Fundamentals of Electrical Engineering
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Lecture – 63
DC Motors (Contd.)

We are back again.

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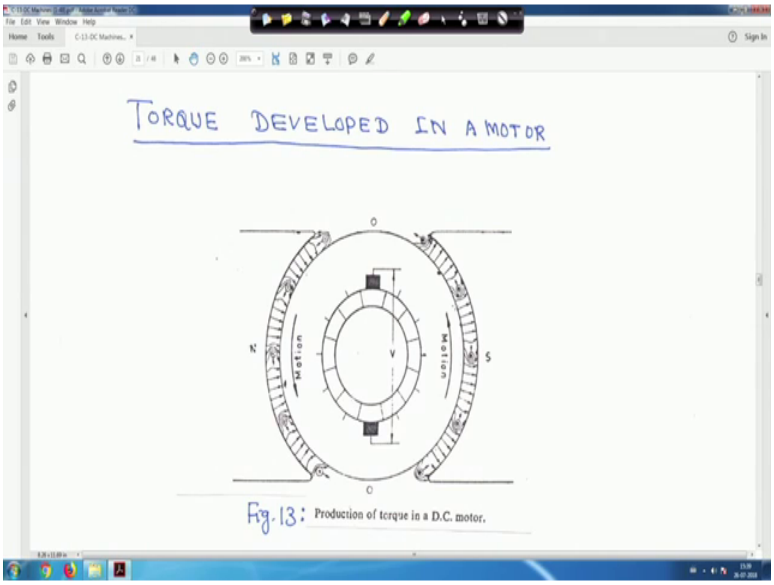

Next is torque developed in a motor; so this is also that you are what you call this motion is given, this commutator segment, these are brushes and these are the conductor placed side. Here it is look at that here it is make flux, and this N pole, and here it is S right, here it is dot.

So, this means current entering into that and leaving the place there means there this is your, this is your convention right. And this is the production of toque this is what you call it is it was cylindrical in shape right. So, you will find things are simple that.

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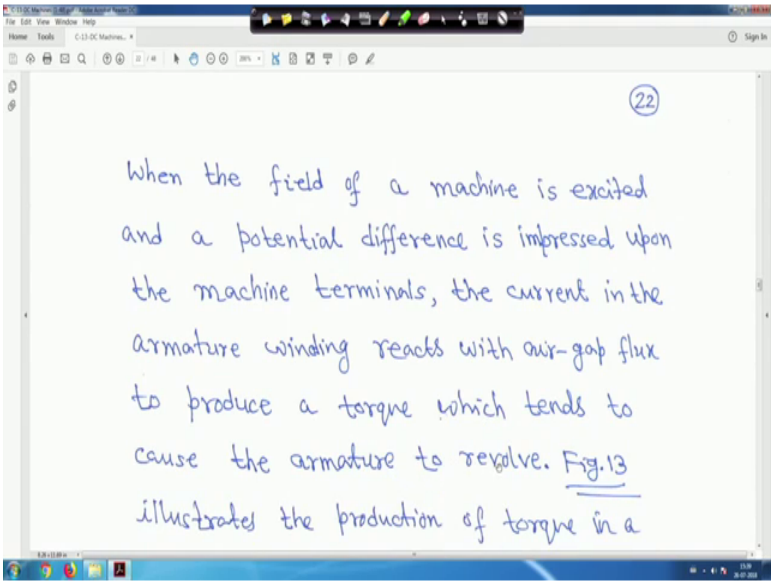

Now, when the field of a machine is excited and they and the potential difference is impressed upon the machine terminals, the current in the armature winding reacts with air gap flux to produce a torque which tends to cause the armature to revolve right. This is actually figure 3, this is actually figure 3. And these two dots are here, this is basically the neutral zone right.

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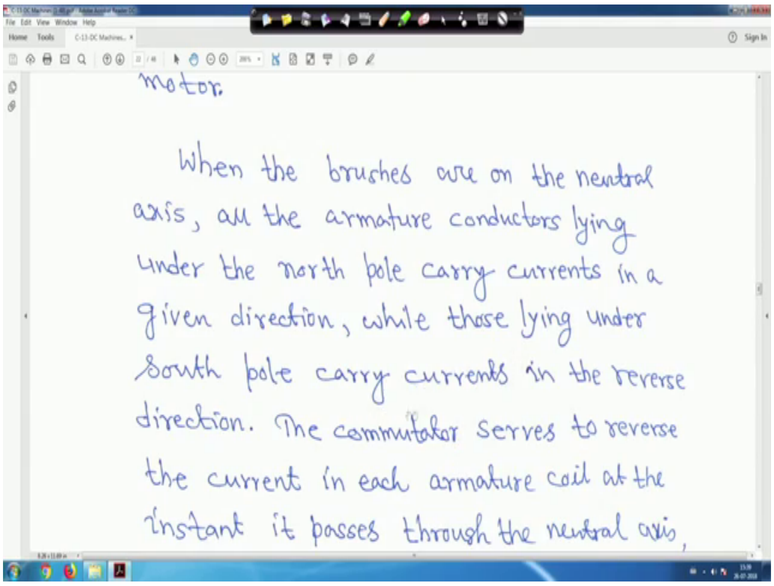

So, figure 13 illustrate the production of torque in a motor. Now when the brushes are on the neutral axis all the armature conductors lying under the north pole carrying currents in a given direction while those lying under south pole carrying currents in the reverse direction right.

So, if you look into this is your, this is your neutral zone. So, all the currents in under your all the conductors under the North Pole flowing in one direction right. And in the south conductors under south pole carrying current in the other direction because where going into the page another region what you call leaving the page and this is the brushes right.

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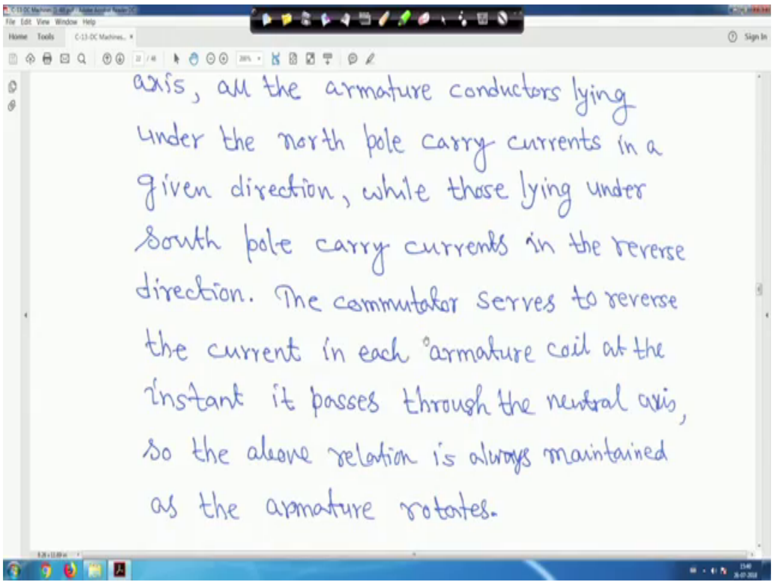

So, the commutators serve to reverse the current in each armature coil at the instant it passes through the neutral axis. So, that above relation is always maintained as the armature rotates. So, when armature will rotate the commutator segment. This polarity this will maintain right whenever it is pi or at any instant when it is passing this neutral axis.

So, this polarity of these two brush; your two brushes always you will remain same right. So, that is your that is you have in a DC machine you have several your brushes you are what you call several commutator segment if you see that open DC machine. So, in that case that you have to what you call just I told it passes through the neutral axis. So, that the above relation is always maintained as the armature rotates right. So, commutator serves to reverse the current right in each armature coil.

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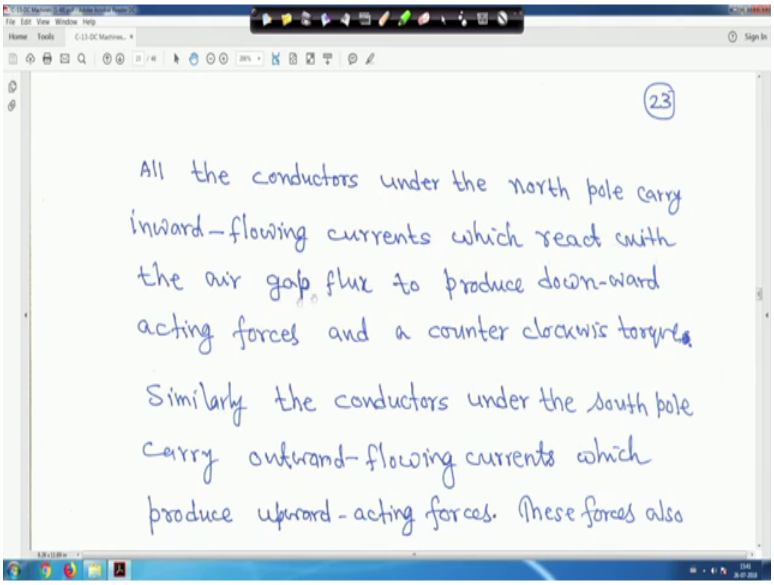

So, next is all the conductors under the north pole carry inward flowing currents that I showed with flux convention which react with their air gap flux to produce downward acting force, and it counter and the counter clockwise torque. So, this is your what you call this is the diagram, because this all the your force diagram at given diagram from stronger magnetic field to the weaker one, everywhere from this diagram it is the look at that arrow is download here it is upward so right. From that you can find out that torque will be developed right.

So, in this case under that and it produces downward acting forces and a counter clockwise dots right. Similarly the conductors under the South Pole carrying your outward flowing current which produce upward acting force these forces also give rise to the counter clockwise torque.

So, so in that means, if the air gap flux is assume to be your what you call radially directed to all points right. So, each of the force act tangentially and produces you are what called turning moment equal to the force multiplied by its lever arm right.

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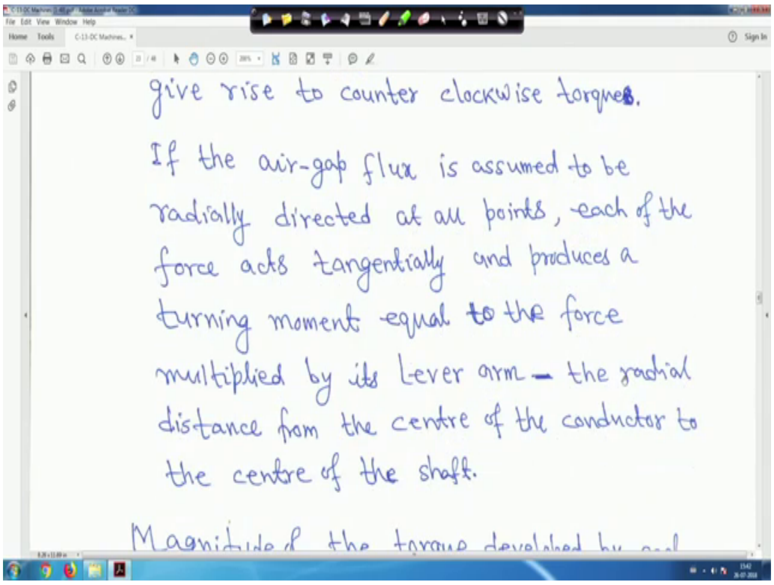

Therefore there is the radial distance from the centre of the conductor to the centre of the shaft. So, this way will we know the force equation, we know the emf equation right everything we know. Therefore, the magnitude of the torque developed by each conductor will be B I l, this is the force into r a Newton metre right.

