Basic Electrical Technology
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Lecture - 25
DC Generators

Hello everybody, so in the last class we were discussing about the DC generator; mainly about the structure of the generator, the way the commutator poles are segmented, the way the brushes are positioned in the neutral zone so as to get an output that is ripple free that is containing as little ripple as possible. Today we continue the discussion on the DC generator and evolve the complete the equation for the generated emf across the brushes. We saw in the class that the generated emf across the brushes E g is given by N phi Z by 60 this is the volts and we also we also did a small example to consolidate this understanding of this particular equation.

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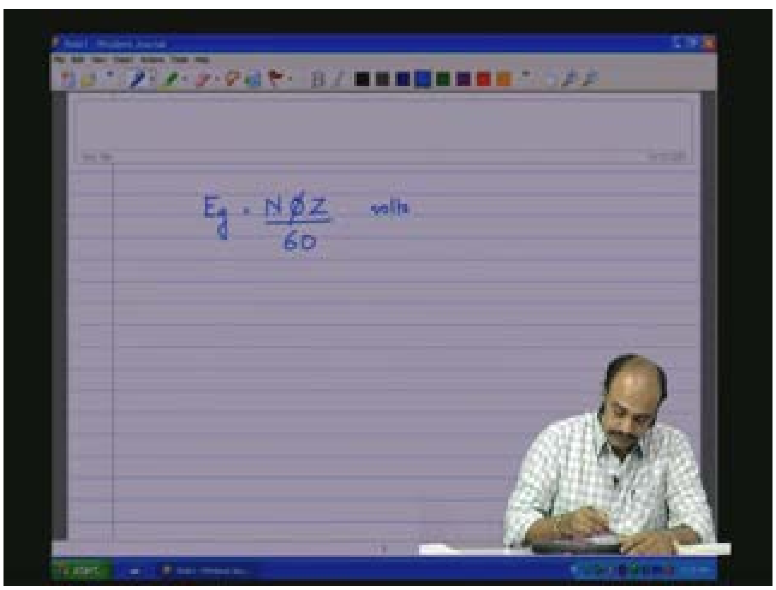

Now here N is rpm of the rotor or the armature, phi the flux per poles, Z is the total number of convert conductors in the armature. here we have always been assuming that there is just one set of north and south poles and in between you have the armature and inside we also draw the segmented commutator. So we have the commutator which is doing the job of rectification and of course the brushes placed in the neutral zone. So, for such a configuration so you could have n slots; so if there are n slots on the armature there will be n coils and if there are n coils there will be n segments on the commutator.

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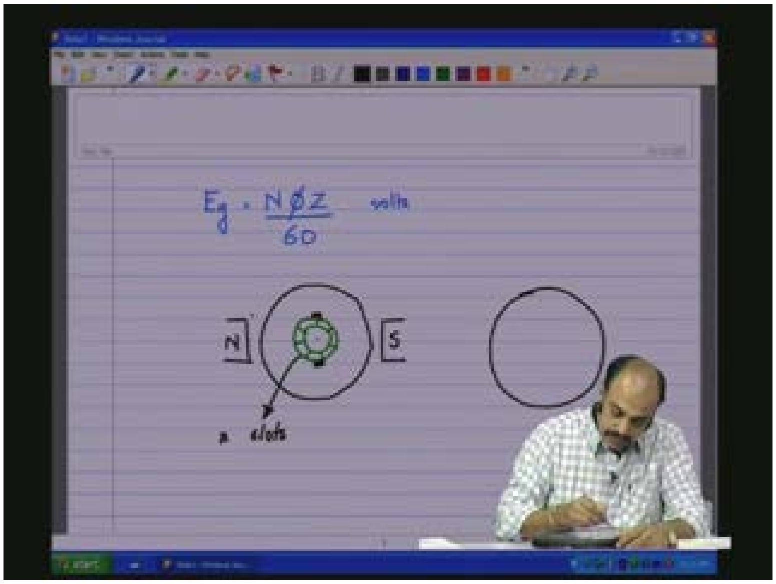

Now we could have multiple pole pairs. We see that here you have one pole pair (Refer Slide Time: 4:07); one north south pole pair. Let us say we place the pole pairs north south north south north south. Alternately poles are placed in placed of opposite polarity but the pole pairs are diametrically opposite meaning this is one set of pole pair, this is another set of pole pair and we have another set of pole pair here so you have three pole pairs arranged in this fashion. So these pole pairs……….. and of course here (Refer Slide Time: 5:13) you are going to have the commutator with the segments and the brushes placed appropriately in the neutral zone. You see the neutral zones will be always in between at the midpoint in between two poles two poles of opposite polarity so it is always that is where you will get zero voltage induced on to the coils and therefore the brushes have to be placed in the neutral zone.

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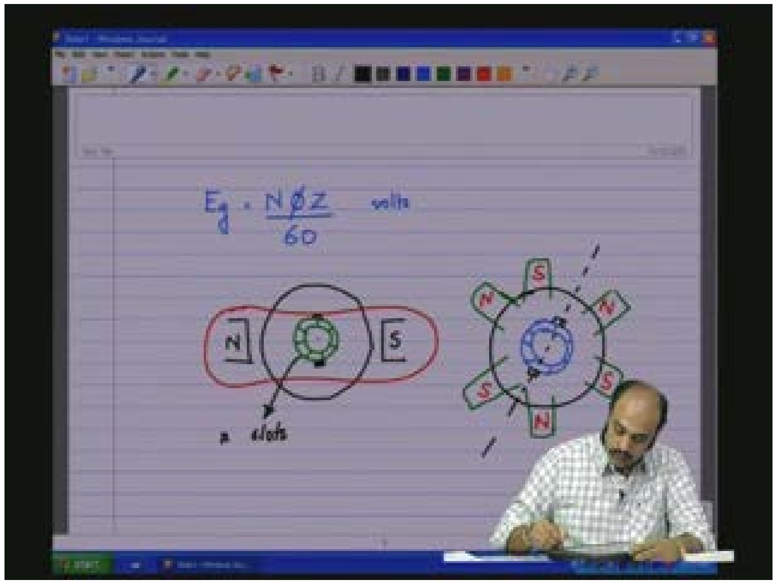

Now here you have three pole pairs and therefore to incorporate also the finite number of pole pairs which need not be always one the modified equation for the generated emf E g is pole pairs p, p is the number of pole pairs N phi Z all others mean the same same quantities as we have described earlier. So p will be the number of pole pairs. As poles do not exist independently they always existent pairs you cannot have a pure north pole or a pure south pole, we normally talk in terms of pole pairs. Or, if you if you want to talk in terms of poles there will always be even numbers, multiples of 2.

