is the velocity at which this conductor is moving in meters per second and this is what is cutting the flux and therefore as it is moving it is at various radial distances angular distances from the centre and thereby the flux amplitudes are going to be varying at different positions and that is going to cause the d phi by dt effect the d phi by dt effect here in meters per second and it is going to result in a induced emf in the conductor.

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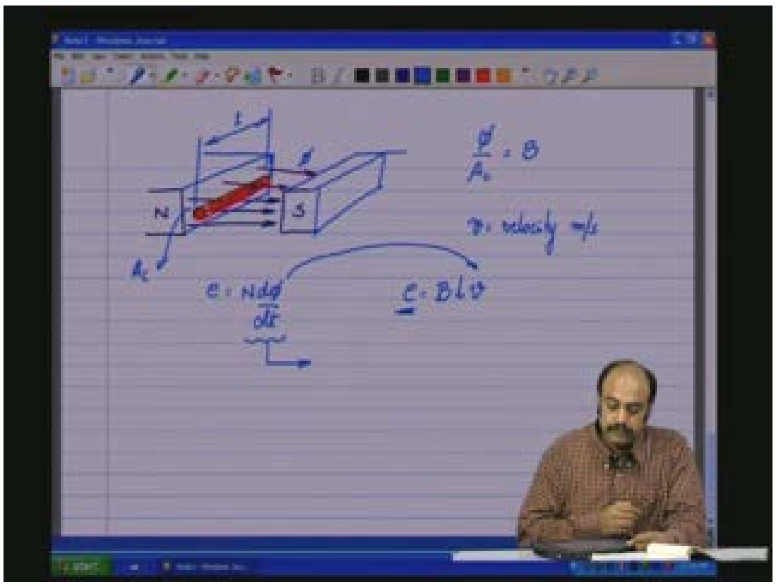

So, the induced emf of the conductor this gives induced emf in the coil which has N turns, this gives the induced emf in the conductor (Refer Slide Time: 30:17) in the conductor which has length L moving at speed V meters per second. So both are actually one and the same law Faraday’s law of electromagnetism whereas one is with respect with reference to the coil the other is with reference to the conductor.

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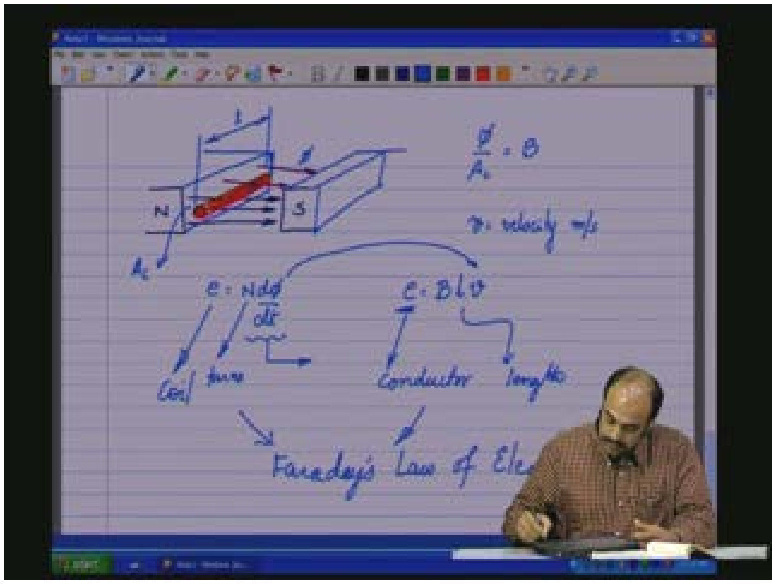

So now we start again with a north pole here and have a south pole here and let me also have a circular marking which gives the periphery in which the conductor is going to rotate is going to move about. So let us now have a conductor which is positioned like this.

So once we have the conductor this single conductor position like that now let us see the current through the conductor as it is moving along this moving along this field here. So as it moves let us also take the position (Refer Slide Time: 32:30) consider an imaginary no let me draw about a different colour consider an imaginary XY axis, this is spatial this is spatial axis spatial coordinate system, so when the conductor is in this position the flux is full max and the conductor starts rotating from here to this point moves from here to this point, the flux at these points are gradually decreasing until it becomes zero here. So you have the flux which reduces becomes zero at this point (Refer Slide Time: 33:33). Then form here to here the conductor is at the south pole, the flux is at negative max and then when it further goes the flux keeps moving in this fashion, zero again at this point and then when it again moves here the flux value is back again to its positive max; this is the zero as far as the flux phi m is concerned.