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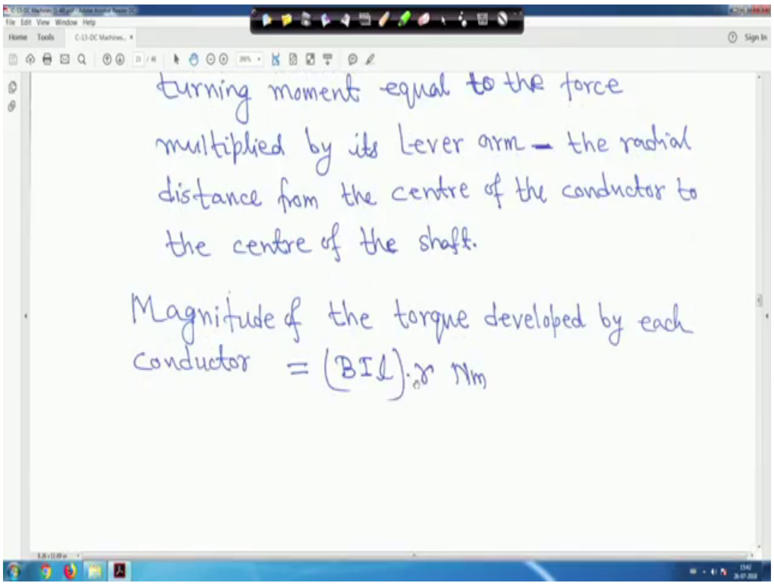

Then where r actually your, what you call this r actually measure that from this actually it is a cylindrical shape right, it is a cylinder shape not shown in the diagram. It is made at made from centre to this to that part right. So, it is a radius, so all these write up is there, so just read carefully. So, this is my torque equation B I l into r Newton metre.

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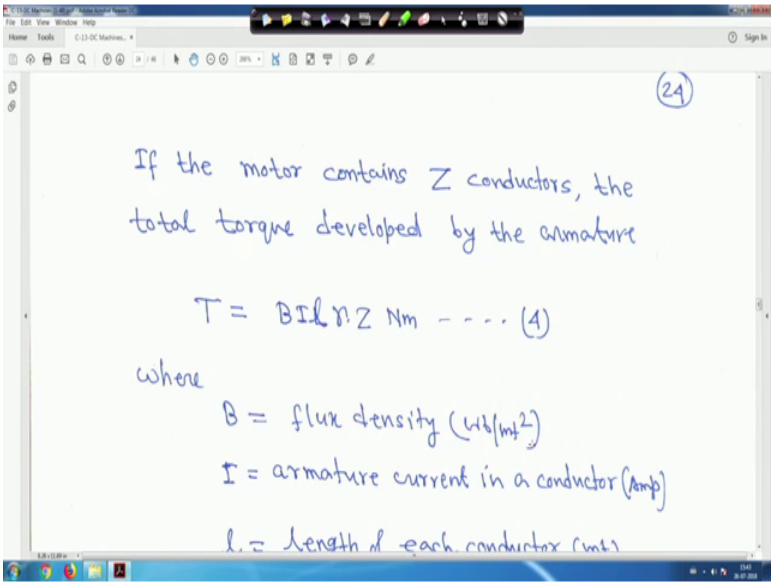

Now, if the motor contains Z conductors the total torque developed by the armature will be B I l r into Z Newton meter, because that was for one conductor, but total will be B I l r into Z Newton meter.

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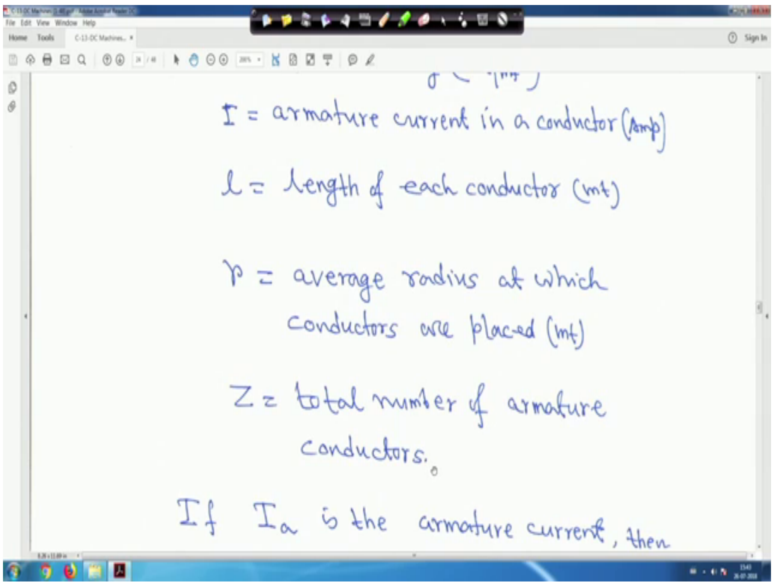

Now B is equal to flux density vapour meter square, I armature current in a conductor that is ampere, l is equal to length of each conductor that is meter. And r is average radius at which conductors are placed that is also metre. And Z total number of armature conductors right.

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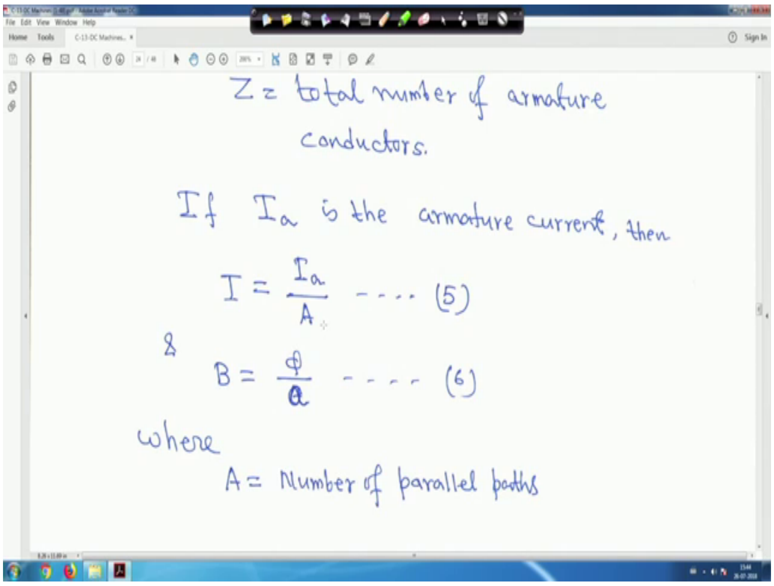

Now, if I a is the armature current, then for your I should be is equal to I a upon a; that means, your what you call I is the armature current. Then and have a number of parallel path right, so I should be is equal to I a upon A right. So, second thing is the flux density b should B is equal to phi upon small a right and your A is the number of parallel path right. So, it is it is uniformly so it is you are uniformly distributed. So, it will be what you call the current per your what you call per path and this is phi upon A, Weber per meter square, phi is the flux, and A is the your cross sectional area I mean what is this we will see that.

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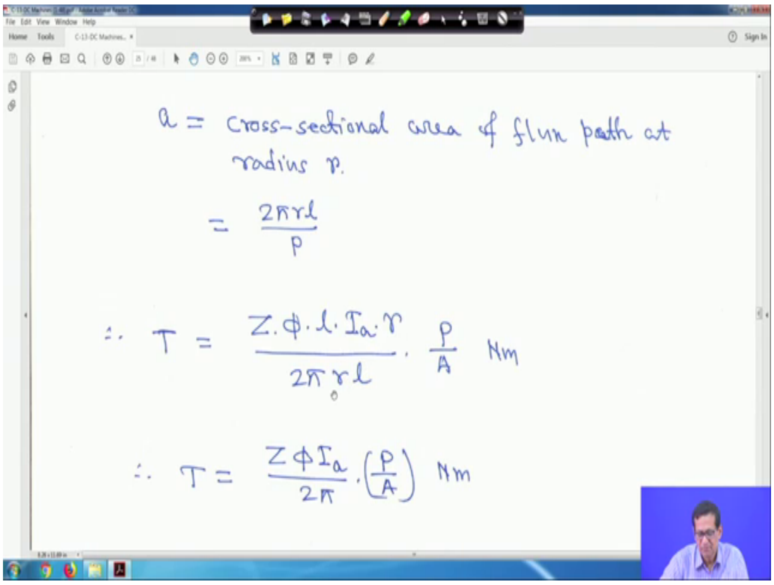

Now, a is equal to cross sectional flux path at radius r; that means, you have to it is too that is a cylinder it is surface area is 2 pi r l, if l is the length, r is the radius and flux path at radius r. That means, basically it is basically 2 pi r l by P that is surface area per pole right. So, that is why cross sectional area of flux we call it is a flux path at radius r, it will be 2 pi r l upon P; 2 pi r l is that your so we are assume this is cylindrical. So, surface area right.

Therefore if you substitute all you will get T is equal to Z phi l into I r upon 2 pi r l into P by A Newton metre that is or we can write same question T is equal to Z phi I a upon 2 pi into P by A Newton metre, or your 0.159; then Z phi P I a upon a 7, this is the 1 upon 2 pi you make it right this is 0.159. But T is equal to then this is a constant this is a constant. So, T all these things are constant, so we can write your T is equal to K into phi into I that is phi into I a rate 0.159 Z P upon A is a constant, Z P upon your I mean I have rate taken this one Z P upon 2 pi A it is a constant.

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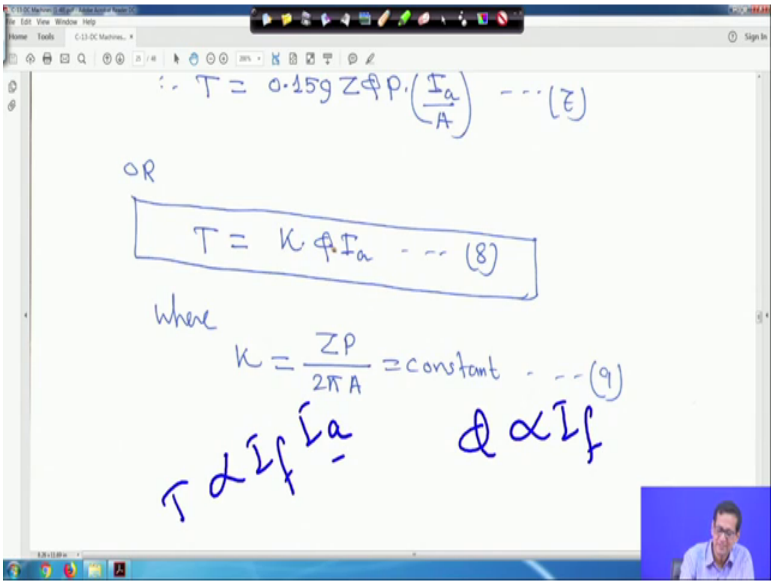

So, torque is proportional to your, what you proportional to product of flux and your armature current right, and in that DC machine flux actually depend on the field current. So, flux is proportional to the field current right we will see the series motors and how is it.