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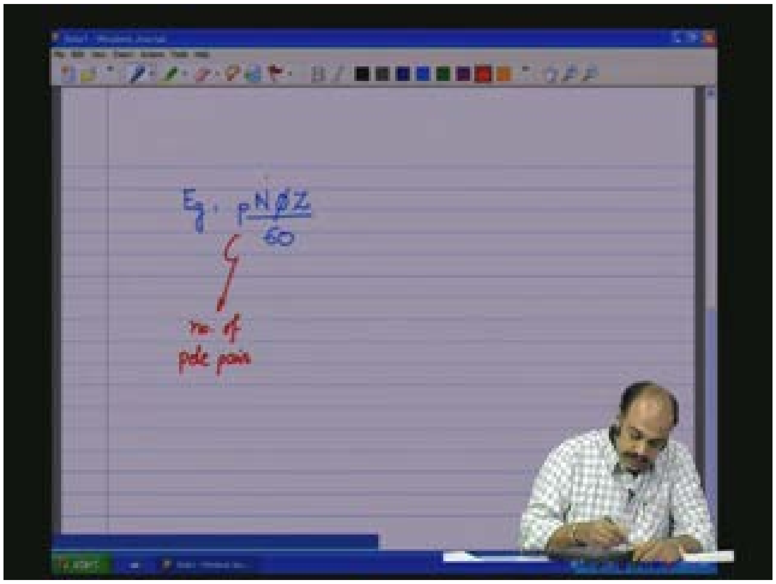

So number of pole pairs: N is the speed of rotation in rpm speed in rpm, phi is the flux in Webers per pole ; per pole means per pole pair and Z is the total number of conductors in the armature, so Z is the total number of conductors in the armature. So this would give you the induced emf of a DC machine or a DC generator which has p number of pole pairs, N is the speed of the rotation, phi is the flux per pole and Z is the total number of conductors in the armature.

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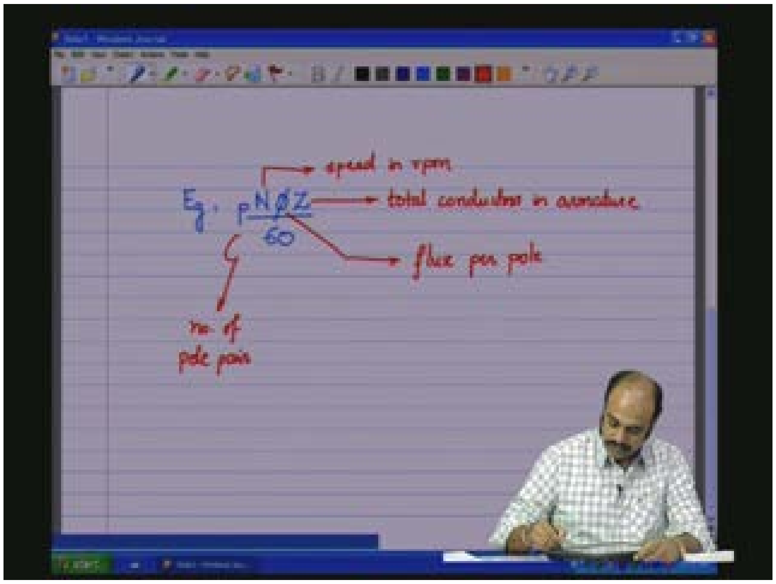

Now there is one important aspect that we need to study. We have the energy coming from the magnetic sorry mechanical domain, goes into the magnetic domain and then finally comes out through the electrical domain by means of the brushes and this comes out as the induced voltage E g. so one is applying a torque here. Now if one loads if one loads here that loading effect on the electrical side should percolate back and get reflected on the mechanical side so that you draw more energy so there should be…………… any load here should reflect as a reverse torque here such that the prime mover whatever is moving the mechanical shaft should now apply that extra torque to overcome that load and still rotate it at the same rpm so that you get the same you get the same induced emf E g.

So this loading effect here in effect has made the prime mover whichever is driving the shaft to now give more energy to the mechanical shaft to supply the energy to the loads. This is how in any conversion energy conversion process there should always be a loading effect that show which should percolate back.

How does this happen; how does this loading effect back on to the shaft happen in a DC machine; because that is an important thing to understand and that is happening by means of what is called the Lorentz force.

We saw that in the DC machine there are two important equations that you need to remember: one is the Faraday's law of electromagnet electromagnetics the alternative equation which is E is equal to B L v, the other is the Lorentz force acting on the conductor.

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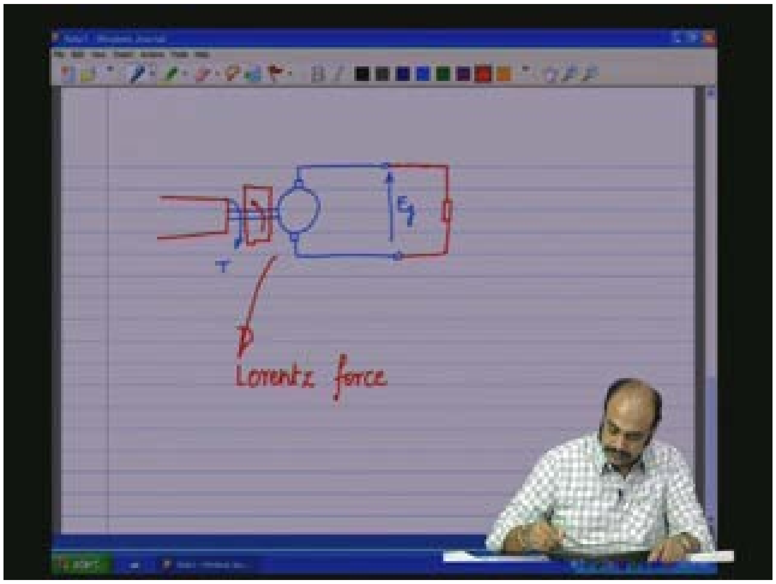

So what is it?

So let us let us take a north pole and a south pole and let there be flux lines. So these are flux lines or B which is equal to phi by A (Refer Slide Time: 11:08). Now here let us place a conductor and let a current flow through the conductor and we are passing a current through the conductor and that is going into the board; the direction of the current is going which is…………….

Now we saw that when there is a current flowing through the conductor by the right hand rule there is going to be a magnetic field setup around the conductor, so that magnetic field that magnetic field is, as it is going in by the right hand rule if it goes in then the fingers will encircle in a clockwise direction that is it is going into the board, the fingers are encircling in a clockwise direction so which means the field will be in a clockwise fashion so we have the field due to the current i and that is in clockwise direction.

So now you see what is happening the field produced due to the current the orange ones which are shown and the field of the permanent of the magnet they both are going to the field is aiding

(13:02) the field conductor the field produced by the current of the conductor is aiding the north south field and below the conductor the field produced by the conductor current flowing in the conductor is against the magnetic field of the north south conductor. So here it is against and here it is leading. So equivalently we will land up with a field distribution so there is a current i flowing here and because of the i flowing we had those things. Now the field on the bottom side of the conductor it tries to cancel so the field is weak and the field is strong on the top of the conductor whereas it is weak on this side. So this field is activating now like a rubber band which is trying to push the conductor down. So there is a force which pushes down because of the current i which is flowing though the conductor i. now this force is called the Lorentz force.