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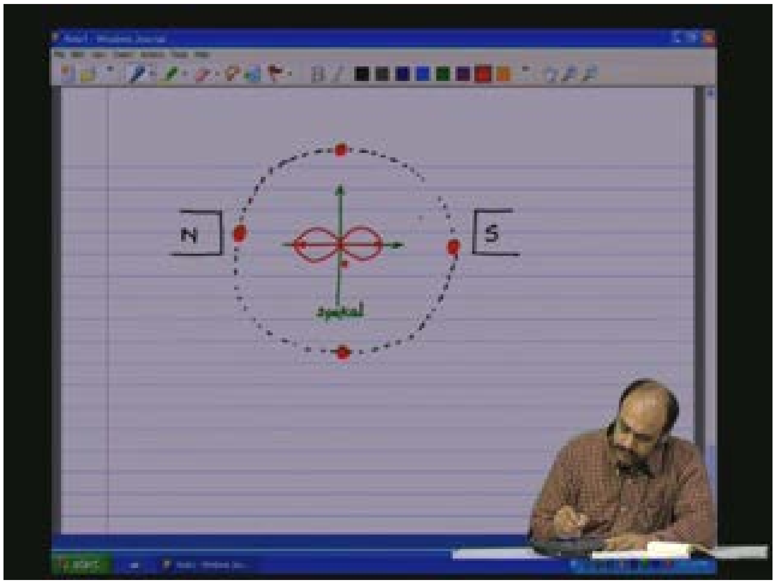

So this is the alpha axis and the beta axis in the special coordinate system. Now, when the fluxes at this point we are talking of this maximum therefore you have the induced emf e which is equal to Bℓv the B is maximum at this point the induced emf is maximum and therefore the current which is going to flow through the external load is also going to be maximum. So, if we now project this on that temporal axis let me now draw the amplitude of e the induced emf with respect to time. So as it is at this point let us call this as a (Refer Slide Time: 35:29) so this point is a that we are going to begin, this is at zero sorry this is at peak let me…….. so it is at this point this is zero so this is at E max then it rotates 90 degrees and it becomes zero here and then from this is point b, this is point a, this is point b corresponding to the spatial is point c and d. So from b to c from b to c this is going negative, so this starts going negative and reaches the maximum point c in the other direction negative direction that is here. And then from c to d it again becomes zero in the orthogonal axis, axis orthogonal to the alpha axis which is along the north south pole direction and then from there this is point d and then again d to a, this again is point a and it comes back to……

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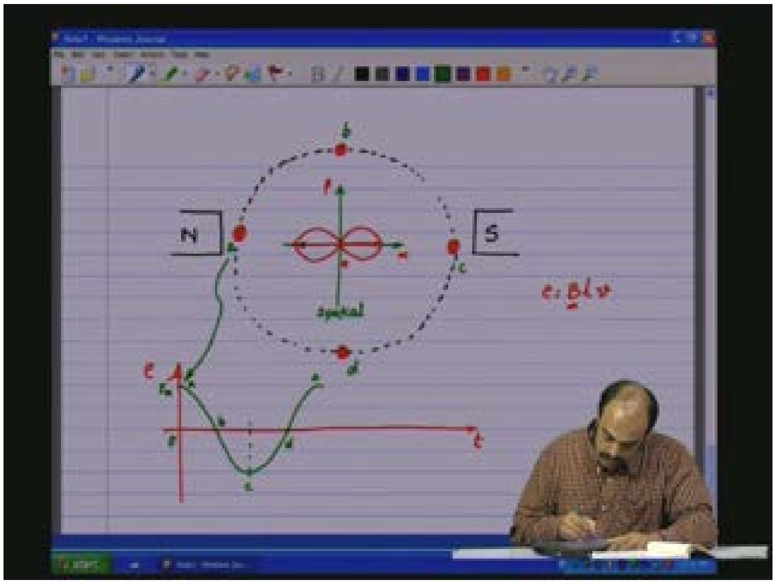

So this keeps going on and on, this is for one complete cycle of rotation. You see that you get an almost sinusoidal voltage that gets induced on the conductor as the conductor is moved from a to b b to c c to d and so on. Now this gives the basis for generating some voltage from the mechanical rotation of a conductor to an electrical induced voltage. So let us now form a device like this.