So that means you are another thing before although it is not marked here, but I am telling that flux actually professional to the field current right. That means, your torque actually proportional to then, your field current product of field current and armature current right instead of phi we are made it is I f.

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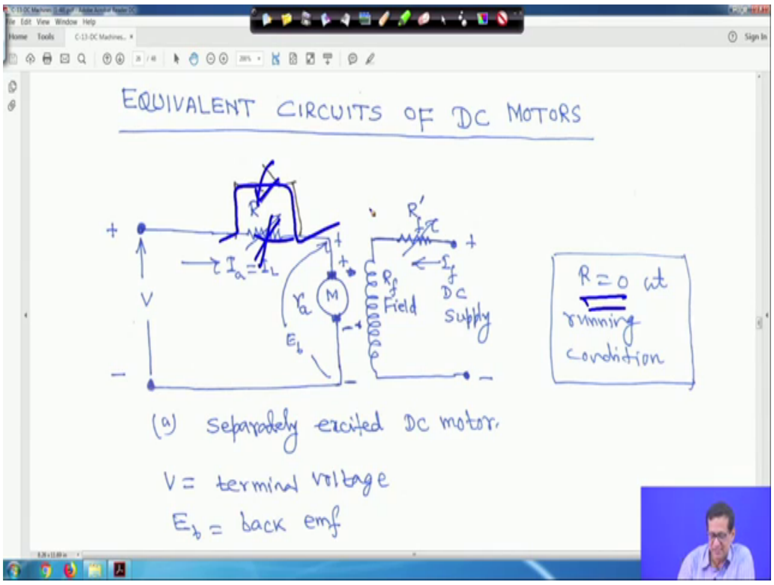

So, now equivalent circuit of DC motor, now this diagram have drawn this is a separately excited your DC machine right DC motor. So, if you look into that a separately excited means the field actually is given a different your supply right. You have from a different source DC supply separately is given to your field. And this is your what you call this is your motor, this is the supply voltage, this is the armature resistance r a which is very small, E b is the back emf, polarity is marked as here I a is equal I l armature current is equal to load current r is equal to 0 at running condition.

Actually when you start the DC machine right, first year also perhaps you will lab electrical lab also for this thing or whatever it is right whenever you start the DC machine at the beginning that R should be at this your what you call maximum position right. Because as soon as otherwise as soon as we switch on back emf will not be there and you if you make it at a very small you are what you call where is I mean it is at a minimum value. Then armature resistance of DC motor is very small therefore, a huge current will flow and fuse will blow, if you do not connect fuse somewhere here right.

So, at the time of start what you do that this resistance should be at maximum and then you start there what you call that you are then you give the supply. Then your, what you call motor will what you call say it is start slowly and slowly we will pick up and then back emf will be developed. Now after that I when speed is pick up slowly and slowly cut the resistance and bring this resistance to 0. But look into that in laboratory what we do that we are connected one SP ST single pole single throw switch. And this switch is open at the when mesh is when we start and this resistance maximum this switch is open.

When you cut this resistance to 0 right maybe because of some contact some little resistance may be there after that you close this switch such that the path will be like this. So, this is totally off from these and as soon as you close it that will give you the what you call that no circuit resistance, no external, no external resistance in this in this circuit as soon as you close it.

So, little bit you will find as soon you close it you will the speed is slightly increase. Because here because of the contact or something some still some your what you call some resistance was there that is why use SP ST the single pole single throw switch such that you can close it.

When ; that means, what; that means, your you start this where R is maximum right and then slow when and some give the supply and regarding starter is not study in this course, DC machine starter will not study. But as soon as speed will speed will pick up slowly and slowly you cut down the resistance and being the resistance r is to 0.

Once r is 0 right; the running condition then you close this SP ST switch such that this will be completely cut off and this will the path right. So, this is your separately excited your what you call DC motor, and V is the terminal voltage, and your E b is the back emf.

So, in this case and this is R f, R f is the field resistance, this is the field that this you also you can vary. This is your field resistance R f dash and this is your field and field resistance is R f and this is the additional resistance in certain area, this is call R f dash right. And this is your field running and field resistance R f and this is the supply right.

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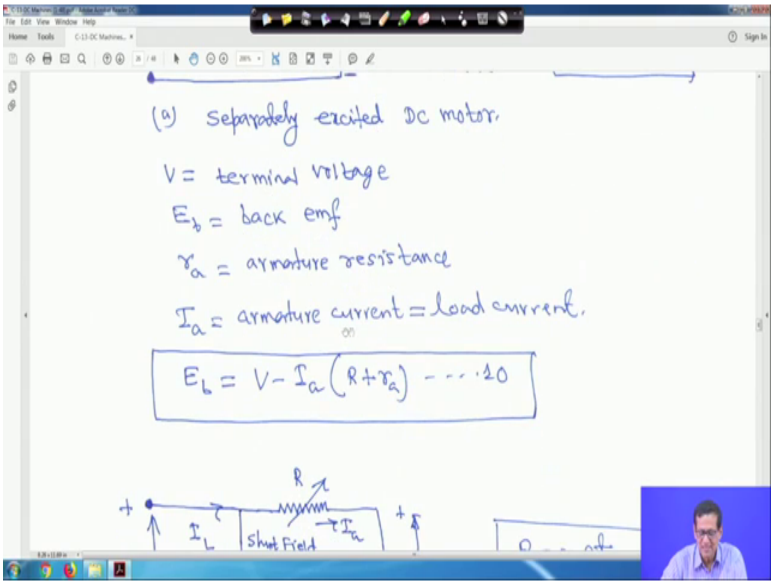

So, r a is the r a is very small for DC machine I put a question to you we are in this thing. How it how can you measure that armature resistance of a DC machine in the laboratory? This is a question to you think right. So, I a is equal to armature current is equal to load current, and E b is equal to V minus I a into R plus r a.

Of course, the running condition R is equal to 0 then if you apply here if you apply here you are what you call KVL in this in this in this circuit. Then you will get you can easily make it polarity everything is marked. You can make it you will get E b is equal to V minus I a into r a R plus r a, but a running condition your R is equal to 0 right.

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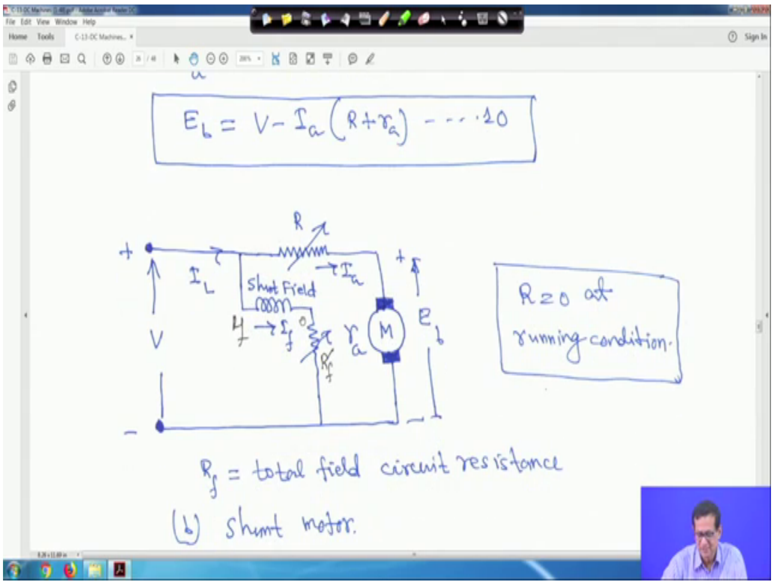

Now, if it is a your and this is your what you call yours your shunt motor. So, in this case the shunt field is here this is the field winding and this is the R f dash right this is the R f dash. So, here SPST I have not shown, but you can you can put it here also. So, I mean here also you can put it, but not shown here I did not show it here right, I did not show it here you can put it right.

So, I am now cleaning it. So, in this case also philosophy will remain same, remain same only here from the same supply you are what you call you are giving that you are giving the supply to the machine as well as your shunt field. Because it is your we are parallely connected.

So, this is field resistance shunt field it is R f and this is your R f dash some external resistance is there R f dash right. Because if by inserting R f dash right this resistance you can vary hence you can hence you can control the field current this I f, field current controlling means we are controlling the flux right. So, but anyway R is equal to 0 at running condition.

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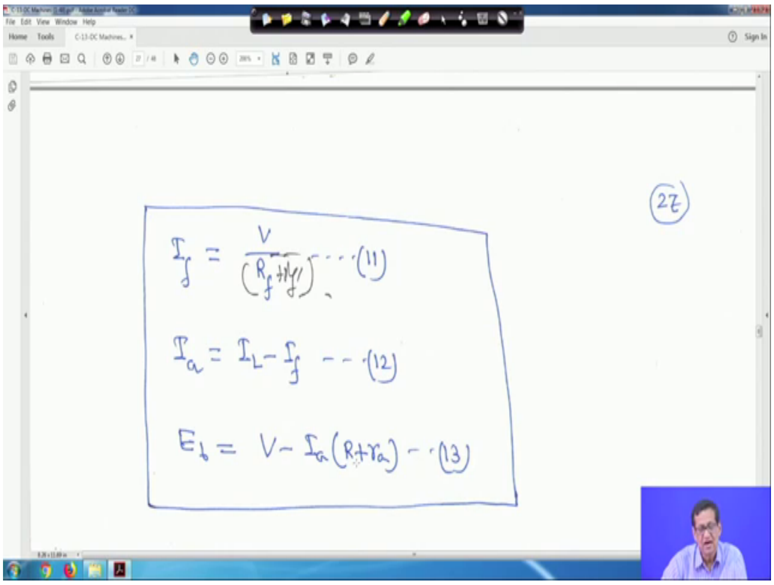

So, therefore, I f is equal to V upon R f plus R f dash because this is the current I f voltage this is a parallel circuit. So, I f will be is equal to V upon R f plus R f dash right. And if you apply your same way if you apply your KVL, so you will get it your I E b is equal to V minus I a into R plus r a. But a running condition r is equal to 0, and if you apply KCL here, if you apply this is your armature current, this is your line current, and this is your, what you call that a field current. So, if we apply at this look at that cursor at this point we apply KCL right, you apply KCL at this point you will get your I a is equal to I l minus I f right. So, this is simple thing.

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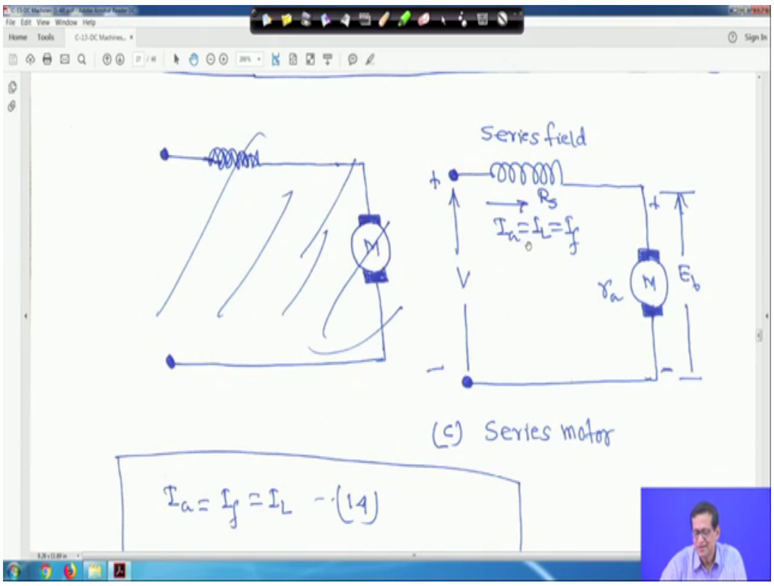

So, for series motor actually series winding being actually it is in series with that armature. So, in that case armature current is equal to load current is equal to field current for series motor. Here series filed is in series with the armature it is in series right and this is your back emf and this is V. So, this is series motor in the series motor armature current is equal to field current is equal to load current. So, and if you apply your and this is a series field resistance R S right and if you apply here also your what you call that KVL.