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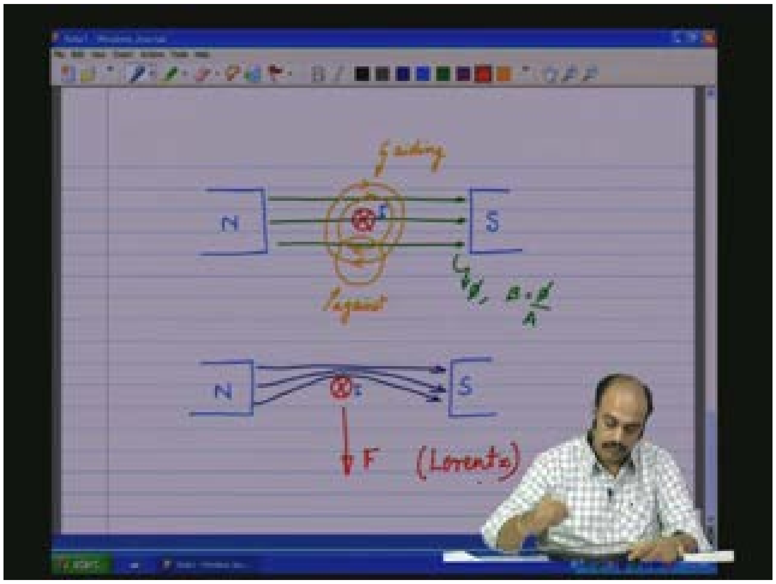

Now there is an interesting rule interesting rules memory tip for you to remember the direction of the force. if the current is if the thumb is pointing; take again the right hand, always the right hand; if the thumb is pointing in the direction of the current flow in the conductor and the forefinger or the index finger is pointing in the direction of the north south magnetic field then the middle finger which is at right angles to both the thumb and the forefinger you see that all three fingers form the three coordinates of coordinates of a system and each is orthogonal to the other. So the middle finger now points in the direction of the force. So, if you point the thumb in the direction of the current and the forefinger extended which is now orthogonal to the thumb pointing in the direction of the applied field which is the north south magnetic field then the middle finger which is also orthogonal to the other two fingers will now point in the direction of the force in the direction of the Lorenz force and that is the direction with the conductor will tend to move.

So what is the value of this Lorenz force?

The Lorentz force F is given by a very simple equation B into I into ℓ where B is the flux density of the magnetic field and in this case it is the flux density of the north south magnetic field that is being applied and which is this (Refer Slide Time: 17:14) and then I is the current flowing through the conductor which in this case is this the current flowing through the conductor and ℓ is the length of the conductor of the conductor. So this gives the force Newton's on a conductor which is placed in a magnetic field B of length ℓ carrying a current I through it. So the direction of the force as I have said I said you use the right hand rule to find out the direction of the force.

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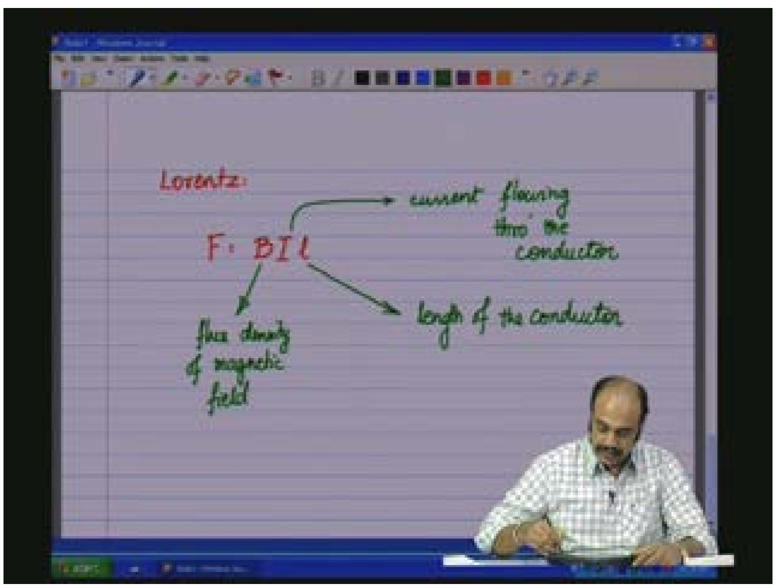

So now let us apply this Lorenz force principle to the DC machine. So we have DC machine with a north pole and a south pole as shown here. Now let us have the armature or the rotor as they may call circular fashion like this. Now there are coils and we will represent the coils in terms of circular conductors here in this fashion and so on like that.

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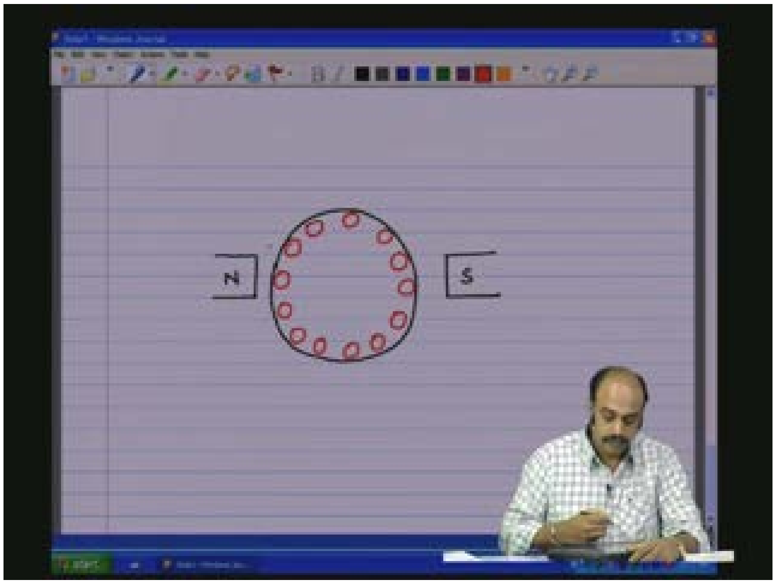

So, at a given instant of time, now this is the neutral zone this is the neutral zone (Refer Slide Time: 19:33) there is no voltage being induced on this conductor and this conductor so there is no current flow. Now let us say there is a current flow in this in this conductor and let us say it is going into the board and we because it is away from the neutral zone there is going to be a current flowing in here, all these will be in the same direction with magnitudes varying, the one which is nearest to the south pole will have the largest magnitude so on; again this conductor is going to have zero current because it is in the neutral zone and then here the direction will be opposite coming out of the board with varying magnitudes the one nearest the north pole is going to be having the largest magnitude of the induced current.

Now these are the armature conductors. Now these armature conductors are connected to the commutators is it not? So the armature conductors are connected to the commutators and through the brushes through the brushes we see that the external circuit is connected (Refer Slide Time: 21:27). Now we apply a load to the external circuit which has a voltage induced E g due to the generator action and varies a current that flows through the external load. So this is a current I and there is a load R L.