Let us have the north pole like that (Refer Slide Time: 38:16). So this is our north pole this is our north pole and let us have our south pole. So this is our south pole. So you have flux lines from north to the south.

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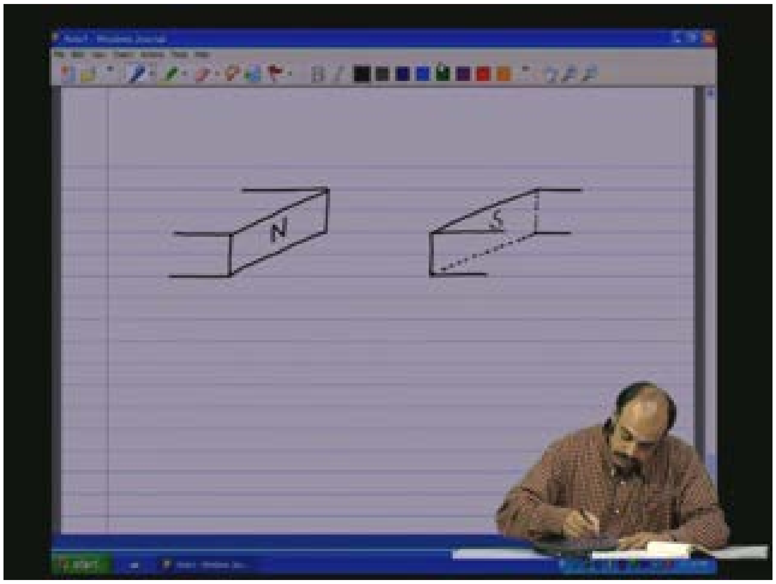

Now let us draw a coil right through here. So, we have a conductor of length L, there is a conductor which is this, there is also another conductor which flows through like that so this completes the circuit. So let us have some mechanism whereby I will have a ring I will have a ring here so let me have the ring in a different colour so let us have a ring like this (Refer Slide Time: 40:35) and let us solder this wire on to that, it is soldered. Likewise, let me also have a ring for the other wire also and let me solder this to this. We have this wire which is made in the shape of this coil here, the two ends are soldered to rings two rings and let us call this one as ring A and ring B and to these rings let us…………… just we have two carbon brushes like this which are just touching these rings. We have two carbon rings and these carbon brushes are making only spring contact with that one and through this we bring out the leads and then we can now connect a load resistance. This is the load.

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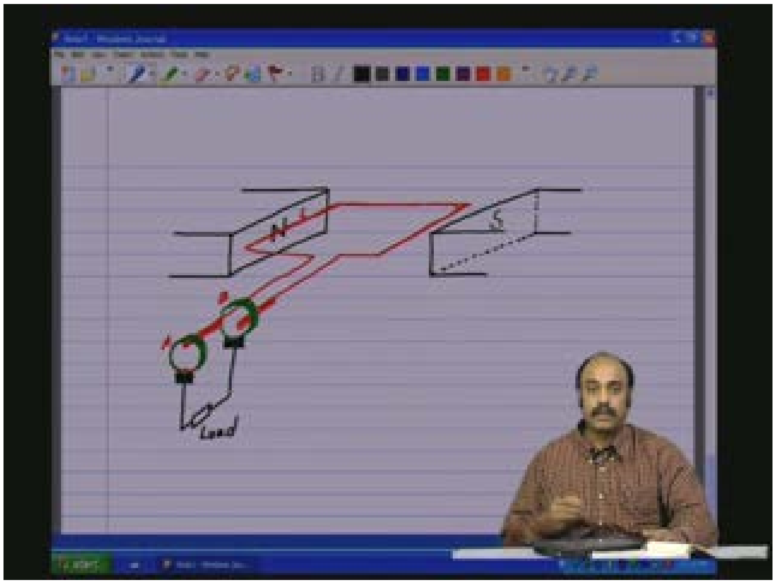

We have a very simple DC no we have a very simple generator not a DC general generator which generates AC signal. Let us look at the operation of this one. Let us say that this coil is moving rotating. So by some mechanism we are going to provide energy mechanical energy such that this whole coil is made to rotate about an axis. So this whole coil is rotating about this axis that is let us have this axis so the whole coil is rotating ago along the axis the blue line is shown here.