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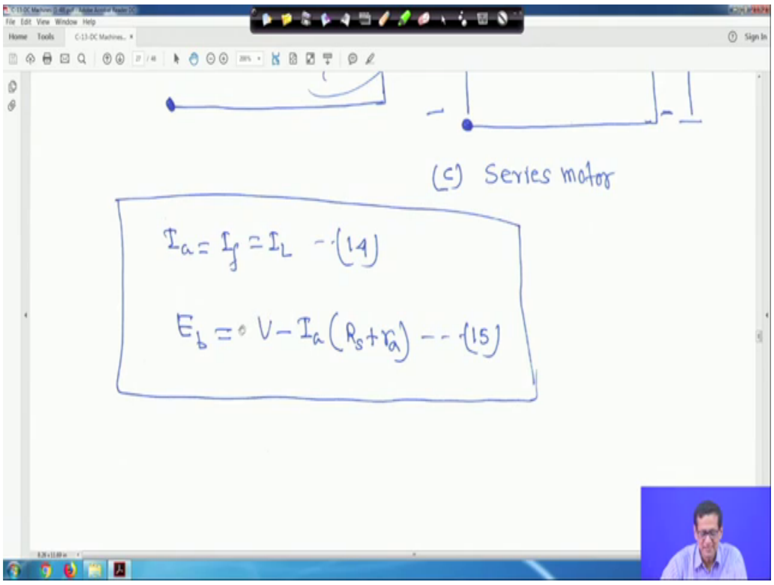

So, we will get E b is equal to V minus I a into R S plus r a; R S is the series field resistance. How to control the fact of series field? This is that will not study in this in the in this course just some basic right could not beyond that at first year level. So, this is equal to E b is equal to V minus I a into R S plus r a.

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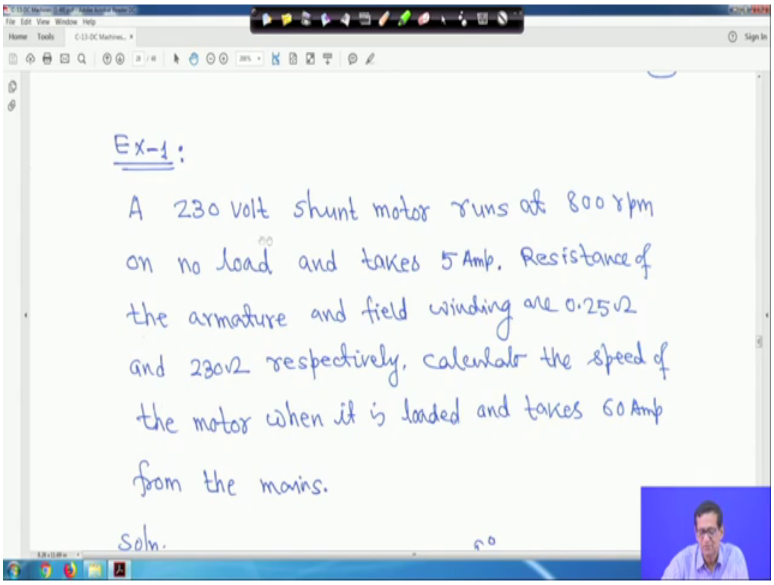

So, next take one small example suppose a 230 volts shunt motor runs at 800 rpm on no load and takes 5 ampere. Resistance of the armature and field winding are 0.25 ohm and 230 ohm respectively. Calculate the speed of the motor when it is loaded and take 60 ampere from the main this is the problem. So, no load condition as well as you say another loading your, what you call another when it is loaded it is taking 60 ampere. But at no load it is taking 5 ampere, 2 conditions and other things are given right. So, we have to find out this speed right.

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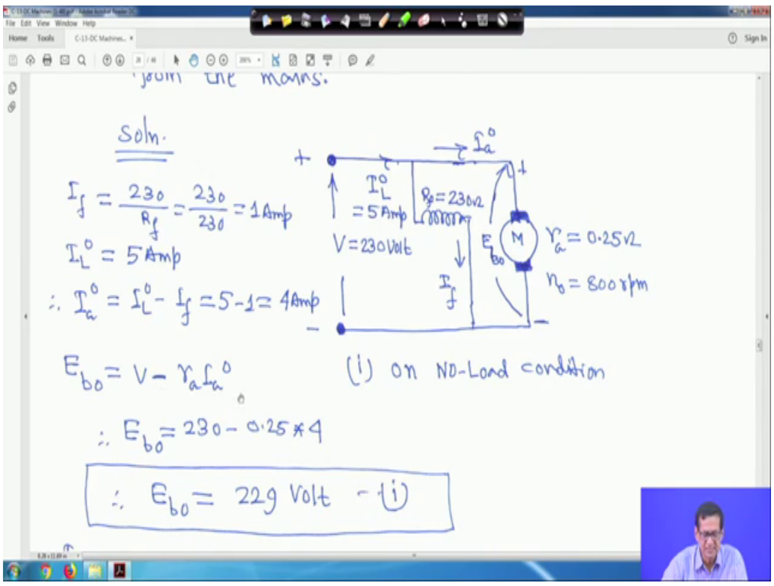

So, this is the no load conditions this is shunt motor circuit diagram, this is I L 0, this is your what you call I f, because 230 volt being a voltage supply voltage is V, R f is given to 230 ohm no external resistance shown here, I a 0 your what you call your this is the I a 0, r a is given 0.2 ohm and no load speed 800 rpm, and this is the back emf. So, field current if is equal to 230 upon R f, 230 is supply 230 is the R f, so 230 by 230 is 1 ampere.

So, I L 0 is given 5 ampere it is given, because here it is given your what you call on no load and takes 5 ampere right. And this is driving 5 ampere current from the line, so I L 0 is equal to 5 ampere. Therefore, I a 0 is equal to I L 0 minus I f, so 5 minus 1. So, I 0 is equal to 4 ampere right. Therefore, this circuit only E b 0 is equal to V minus r a I a 0 find out the back e mf. So, E b 0 is 230, minus r a is 0.25 into I a 0 4, so E b 0 is equal to 229 volt right. Now this is on no load condition.

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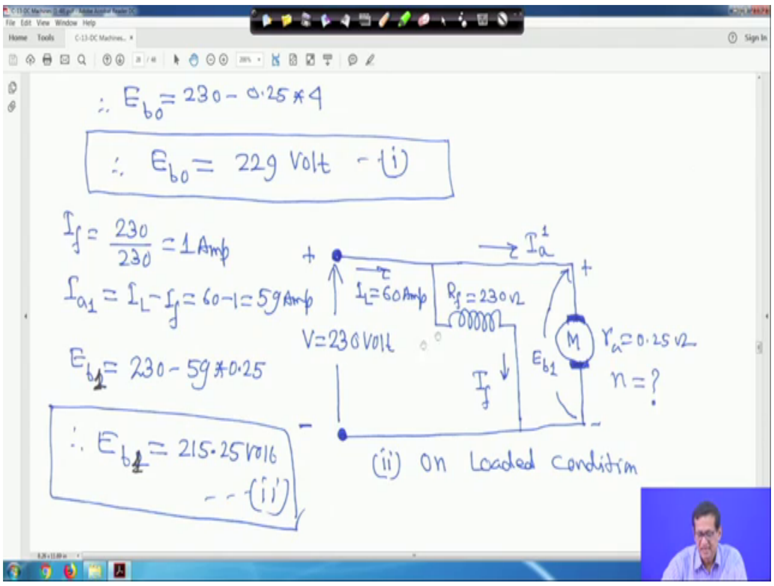

Now, when it is loaded this is the circuit at that time it is driving current of 60 ampere right and this is the current say I a 1, r a is 0.25 ohm. You have to find out what is the speed right? And this is 230 ohm; that means field current your what you call I f 230 upon 231 ampere.

So, at no load or full or at this load field current will remain same, again it is 1 ampere. That means flux remain constant both the cases field current constant means the flux remain constant therefore, I a 1 will be your I L minus I f, so 59 ampere, 60 minus 1.

Therefore, E b 1 will be V minus your, I a 1 into your r a 0.25. So, directly I am writing this you will get E b 1 is equal to 215.25 volt right, this you will get it. So, this is on loaded condition, this is the circuit you just draw two separate circuit, I will solve like a DC circuit you can only looking at this all this conditions right.

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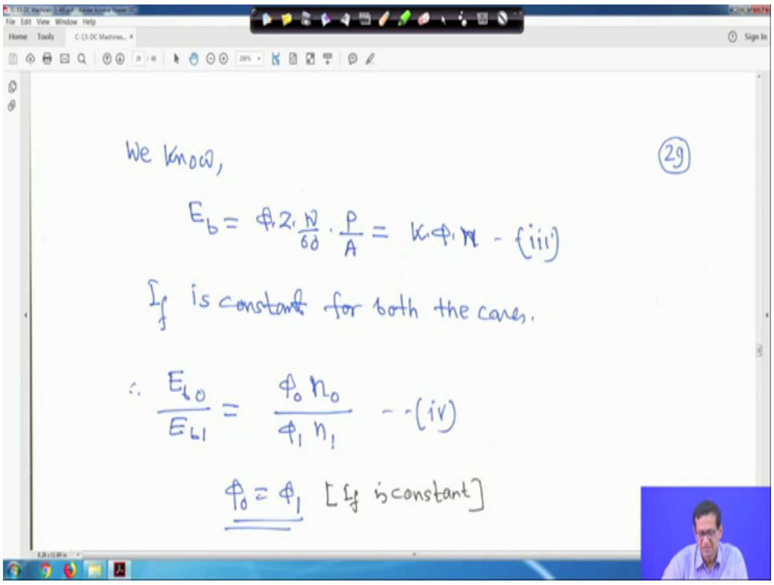

So, after this, what you will do? That we know this E b is equal phi Z N by 60 into P by a is equal to K into phi into n, but if is constant for both cases. If I f is constant means the flux is constant right therefore, E b 0 by E b 1 you can write phi 0, n 0 upon phi 1 n 1. Because this is the condition from where you can write one equation E b 0 is equal to K, phi 0 n 0.

Another equation you can write E b 1 is equal to K phi 1 n 1. So, K will be cancel because where these are constant, so it is phi 0 n 0 upon phi 1 n 1, because but field is constant if is constant for both the cases current is 1 ampere. Therefore, phi 0 is equal to phi 1. So, if it is phi 0 is equal to phi 1, therefore E b 0 you computed 229 E b 1, we computed 215.25 is equal to n 0 we know 800 divided by n 1, the speed.