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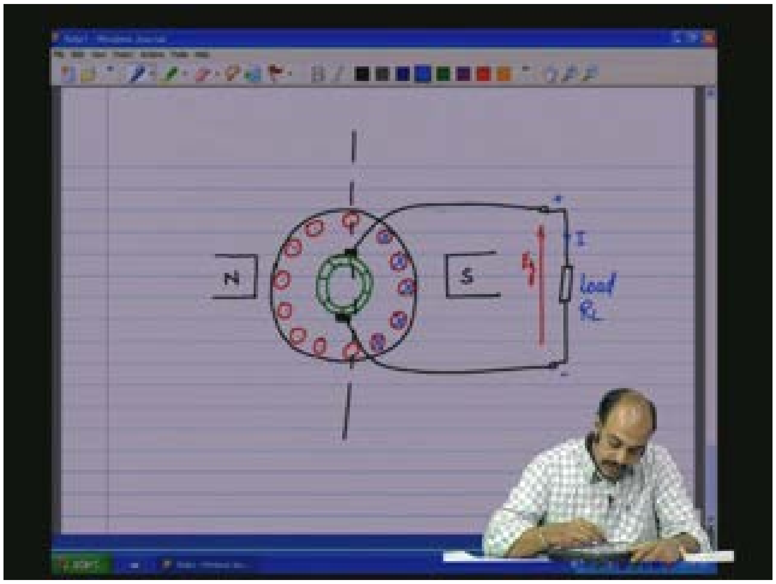

Now this I is going to flow through the respective conductors that is through the armature. Now, if we take a particular if you take a particular conductor let us say this particular conductor which I am showing here with the cursor (Refer Slide Time: 22:13) now that is flowing into the board, now there is a magnetic field which is being applied in this direction and therefore there has to be a force which is in this direction, you have the force. Likewise, this conductor will have a force in this direction, this conductor will have a force in this direction, all these forces will add up, each conductor will apply a force in this direction downwards.

Now this the current is going the current is coming out and by again applying the right hand rule you see that the force will be applied it will be in the direction pointing up and therefore they all will be aiding; the forces on each current will be aiding, so these are the forces the Lorenz force due to the load current which is flowing through the armature. Now this force is applying a torque on the shaft and the prime mover has to overcome this shaft which means now the rotation is in this direction anticlockwise this is the rotation of armature but the loading effect is giving a rotating torque rotating torque which is in the clockwise direction so an extra power has to be generated by the primary which will try to force against these clockwise loading effect torque such that the armature continues to rotate in the……….. P so thereby it draws more energy from the prime mover and dumps it to the electrical side. This is the energy conversion processes on loading. So this how any load gets reflected on to the mechanical shaft and thereby access a load on the prime mover.

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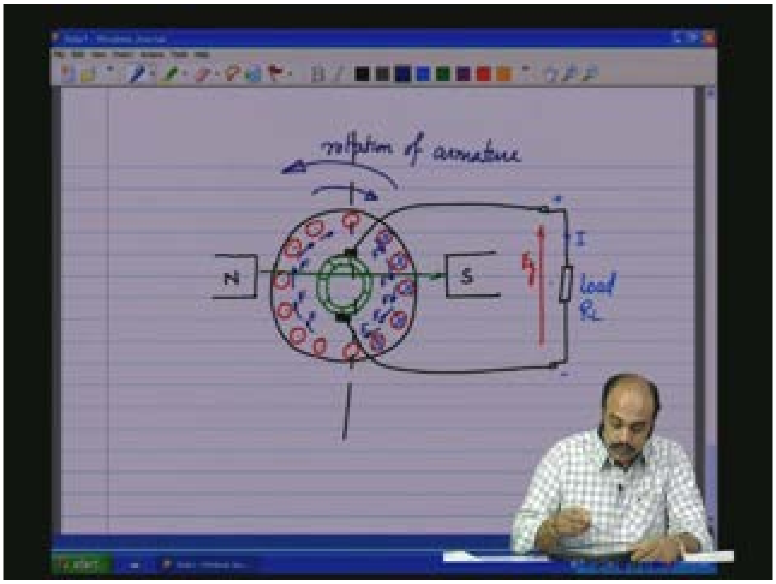

So having looked at the loading effect we have one more important effect which we need to consider and that is the armature reaction. Armature reaction is another undesirable effect that we want to avoid. You see that till now in the consideration of in the discussion of the operational principle of the DC generator there was a flux between the north south poles and there was a coil and due to the motion of the coil there was a current induced in the conductor of the coil which flows through the brushes and to the external circuit. But the moment there is a current in the conductors of the coil there will be a field around it, now that field is going to react with the main field of the north south magnetic poles which has been applied. Now this will distort the way the field will look like and the neutral zones which we thought were zero field zones where no induced voltage no induced voltage in the coil can exist all these concepts are going to are going to be a bit distorted because of the presence of the current which flows through the armature conductors. Now let us look at this effect what it does.

We have the north pole and we have the south pole, still we are sticking with the same one pole pair and let us have the circular armature. Now in this circular armature we are having the conductors. So let us have the conductors in the circular……….. and this orthogonal plane was supposed to be our neutral zone (Refer Slide Time: 27:32) where there was not supposed to be any induced voltage and thereby no induced current because at this point the flux is equal to zero in the direction. Now there is a flux north south flux which flows in this direction, this is a flux due to the applied north south poles.

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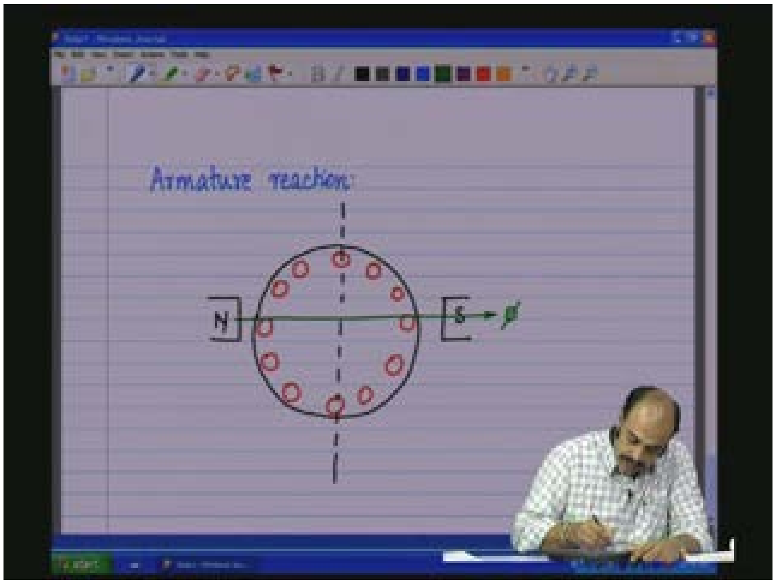

Now we see that there is current and like in the previous loading effect diagram let us say the load current flows through these and in these conductors the currents are coming out of the board; of course imagine that there is a commutator here, the coils are connected to the commutator, brush is there and the brushes are connected to the external circuit and external load current is flowing which is causing the currents to flow through the armature coils, all these are happening.