Now this conductor here when it is at the north pole this is going to have a positive field as we saw before positive max field and let us say the current is going to be induced in this direction i, there is a current i which is going to be induced in this direction and this conductor is closest to the south pole and this is going to have a negative max field and there is going to be a negative current of other direction same amplitude going to be induced in this. Now this is in a perpendicular direction this is along the field this portion of the conductor does not cut the field does not see any differential flux amplitudes throughout its rotation and therefore there is not going to be any induced emf on this line, there is not going to be any induced emf on this line and this line. So these two are going to have currents which are going to get induced one in this direction and one on that direction and this is fortunate for us because we have drawn the coil such that current can flow like that through this coil flows through this flows through this coil and comes out through this. So, as these slip rings, that is these are called the slip rings these rings which are soldered to the coil ends along with the coil are rotating it is brushing or making contact with these brushes which are fixed of course. So it is rubbing against these brushes which means it is in constant contact with the brush. So a current with current this current which flows through here like this, comes into contact through this brush, flows through this external load and then flows in in this direction and then again flows into the other coil a through this ring and the soldered coil end which completes the circuit and thereby you get a output here induced output here.

So as the whole coil is rotated we see that we see that the voltage across the load e load which is the induced emf across the brushes starts with……………. now in this position it will be having a maximum north and……………… because the north and the south are going to produce this leading currents and as it starts rotating and takes an orthogonal plane this is going to pass through zero because when the coil is perpendicular in a plane which is perpendicular to the plane which is right now shown it will be zero because there is no flux in the perpendicular plane and then when its starts again rotating towards further towards the south pole sorry this this portion rotating towards the south pole it starts going in the other direction and then again when it becomes perpendicular to the existing direction orthogonal direction there is no flux and then so on it keeps going like this (Refer Slide Time: 47:38).

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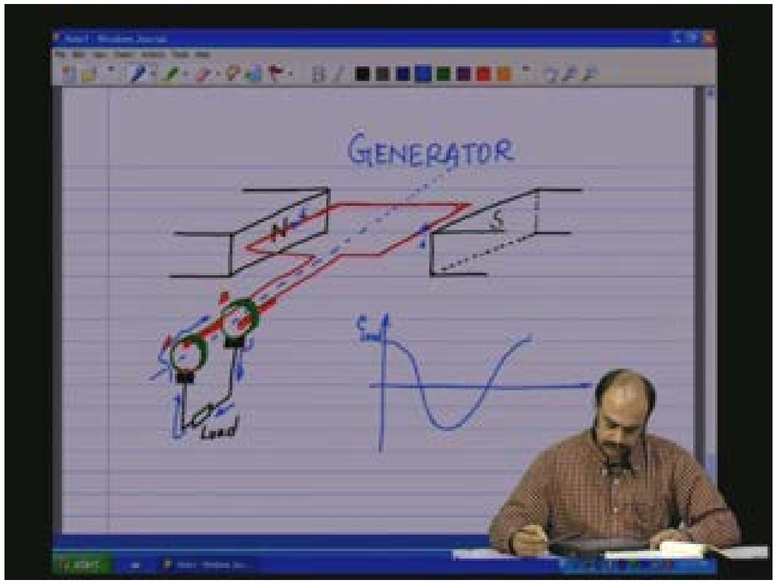

so when the when the flux When the flux is in this position the position which is which is like this (Refer Slide Time: 48:01) let me let me remove all these things let it be easier for you to…. now I will show it in a different colour let us say the coil has now taken the position which is like that and this is gone like that that is this is the vertical position probably it is confusing……

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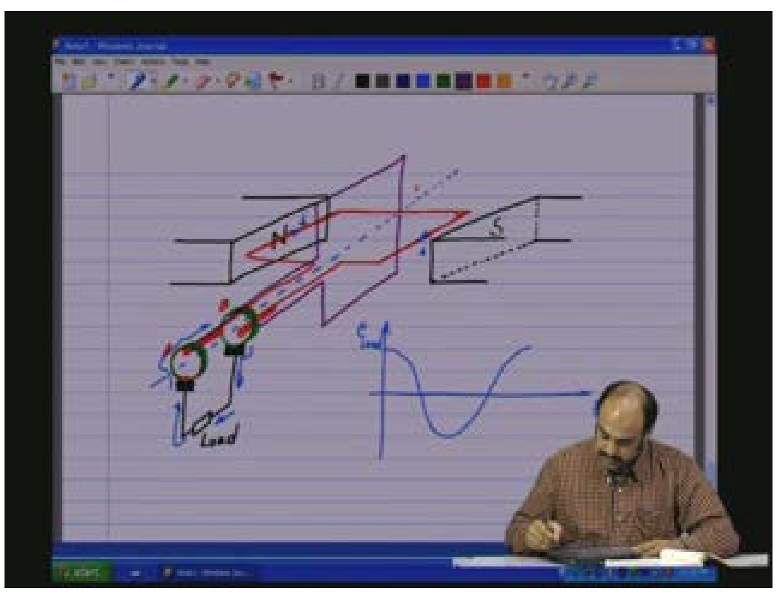

Let me redraw that one, it is better to look at it like this. Let me make some space here. Let us draw the four possible modes in 2D so that you get a good idea.