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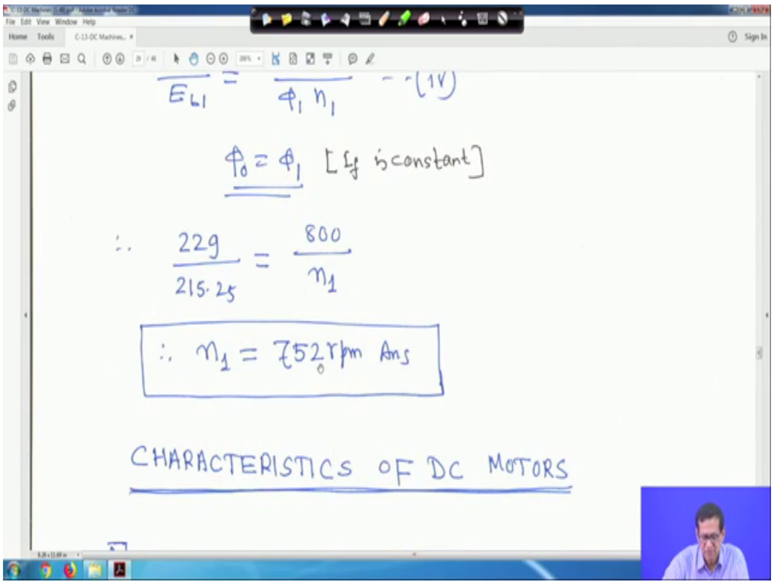

Therefore n 1 is equal to 752 rpm, this is the answer right. Now this one example we will take another 3 or 4 later. Now, characteristic of DC motors.

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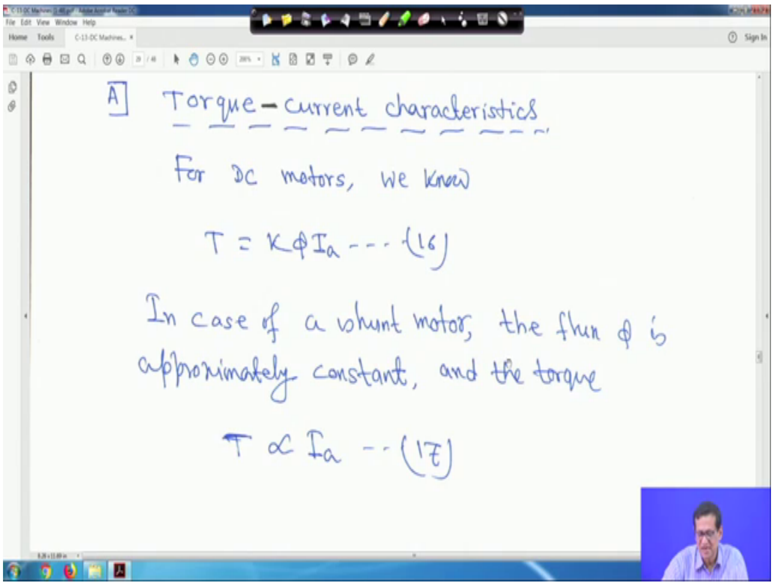

Now, first is a torque current characteristic. For DC motor we know the torque is equal to K into phi into I a right. Now in case of a shunt motor the flux phi approximately constant and the torque is proportional to I a that is why the previous example I took because flux for DC shunt motor remain constant because field is supply voltage more or less remain constant, field resistance more or less remain constant. Therefore, flux will remain constant because field current you will constant means the flux is constant. Therefore, torque actually proportional to I a; that means, it is almost straight line characteristic right.

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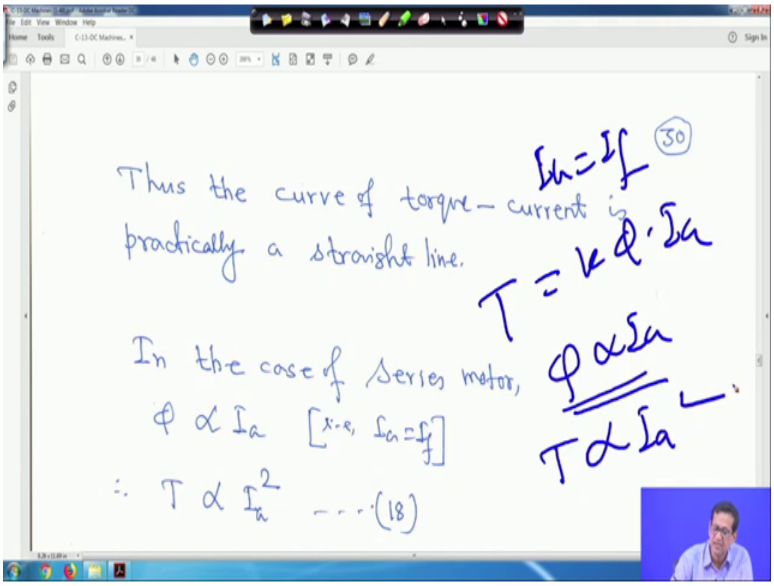

So, therefore, there is the curve of torque current character is practically a straight line. Now, in the case of series motor the because series field in series with the armature, so, armature current is equal to field current right. That means, flux is proportional to I a because torque is equal to your torque is equal to suppose K into phi into I a.

For series motor your flux actually professional to I a because in series motor your I a is equal to I f. Because series field is connected in series with the armature, so I a is equal to I f; that means, if phi proportional to the I a means the torque actually proportional to I a square. So, that is why this your everything is written here that is why torque is proportional to I a square.

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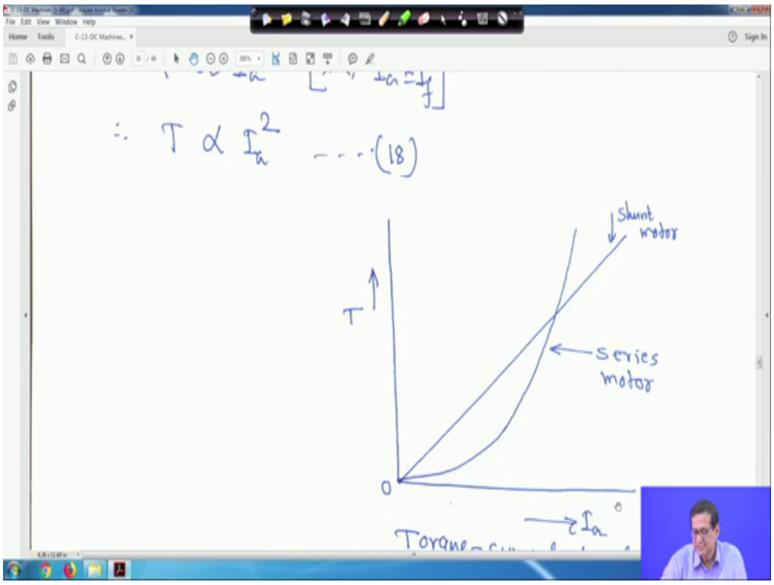

So, if we draw the characteristic this is the torque, this is I a armature correct. For shunt motor this is straight line right this is marked it here, and for series motor it is parabola right. So, this is the torque current character, your current characteristics of your series motor and shunt motor.

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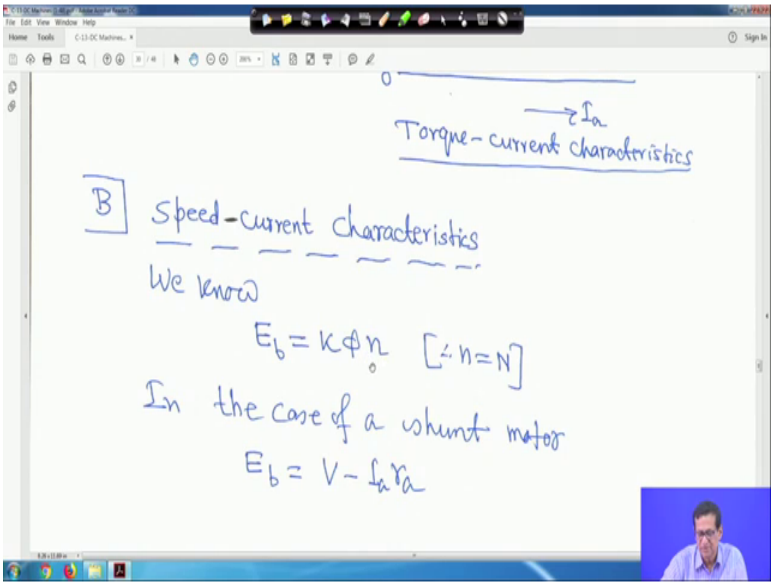

Now, second is speed current characteristic. In this case we know again back emf is equal to K into phi into n, actually n is equal there is example we might have used capital N, but n is equal to small n is equal to capital N. Now in the case of a shunt motor we know this back emf is equal to V minus I a r a right, under running condition we know that, so it is E b is equal to V minus I a r a.

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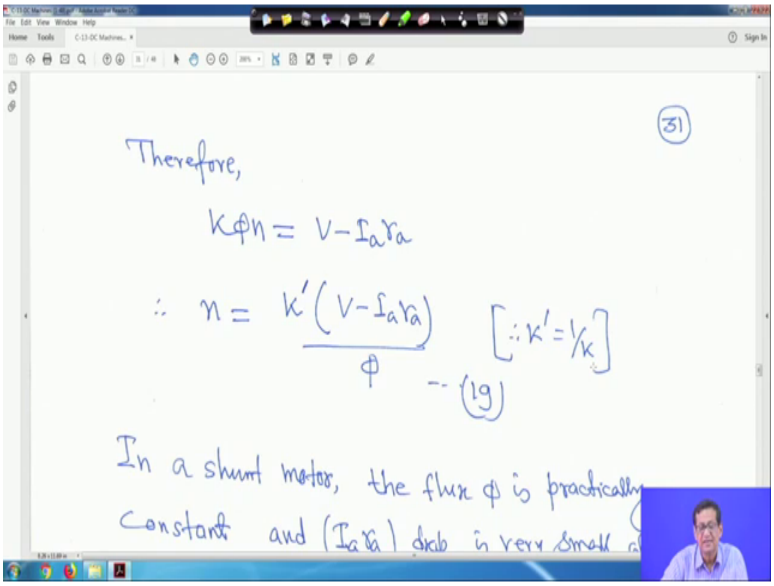

So, therefore E b is equal to K phi n is equal to V minus I a r a right; that means, n is equal to we can write your K dash V minus I a r a by phi, where K dash is equal to 1 upon K right. Therefore, in a shunt motor the flux phi is more or less practically constant it is more or less constant that we have seen also field current more or less constant, so flux constant, so flux is a constant.

Therefore, I a r a drop is very small because r a actually for a machine is very small, DC machine is very small right. So, this I a r a drop is very small about 3 to 6 percent of V therefore, the percentage drop is speed from no load to full load is of the same order right.