Now if we look at the flux distribution of these now let me use a different colour. So let us say there is a flux distribution in this which goes like that, there is the fluxes which goes like this, so it goes this it you have the loops because there are currents flowing within these loops and the direction again given by the right hand rule we will be having something like this, clockwise. So this is the way currents here are.

Likewise, on this side also we are going to have a flux distribution or the field distribution. So let us say we have the field lines like that. now this is coming out of the ring and then by the right hand rule we could say that this we are going to have in anticlockwise direction like this as shown (Refer Slide Time: 30:06). So you see at the centre that these two are not going to contribute anything to the field. Now if you see at the centre at the inside the core, inside the armature of the machine the flux is flowing in this direction the flux is flowing in this direction; you see all the fluxes are pointing up so which means there is an effective flux effective flux which is pointing up in this fashion.

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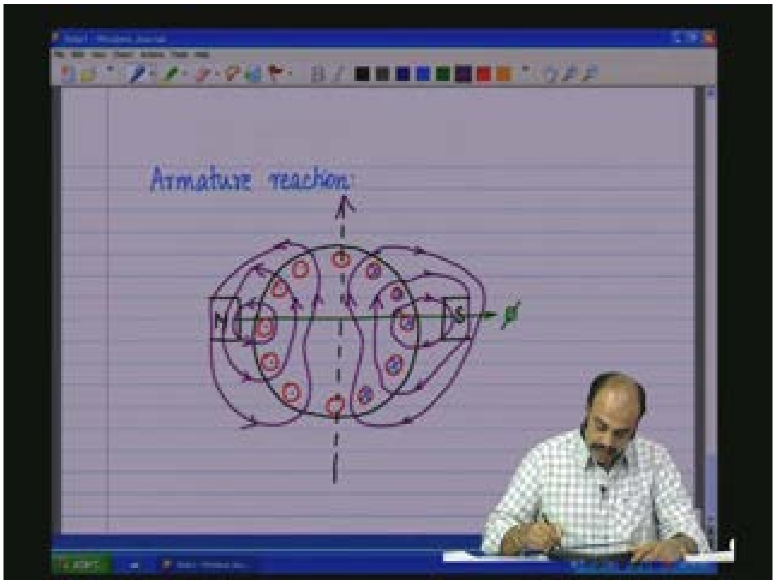

So this leads to this leads to the following equivalent representation. So you have the north, you have the south and I have the armature here the circular armature and what was supposed to be the neutral zone where no flux was supposed to be there. So we have one set of flux here. Now this is the flux which is due to the north south pole.

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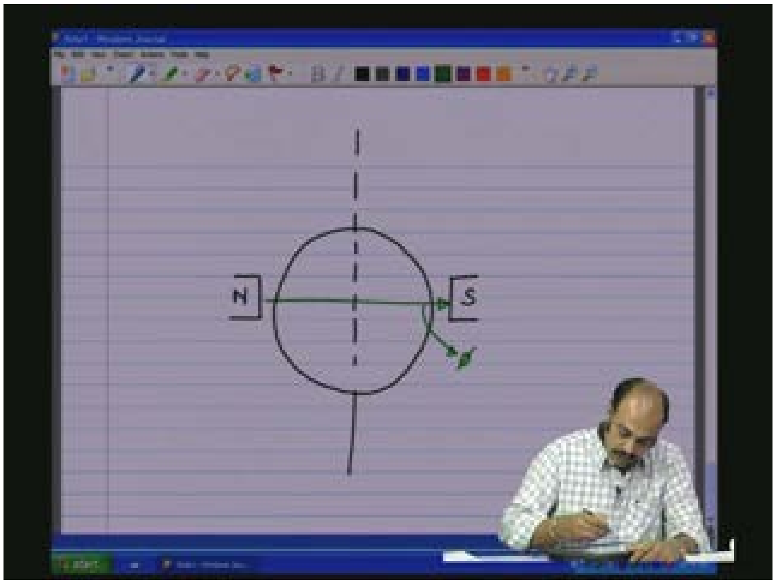

Now there is another flux in this direction because all these add up inside in the core that is going to produce an equivalent flux in this direction and this is due to the armature currents called the or the load current, so armature current or the load current dependent on the load. So you have these two fluxes and we thought that in the neutral zone there was not supposed to be any flux and therefore any coil here will not have an induced voltage. But due to the armature current which produces these which produces the fluxes that is which produces the fuel loop these loops here which produces these loops here due to the currents flowing in the various conductors has a resultant pointing now.

Now these two are going to have a resultant somewhere let us say along this line (Refer Slide Time: 32:36). So this would be the resultant flux direction resultant flux direction. So because of this one major problem is that the brushes which were supposed to be located in the neutral zone because in the neutral zone there is no voltage induced in the coil there is no………… at that point the brushes short circuit the coil and there is no problem, there is no huge circulating current. But now with the armature currents causing these flux and this flux is always going to be in this direction whatever may be the position of………….. will result in a voltage being induced in the coil and that coil that voltage which is getting induced in the coil due to this armature flux armature current produced flux will short circuit the coil and produce a huge short circuiting circulating current and therefore i square R losses. And as a result when the brushes are passing over that coil there is a current flowing through that and then there is an inductive reactance in the coil because the coil is inductive in nature, it is trying to suddenly break the coil and a huge spark results so the sparking will also be very high, the brushes and the brushes will go back much more quickly.

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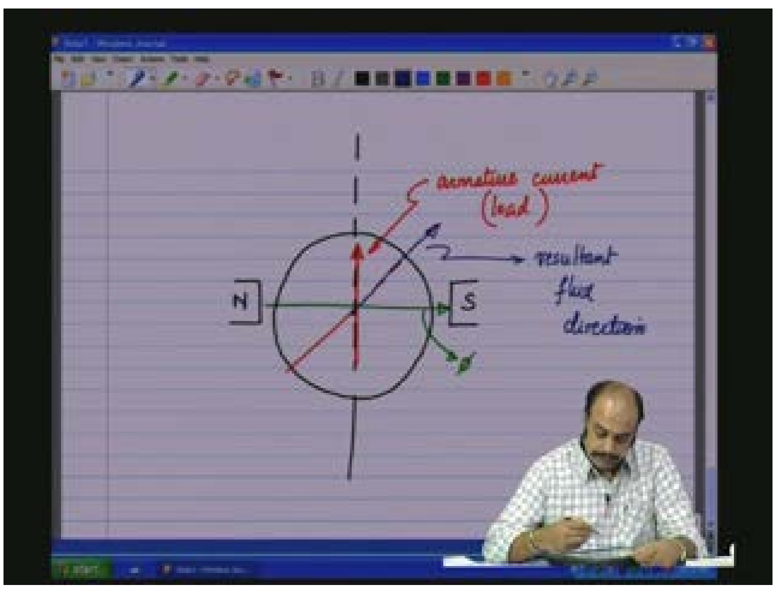

So therefore to avoid these two problems: one is i square R loss through to the circulating current; circulating current itself will heat up the winding and the other one is the huge sparking. We need to place the brushes in the neutral zone. So we said that the neutral zone is always orthogonal to the main flux. Now here we have the resultant flux and therefore orthogonal to that would be this (Refer Slide Time: 35:03) and this would be the neutral zone so the neutral zone has shifted. So, if this is the direction of the rotation so the neutral zone has shifted in the direction of rotation, it has gone a bit further and therefore the brushes will have to be placed here; let us say we place the brushes here; let us have the commutator so the brushes will need to be placed at this point to avoid to avoid the circulating currents and also of course the increased sparking.