This is north, this is south; north pole south pole, the north pole south pole, the north pole and the south pole (Refer Slide Time: 49:42). Now we are going to show the conductors in 2D as just the cross section when you cut the section of the coil and it is going to be in this position and then rotates again and comes into this position and rotates and comes into this position (Refer Slide Time: 50:10). So let me call this one as coil side a 1 a 2 a 1 a 2 a 2 a 1 a 1 a 2.

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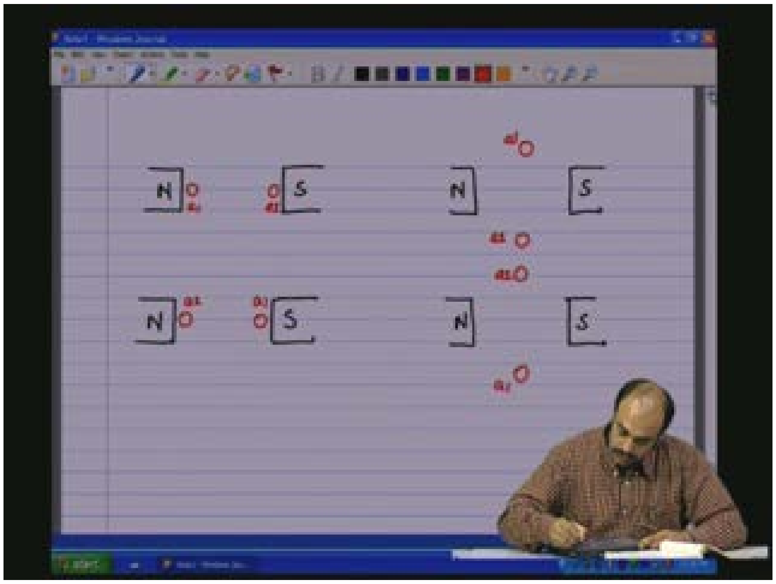

Therefore, if you look back to the previous figure this is a 1, this is a 2 and the current going into the page we are going to put X mark like that and coming out of the page is like this. So, as the coil has rotated as the coil has rotated 90 degrees you see that there is no current flowing in this position because the induced emf is zero and the coil further rotates in the other direction which makes this is in this direction. However, the direction in a 1 and a 2 have interchanged; you see that the direction has changed in a 2 and so in a one and therefore we are showing it as the negative direction here this portion shown as the negative direction and when it comes again to this point it again becomes zero, no current flow in any of the coil sides and then from here it shifts here. So this is position 1 position 2 position 3 position 4 and then back again to position 1 2 3 4 so on it keeps flowing in this fashion.

These are the various positions the four important positions in the motor in this particular equipment. So what we have here is a generator but it generates an AC waveform. How do we generate a DC waveform from this; means how do we rectify it. So, if we pass it through a rectifier we get from the AC waveform that the AC induced voltage a DC. But we are not going to build the rectifier using diodes but it will be built in along with the motor here.

So let us make a slight modification in the way the motor is built. Let us have again the north pole and the south pole and let us have up coil here. Now this coil is shown like this in this fashion (Refer Slide Time: 53:49). See the poles can of course be extended and we have the north and the south pole like this. Now this coil is now connected to the rings in this fashion. So let us have a ring in this fashion. Now this portion is…….. this one end of the coil is now soldered to this. Probably we will solder it from the inside so that the brushes………. so we solder one end of the coil to this and the other end of the coil is soldered to in this fashion let us say.

There is a vertical split in the ring such that this portion of the ring does not make contact with this portion of the ring and then we still have the brushes we still have the brushes like that which is making contact we still have the brushes which is making contact and it is from the brushes we are going to take it to the external load like this.