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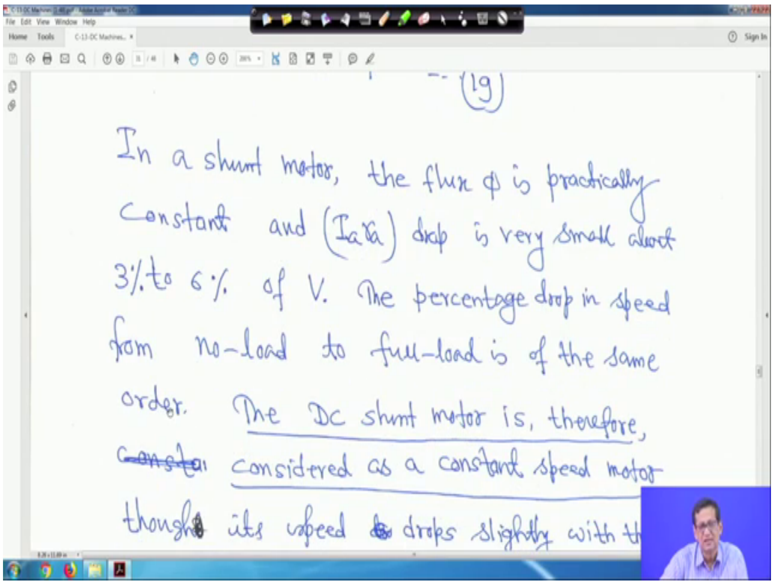

Therefore the DC shunt motor is therefore, considered as a constant speed motor. Sometimes they ask these questions that why DC shunt motor is a constant speed motor? This is the reason right, so though it is speed drop slightly with the increases in load.

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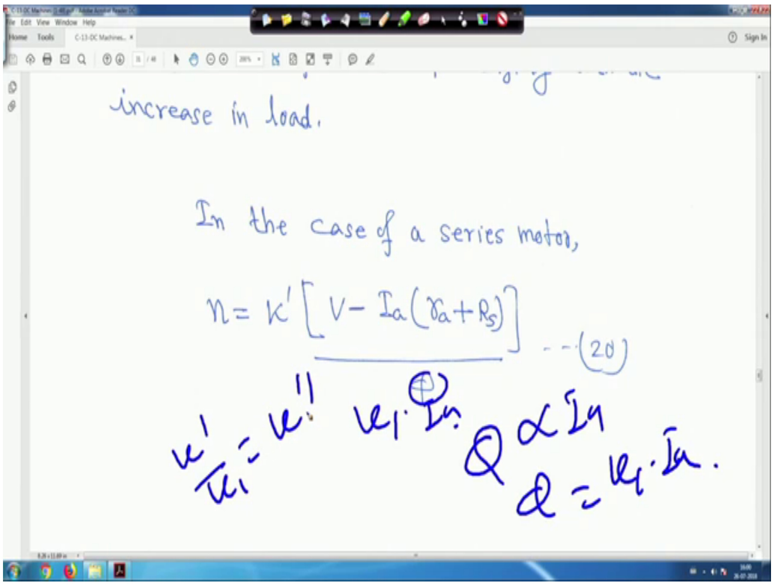

So, in the case of a series motor again n is equal to K dash V minus I a r a and R S is the series field resistance where you have to add R S divided by phi. But in the series motor phi is proportional to I a, because I a nothing, but the armature current is equal to field current in series motor. But that is why phi proportional to I a and series motor I a is equal to I a therefore, you can write n is equal to say K double dash V minus I a into ra plus R S I a.

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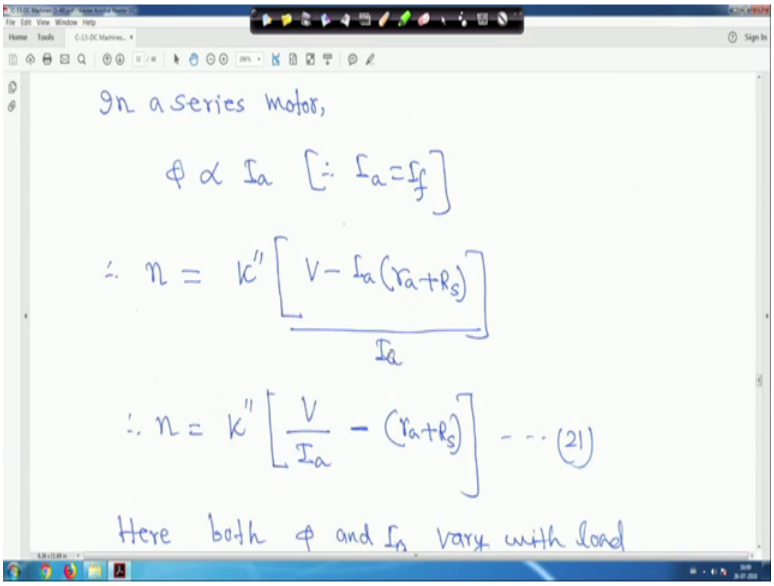

So, here actually here actually it is something like this, if it is if phi just hold on if phi actually proportional to I a that means, phi is equal to say some constant K one into I a. If you substitute here some K 1 into I a therefore, K dash upon K 1 we are calling as K double dash right something like this.

So, if you do so if you do so so it is coming like this right therefore, n is equal to K double dash this constant V upon I a minus ra plus R S right. So, this part is constant and it is V upon I a here both the phi and I a vary with load because phi is proportional to I a.

If load changes then armature current will change and armature current is equal to field current therefore, flux also will change therefore, both phi and I a value with the load because phi proportional to I a. If the load increases phi also you are increases with load current that is I a increases right thus V by I a decreases. Because if I a increases, so V by I a will decrease right, therefore with the increase in load speed decreases for series motor.

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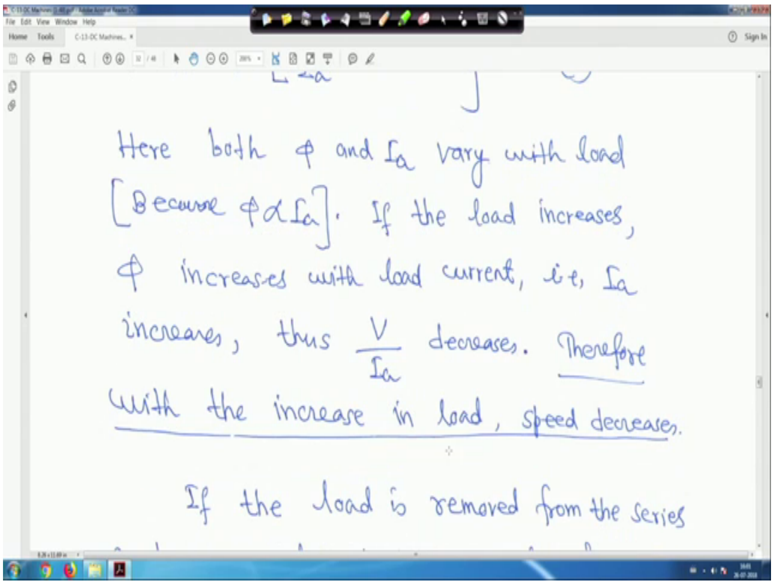

So, if the load is removed from the series motor completely. So, phi become extremely small right, if you remove the load that phi will become very small right and hence the I a. So, I a also will be decreased right therefore, V by I a is very large and is and speed is very high right.

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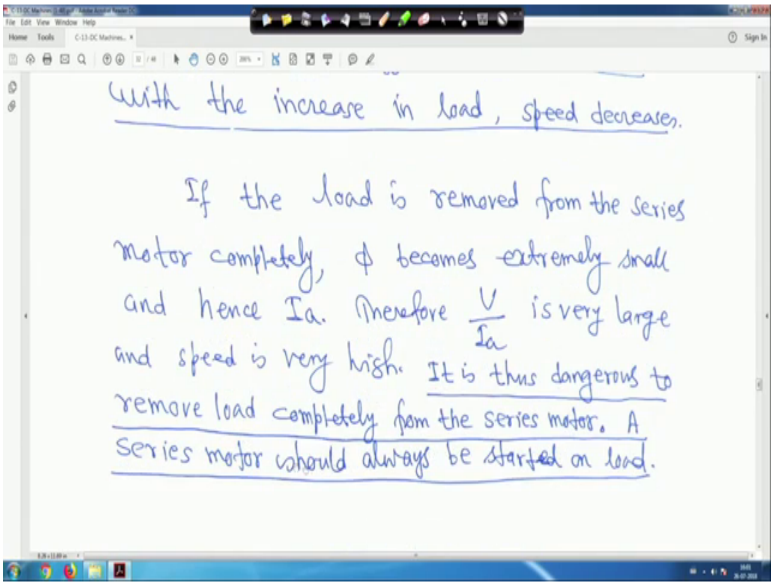

Therefore, it is thus dangerous to remove the load completely from the series motor. Therefore, a series motor should always be started on load. So, series motor should not be run on no load they ask sometime this question why series motor should not be run on no load right because of this region only. So that means, series motor whenever you start you have to start with the connecting some load, then you start right otherwise this is dangerous to remove the load completely for series motor.

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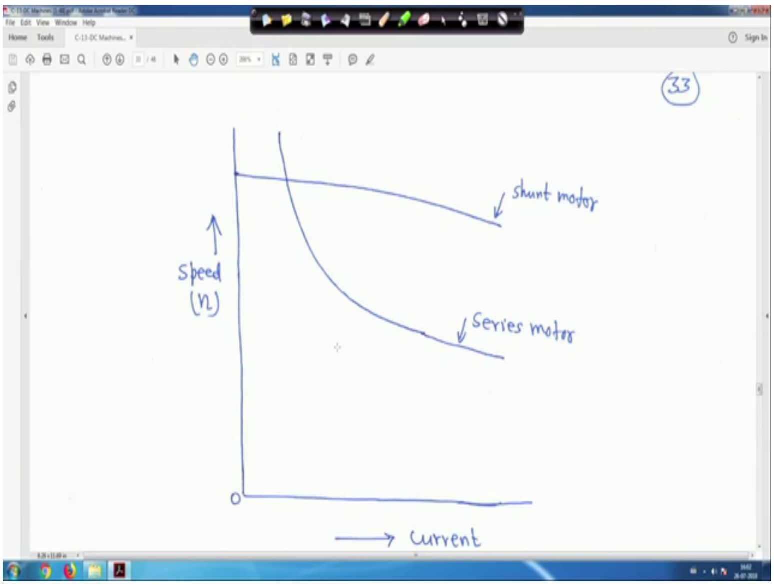

So, if you; that means, for shunt motor the characteristics this is speed current characteristic, this is for shunt motor, and for series motor it is your speeds current characteristic right.

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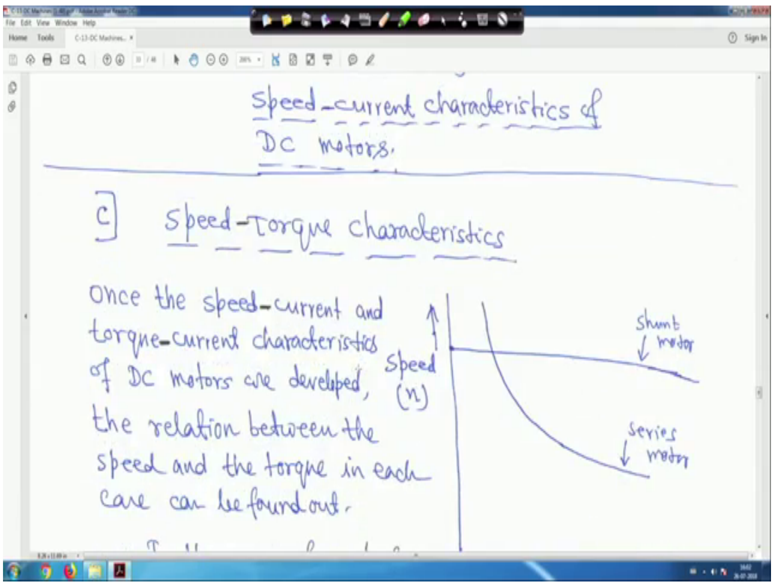

Now, another one is the speed torque characteristic. So, in this case also more or less you will find that a speed torque characteristics for shunt motor and here it is speed current characteristic for shunt motor more or less same right. So, once thus I mean there nature is same once the speed current and you and current torque current characteristics of DC motors are developed. The relation between the speed and the torque in each case can be found out right.