Now if it was so, if it if we just have to shift the………….. like this the problem would have been simple but it is not as simple. The load current is a varying quantity which means the red flux the red lined flux which we are indicating here which is orthogonal to the north south flux the amplitude keeps varying. So, if this amplitude keeps varying then the resultant could be in any direction depending upon the amount of load current. So orthogonal to that only will be the neutral zone. So we see that the neutral zone has a much higher band of angle in which it can exist at various load currents and therefore the brushes cannot be dynamically positioned as the load current changes. So therefore this flux which is created due to the load current or the armature current flowing in it is going to cause a problem and this armature flux which is created due to the armature current flowing in the conductors is called armature reaction is called armature reaction which is basically this flux (Refer Slide Time: 37:24).

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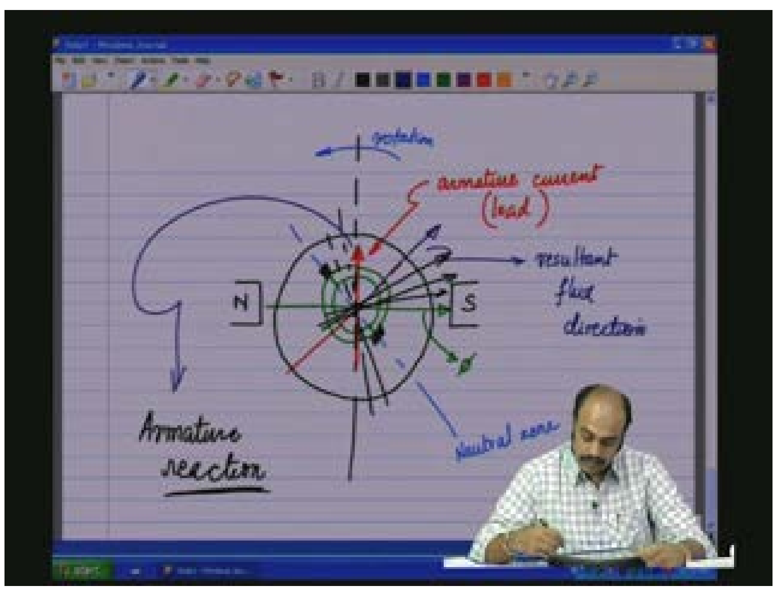

So, one could think of a solution (Refer Slide Time: 38:05). Now let me also put in the conductors and this was supposed to be our neutral zone. we shall put in the conductors that is one conductor representative value of that, let us put a representative value here machine then let us have the commutator so the commutator is also in place. So this is the commutator and we also have the brushes in the neutral zone.

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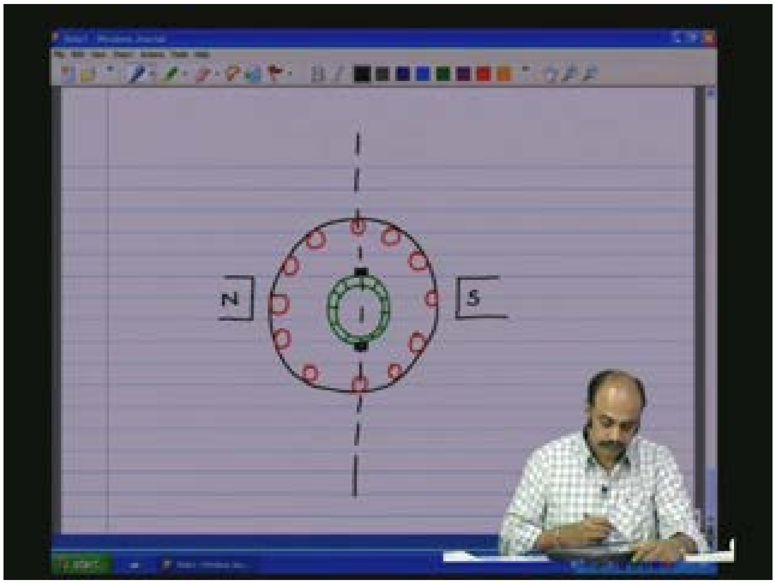

Now what we try to do is how two small poles here……………… so we have these two small poles here and the brushes and from the brushes let us wind it over the poles like that let us wind it over the poles yes this is the negative and from this brush also we will take it and wind it over the poles as shown here, this is plus so there will be a current which flows; actually this is the plus side and the minus side so we will have a current which flows like that in the external load so the current flows in the external load like that so it flows in through here, comes in this direction, goes like that, comes in here (Refer Slide Time: 40:48) then through the armature through the armature like what we had drawn before all these conductors here on this side of the pole south pole will be having through the board and then here it is coming out of the board so this means into board and on this side the dot means coming out of the board and you have currents flowing like that.

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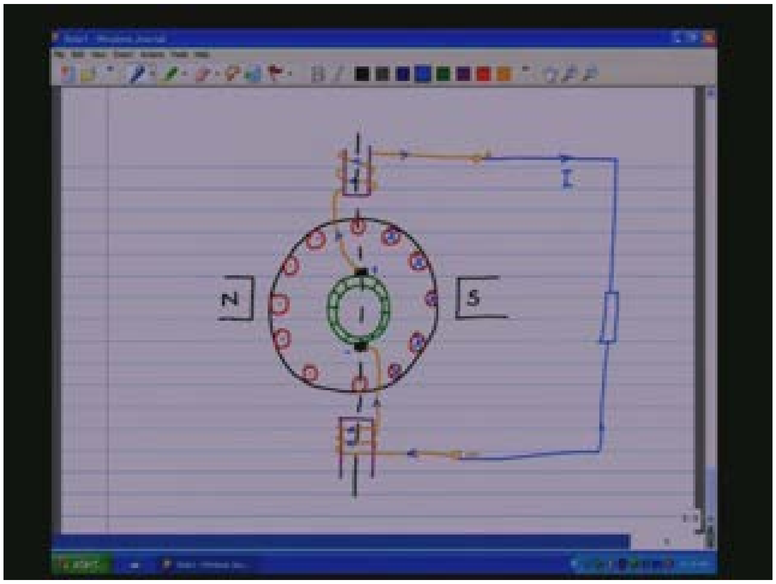

Now if you look at the nature of the winding here we have the coil wound here and the currents flow in this and by the right hand rule by applying the right hand rule we will have a mnf or an equivalent flux, we will call this one as flux C phi C which is going this direction. Likewise, here due to the way the current is flowing here we will have a phi C which is flowing here in this direction.