So now what happens we have the coil side a 1 coil side a 2. Now this right now this is going to induce a current in this direction here and in this direction here flows through the external circuit and the current flows through this coil. Now as the coil is rotating and comes in an orthogonal plane it becomes zero the voltage becomes zero and starts going negative. So when this has turned 90 degrees these two splits are going to be at around the centre of the brush and then on further rotation this split that is let us say this is a 1 and this is a 2 portion of the ring so a 2 ring a 2 portion of the ring is going to be in contact with this left brush and a 1 portion is going to be in contact with this. But at that point when it has crossed over the orthogonal plane there is a reversal in the current for a 2 and a 1 and therefore a 2 becomes positive and a 1 becomes negative therefore you would see in the time axis temporal axis time versus the induced emf versus the induced emf e here so it starts with a peak like that and then the moment it comes to zero here when it is on the orthogonal plane, flux is zero and now on further movement flux would actually have gone negative but here the other ring is now making contact with this brush, this the ring which was positive is now making contact with the other brush and therefore there is a reversal in the contacts with the brush which is again going to make the current through the load in the same direction and this is going to go like that and so on in this fashion.

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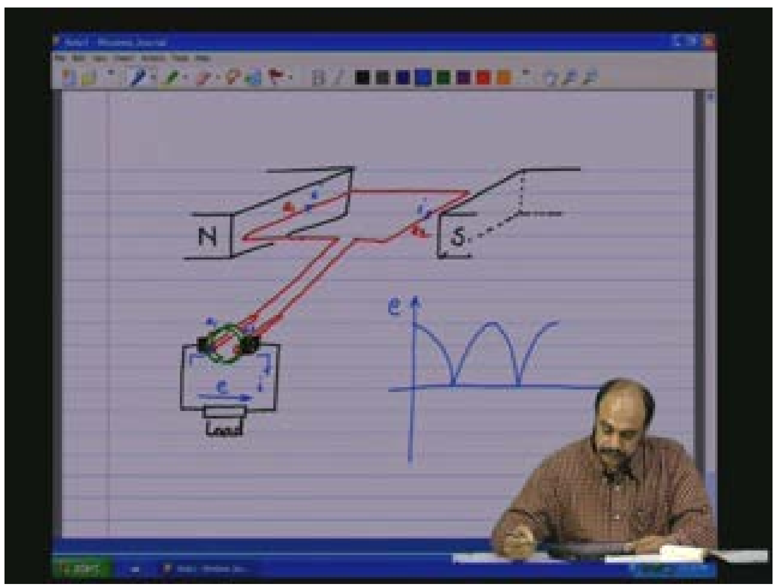

So there is a rectification which is which has come about due to the way in which this ring has been made, this is called the commutator commu tator. The way the ring was formed in this case in the AC motor this is called the slip ring the slip ring. So the commutator can be used for obtaining a rectifier waveform at the output and thereby we get a unidirectional induced voltage and therefore that would be a DC output. Therefore this machine with the commutator even though the current through the coil is both direction that is AC because of the external commutator the voltage across the external load is unidirectional the currents through that one is also unidirectional and therefore this can be considered as a DC generator.

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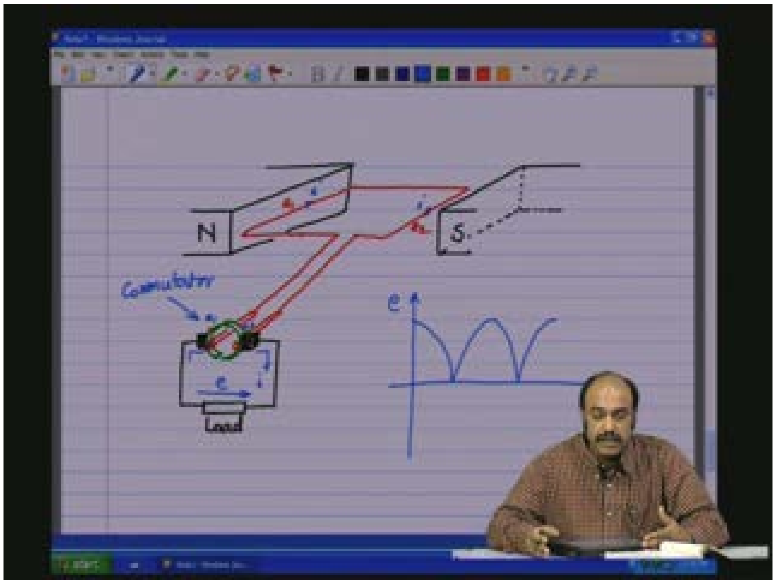

We stop here and continue in the next class consolidating the concepts of the DC generator further. Thank you.