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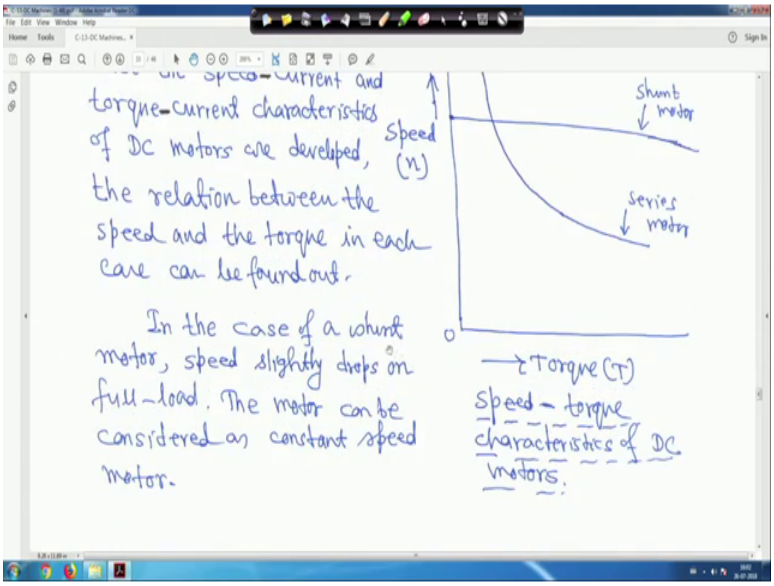

In the case of a shunt motor speed slightly drops and full load. The motor can be considered as a constant speed motor, this is a speed torque characteristics of DC motor right.

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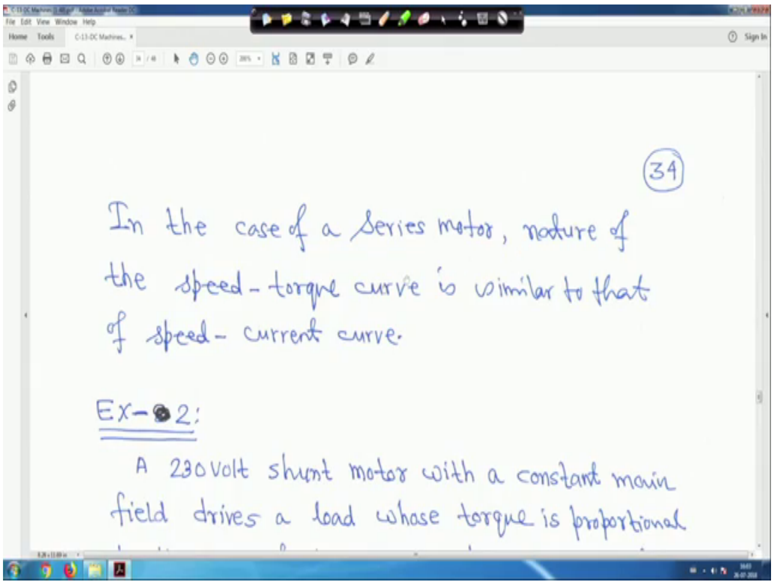

Similarly, in the case of a series motor nature of the speed torque curve is similar to that of the speed current curve right. So, these two this two I did not give here intentionally I did not give here the mathematics 1 or 2 equation, I suggest this is a small exercise for you right. The other two I have explain and this nature of this two and this two are same only thing is that you right 1 or 2 equation and just see whatever whether you are you are what you call same characteristic from your philosophy or your what you call you can get it or not right.

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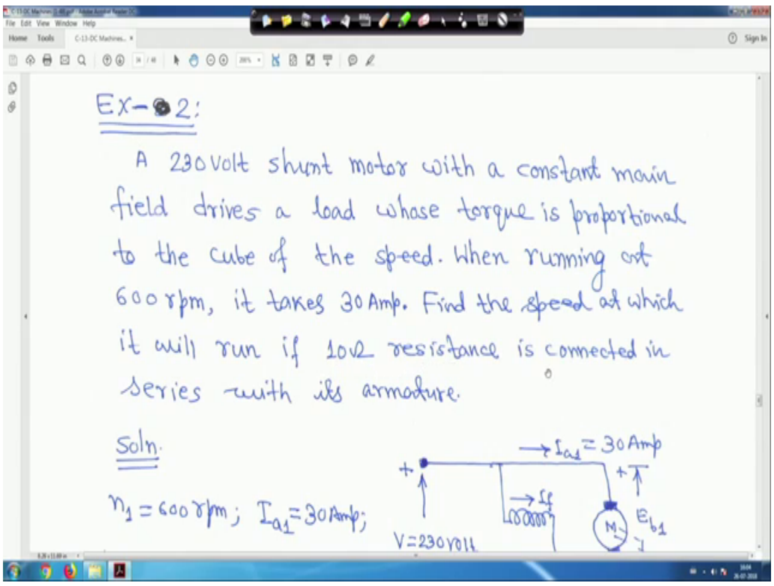

So, next is one example, so a 230 volt shunt motor with a constant main field drives load whose torque is proportional to the cube of the speed the when running at 600 rpm. Now it takes 30 ampere find the speed at which it will run if 10 ohm resistance is connected in series with it is armature. Like actually you have to find the speed at which it will done if 10 ohm resistance is connected in series with its armature.

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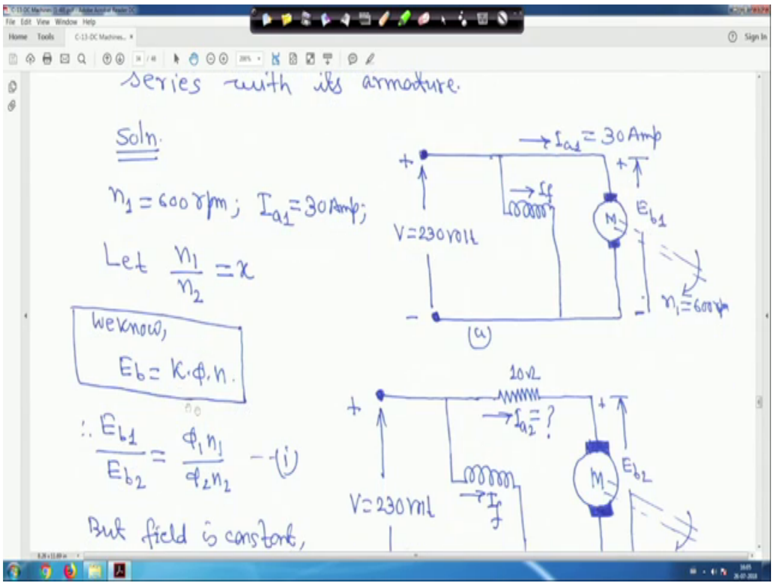

So, look this is the circuit diagram right and it is given that your what you call that 230 volt shunt motor with a constant main field drives a load whose torque is proportional to the cube of the speed. That means, torque is professional to n cube, while running at 600 rpm it takes 30 ampere. You have to find the speed at which it will run it take 10 ohm resistance is connected in series with it is armature.

So, this is the circuit for first circuit this is E b 1 back emf. So, driving 30 ampere, n 1 is given 60, 600 rpm and V is equal to 230 volt. So, when n 1 is given I a 1 is 30 ampere, and let n 1 upon n 2 is equal to x, n 1 is the speed for the first case 600 rpm and this ratio take n 1 by n 2 is equal to x. And we know E b is equal to K phi n.

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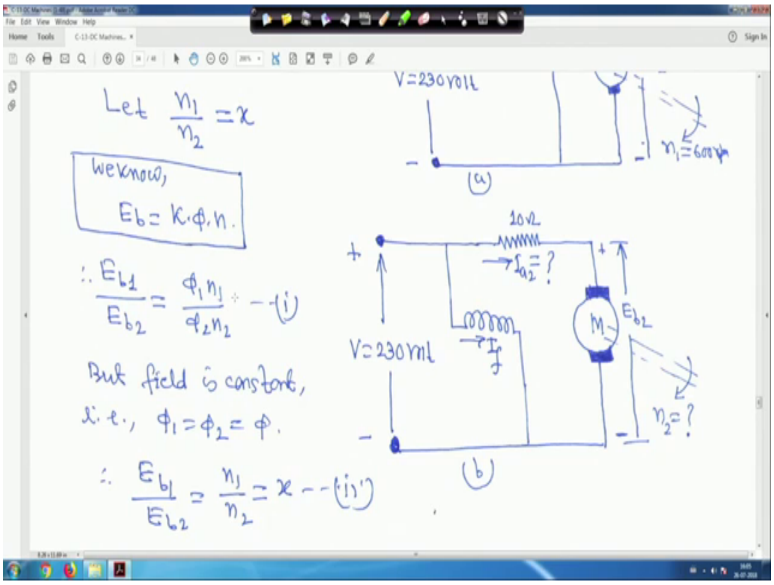

Second circuit is the, that a 10 over resistance is connected here. So, right and this is in the second case what will be the, I a 2 and what will be n 2 right? And this is 230 volt is given, and this is the field current I f. Now, but field is constant, so in that case phi 1 is equal to phi 2 is equal to phi. And E b 1 upon E b 2 will be then phi 1 n 1 upon phi 2. This should be the small formula should be on your fingertips all the time right. So and therefore E b 1 upon E b 2 is equal to n 1 upon n 2 is equal to x, because we have assume n by n 2 is equal to say x right.

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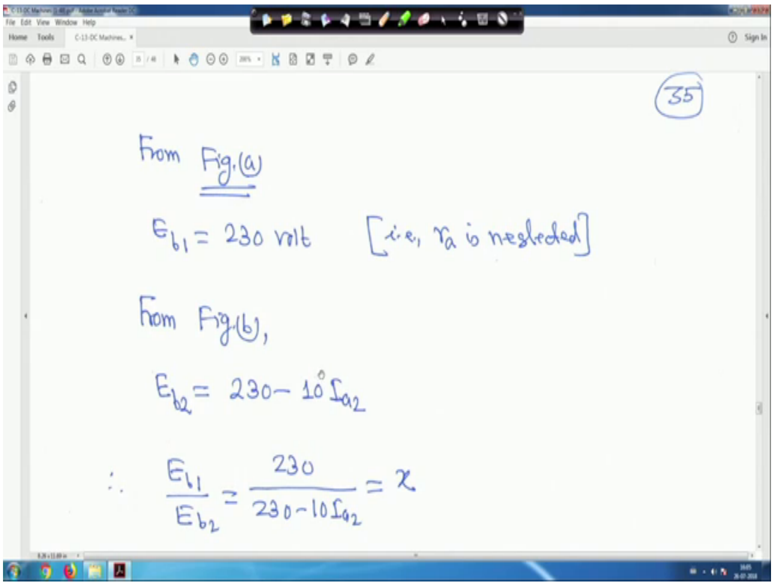

So, from figure a E b 1 is equal to 230 volt that is ra is neglected. So, back emf 230 volt from this figure r a is neglected right. So, in that case your E b 1 will be 230 volt, from figure b E b 2 will be 230 minus 10 into I a 2, because 10 ohm resistance is added. So, it will be 2 minus your 230 minus 10 into I a 2 divide this E b 1 upon E b 2 is 2 is equal to 230 upon 230 minus 10 into I a 2 is equal to say x. Because E b 1 upon E b 2 is equal to n 1 upon n 2 is equal to x from equation 2 right.