Now the armature reaction that is the currents through the armature that was producing a flux that was producing a flux in this opposite direction which is which is in this direction. So this is the flux due to the armature reaction armature reaction and then of course there is going to be the flux phi due to the north south pole.

So, you see there are three fluxes the flux phi due to the north south pole which is standard which is what we want and then there is a flux in red line which is orthogonal to the north south magnetic flux and that is due to the armature reaction as we saw in the previous discussion and then there is a third flux due to these poles which we have small poles that we have added and we have passed the armature the load current carrying armature current through those small poles such that there is a phi C which is in a direction which opposes the armature reaction. See that the phi C flux opposes the armature reaction flux.

Therefore, if the number of terms here on these poles are so matched such that phi C cancels out the flux due to the armature reaction flux then the only flux that would exist is the north south pole flux and this would still be the orthogonal plane would still be the neutral zone. Now these cancelling poles the poles that cancel the armature flux due to the armature current the armature reaction is called are called the commutating poles. They are called the commutating poles. This makes the flux due to the armature current or in fact the armature reaction zero thereby still maintaining the same neutral zone positions and thereby we need not shift the position of the brushes and the brushes can still stay in the same position and the voltages induced in the coils at the neutral zones will still be zero and therefore no short circuiting currents and therefore also know sparking extra sparking or arching when the commutator segments are passing over the brushes at that point that is the neutral zones.

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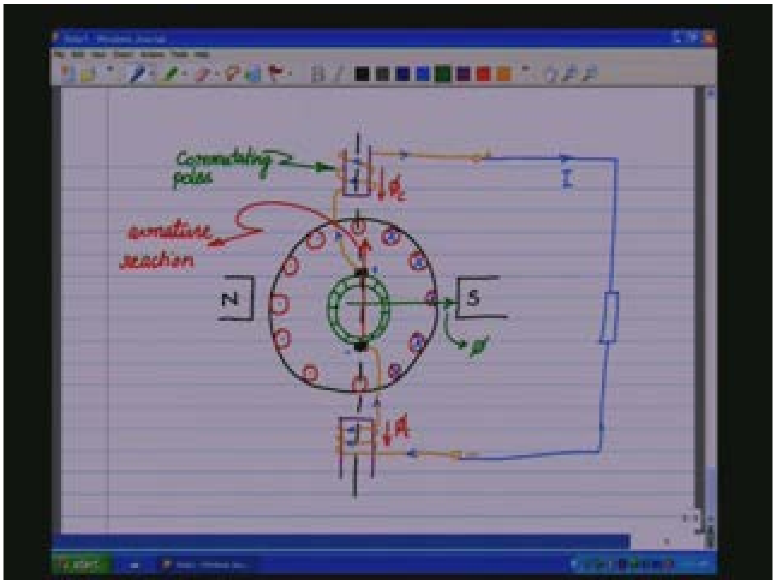

So this is an important concept that is the armature reaction which will be there in any DC machine and that has to be taken care by using the commutating poles. So the next topic that we will deal with is excitations excitations.

So there are different methods in which one can excite the machines. Now what does one mean by excitation?

We saw in the motor; the motor has the north pole, the south pole these two is a pair, three is a flux phi. Now the flux phi called the field that field is called how the field is brought about is called the excitation; the current that brings about the field is called the excitation current and the field or the field flux itself is called the excitation. So how do we bring about or how do we bring about the amplitude of the particular flux in a in the DC machine and what are the methods in bringing about such a flux so that is called the excitation.

So the question that one can ask is how does one excite the machine? When one say how does one excite the machine it means how does one setup the flux or the field within the machine, the base field, the north south field that we have been talking about till now; we have to setup that flux that is called the excitation. So any means or any current that is used for setting up the flux is called the excitation current and any means or any circuit that is used for setting up the excitation field is called the exciter or the excite excitation circuit.

Therefore, excitation in short means that setting up the base flux inside the machine. Now there are different various ways in which one can setup this flux within the machine the field within the machine and here are some of the methods which I am going to list down. One is we could use permanent magnets permanent magnets that is the north south poles that we were talking could just be plain permanent magnets. Second is separate excitation…………. then such a machine is called separately excited machine, such a machine is called separately excited machine or we could have shunt excitation. This machine is also called self-excited machine. And then we have few forms of compound excitation. So these are some of the methods that are used to setup the field within the machine.

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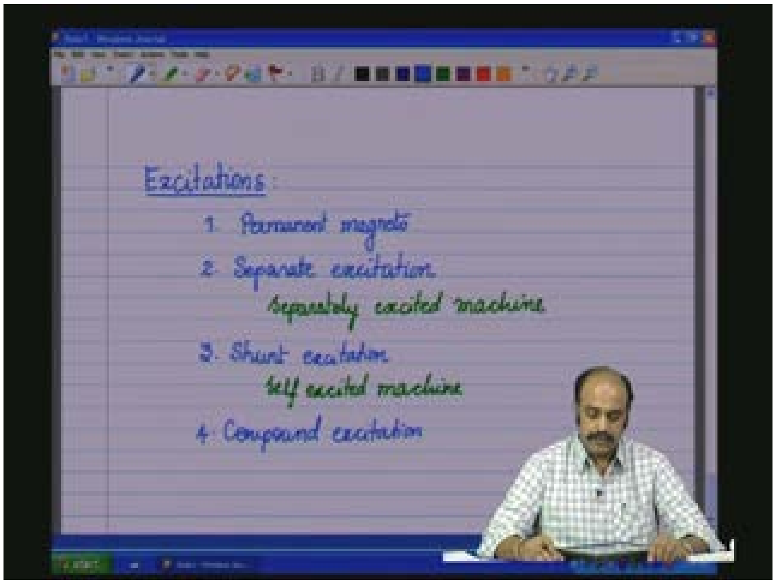

We shall we shall see these methods we shall discuss these methods and what its implications are in the operation of the DC generator in a short while. But this first method that is the use of permanent magnet then it is called the permanent magnet DC generator wherein the north south poles are permanent magnets. See the permanent magnets could be samarium samarium cobalt or rare earth magnetic materials. Alternate to using the permanent magnets would be to use electromagnets which generate the field equivalent to the north south pole pair. So what is done is that you have a machine here with a north south pole pair which is the permanent magnets and we have the armature and then we have the commutator and on the commutator we have the brushes.