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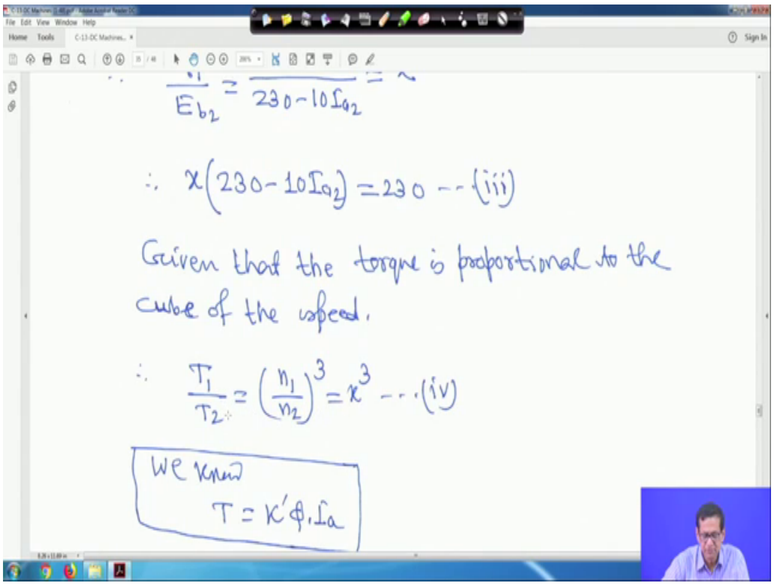

So that means, you cross multiply and given that the torque is proportional to the cube of the speed. Therefore, we can write T 1 by to T 2 is equal to n 1 by n 2 whole cube right that is x cube, so T 1 by T 2 is equal to x cube. So, first condition and this is the second condition, we know the torque is equal to K dash phi into I a right.

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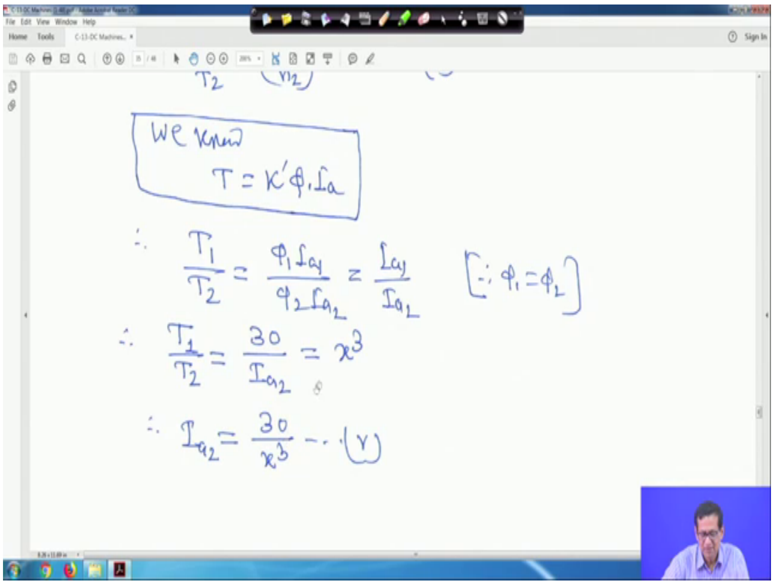

Therefore we can write T 1 upon T 2 is equal to phi 1 I a one the first case divided by phi 2 I a I a 2 second case, but flux remain constant for shunt motor therefore, phi 1 is equal to phi 2, here it is in phi 1 is equal to phi 2 that mean it will be I a 1 upon I 2. That means, T 1 upon T 2 is equal to 30 upon I a 2 is equal to x cube because this is x cube right. Therefore, 30 upon I a 2 is equal to x cube therefore, I a 2 is equal to 30 upon x cube this is equation 5. This I a 2, this I a 2 you substitute here, you substitute here right.

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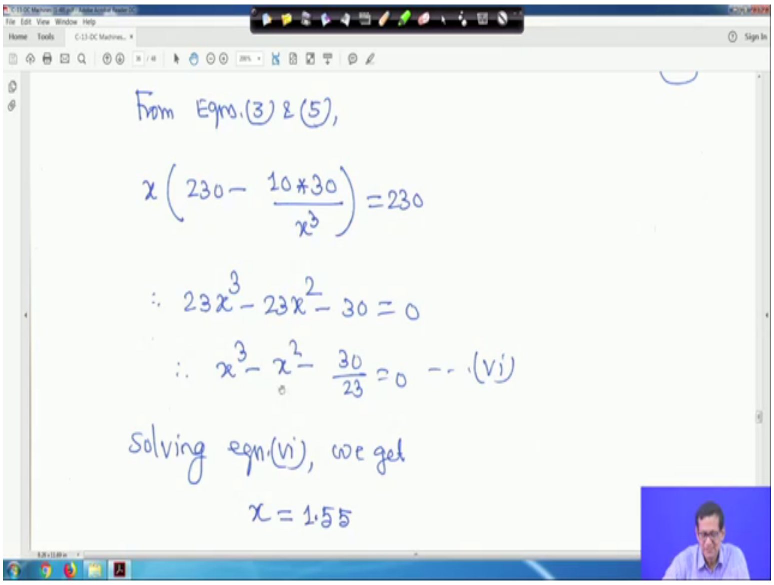

If you substitute this equation will become x cube minus x square minus 30 upon 23 is equal to 0. So, it is a cubic equation you will have 3 solutions. So, little bit of little bit of trying this you will get x is equal to 1.55 right; that means, n 1 upon n 2 is equal to x, so n 1 is 60 600 rpm and x is 1.55.

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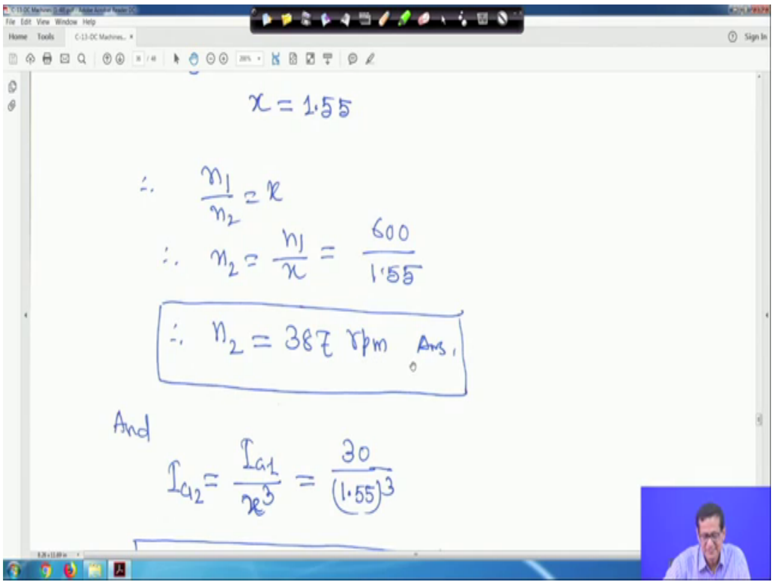

So, n 2 will be 387 rpm, this is the answer for n 2. And I a 2 will be you have got I a 2 is equal to I 1 upon x cube.

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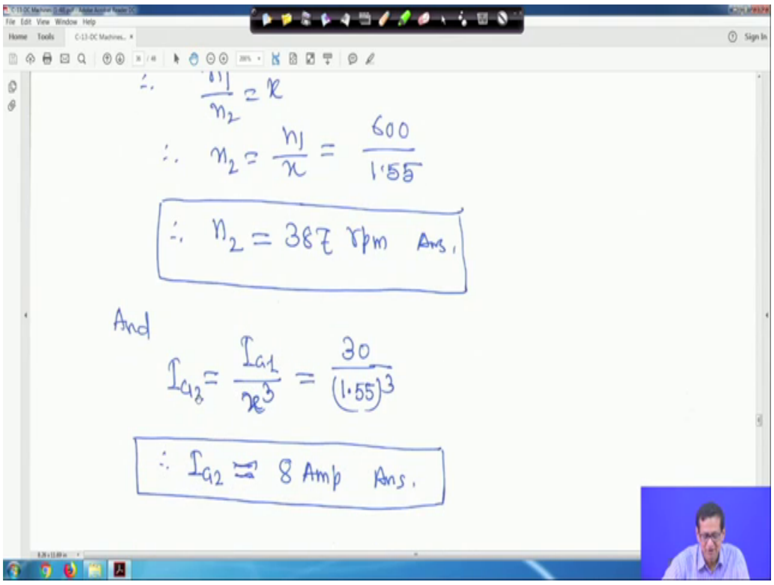

So, 30 upon 1.55 cubes, I a 2 will be approximately 8 ampere. This equation little bit and error trial and error from your intuition you have to try right. So, such that you will get the reasonable values, I mean approximate values.

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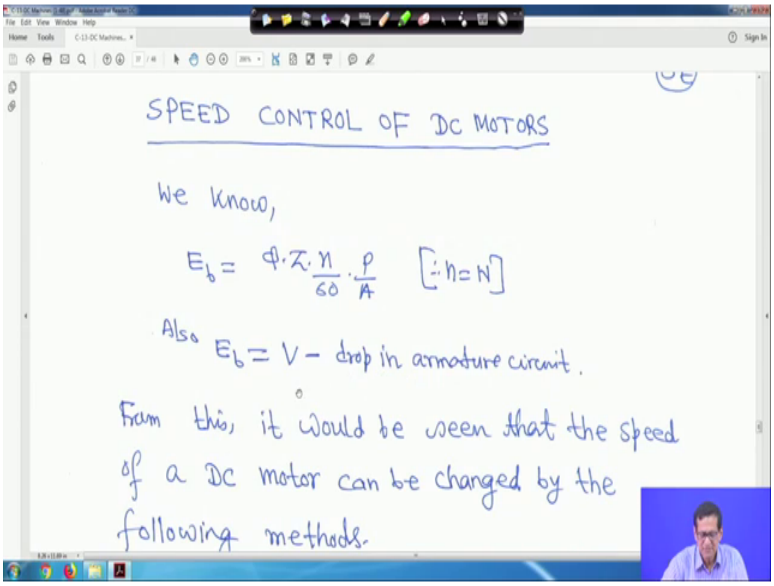

So, another thing is that speed control of DC motor. So, we know E b is equal to phi Z n by 60 into P by A right. So, n is equal to E b is equal to actually V minus your drop in armature circuit ok.

Thank you very much we will back again.