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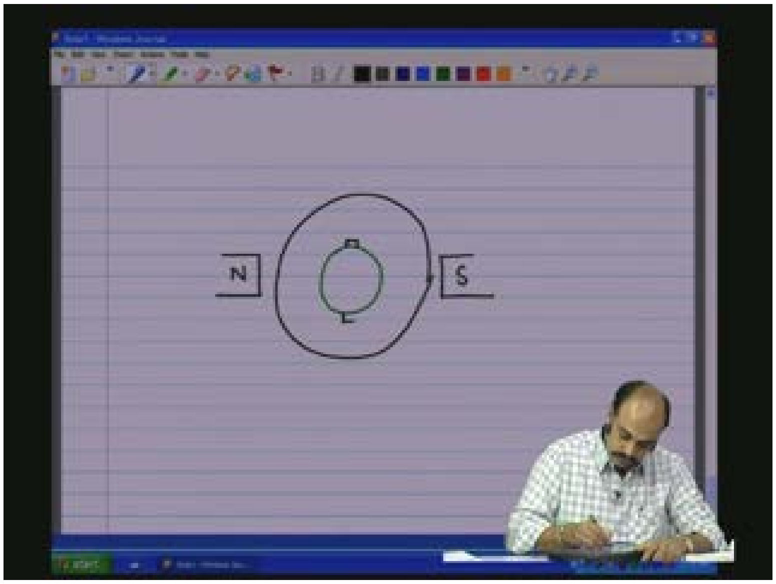

So let us simplify the representation here by assuming that there exists the armature. So we just have the commutator here and the brushes attached which is going to generate E g and from the brushes we are picking up the voltage to be applied to the external circuit. Now these north south poles are generated from let us say a separate voltage source let us say a battery. So we have a battery here and that is wound on to the core like that then goes in here, this is wound on to the next core and then brought down, connected across the battery.

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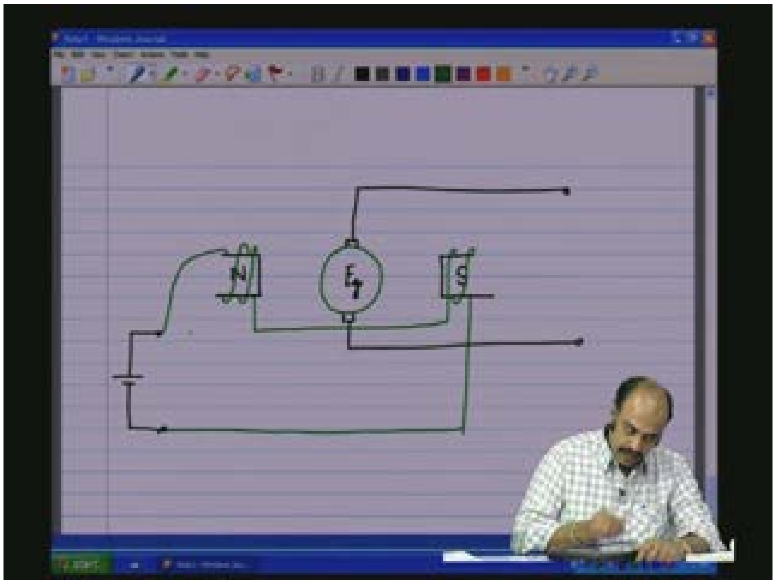

So this battery here is supplying a current I f we call it the field current I f. Now the field current I f is flowing thorough this plus and minus it is flowing through in this direction, goes in this direction here, flows through in this direction which sets up the field and this field……… so now no longer we have this north south, now it is become an electromagnet now it is become an electromagnet with the directions being set by the way the current is flowing through in this green wire as indicated.

Therefore, if we see the direction of the flux here by the right hand rule we see that the flux here is in this direction. So, if the flux is in this direction the direction of rotation is in this direction because the flux shown is in this direction and we were showing direction rotation in the opposite direction. So this is going to generate a voltage E g.

Now the flux is being setup by a source separate source here therefore we say the excitation is separate so it is called a separately excited machine, this is separately excited machine, this is a separately excited machine as seen here. So now instead of taking the excitation from a separate source from a separate source let us take it from the generator output itself that is instead of taking it from this (Refer Slide Time: 55:41) we connect this to the generator output itself which means E g is applied to this; of course we do not directly apply E g so we have to put a series resistance. So we put a serious resistance to limit the current to whatever the required value so this is making a current I f to flow through it, flows through in this same path and comes back through here. So this is the field resistance R f. now such a connection is called shunt connection or shunt excitation shunt excitation.

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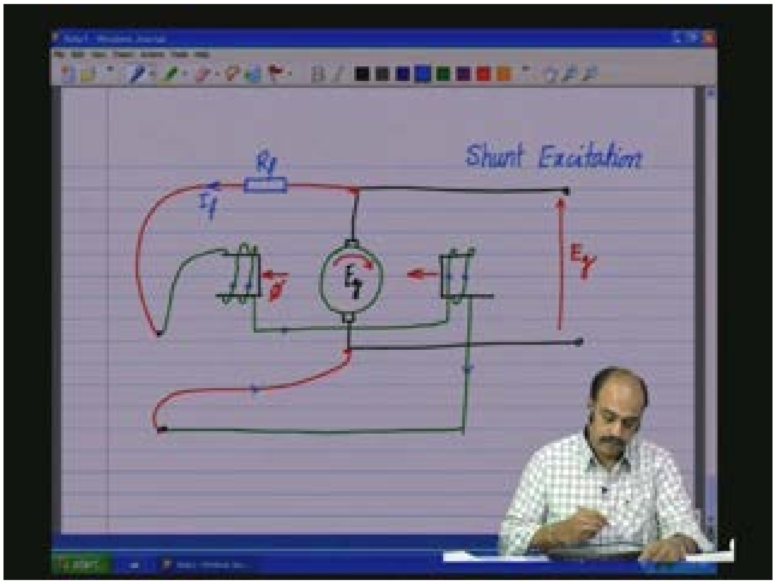

Now in this shunt excited machine the field current is taken directly from the induced emf of the motor so which means that the induced emf if it changes due to the loading effect the voltage that is seen by the field coil will also change so therefore I f will change and therefore the flux or the field in the machine will change and thereby changing the induced emf further. So therefore the regulation will not be as good as in the case of separately excited machine.

In the case of the separately excited machine the field is constant whereas in the case of the shunt excited machine the field can vary because the voltage which is generated also varies with the load due to the loading effect.

So we saw that one can connect in these fashions that is either separately or taking it directly from the generator one could also make combinations of these. We will see how we go about making such changes to get certain benefits out of out of the disadvantages which are existing in the shunt excitation.

The compound excitation consists of a shunt excitation plus a series excitation which will try to compensate for the variations in the variations in the induced emf. So, in the compound excitation itself there are two varieties: the plane compound and there is the over compound and then there is a differential compound which we will discuss in the next class.

So in the next class in the next session we shall also try to get a feel for the voltage regulation that is the voltage versus the field current curves so that which will give us a better understanding of the various excitation, the advantages of the various excitations.

Thank you for now.