Electrical Machines
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology, Delhi
Module 10: Electrical Machines
Lecture 31
Testing of Induction Motor: OC and SC Test

We are going to look at no load and block rotor test of an induction motor.

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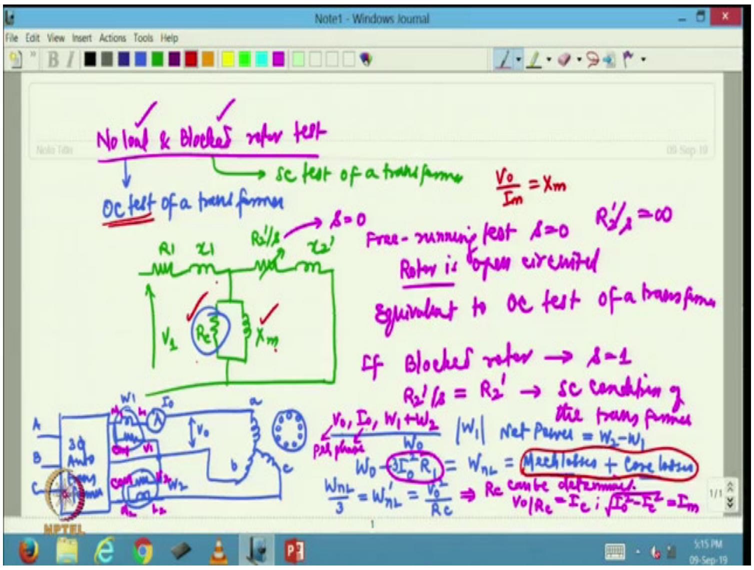

In fact, last class I had started on no load test and I told you that no load test is very similar to the open circuit test of a transformer whereas the block rotor test is very similar to the short circuit test of a transformer. So, this is because if you actually look at the equivalent circuit of the induction motor, I normally have R_1 here, X_1 here. Then, I have R_c and this is going to be X_m and what I have as the rotor parameters, I am going to have this as R_2^l /s and X_2^l and this is going to be essentially short circuited because the rotor is inherently short circuited.

Here is where I am actually applying the value V_1 that is the stator voltage applied per phase. If I am looking at the motor running freely this slip will be close to 0. So, whenever, I am actually running it freely or free running test I am going to have s equal to 0 because of which it is as good as rotor is open circuited because R_2/s becomes infinity, at s=0. So, I am going to have R_2^l /s equal to infinity. So, I am going to have rotor open circuited so this is equivalent to open circuit test of an induction motor, open circuit test of a transformer I mean okay whereas if I am going to have short circuit so if I am going to have essentially the block rotor condition.

If the rotor is blocked, then in that case I am going to have s=1 so R_2^l /s becomes basically equal to R_2^l itself which is very clearly the normal short circuit condition of the induction motor. So, it is equivalent to short circuit condition of the transformer as well. So, realize that the no load test is corresponding to open circuit test of a transformer and block rotor test is equal to short circuit test of a transformer. Now, let us try to look at what is actually the connection that is made under the open circuit condition.

So, I am going to have actually this as 1 of the wattmeters which is going to one of the phases of the induction motor. Let us say this is the induction motor stator. So, this is going to be ammeter and this is coming through the watt meter W_1. I am going to use 2-watt meter method. This is the second phase of the induction motor and this is the third phase of the induction motor. The third phase will also be connected through another current coil of the watt meter. This is the pressure coil. So, the pressure coils are getting connected together in one of the phases.

So, I am going to have actually a 3 phase auto transformer sitting in between so that I will able to apply variable voltage if I want to. So, this is my 3 phase autotransformer and I am going to have essentially the 3 phase supply connected here. So, this is A this is B this is C. Similarly, these are the induction motor terminals a, b and c. Now, I am going to show the rotor as a squirrel cage rotor which is somewhat like this. So, I have shown a squirrel cage rotor. Now, the ammeter measures whatever is the current I_0. I am going to measure the voltage line to line voltage which is V_0 and I am going to measure what is W_1 and what is W_2.

So, I can actually mention the terminals here. This is m_1, this is l_1, this is common and this is V_1. Similarly, this is going to be m_2. This is going to be l_2 and this is going to be common and this is going to be V_2. Now, I am going to note down the readings V_0, I_0, $W_1 + W_2$. Most of the times when I am not going to have the induction motor loaded I am going to see that 1 of the watt meters might kick back that is I will have the needle of this watt meter going below 0 in which case I have to reverse the current coil and note down the W_1 as the magnitude whatever it is the current coil.

I will able to note down the reading. Let me just note down the reading as W_1 but the net power under this condition I have to note down as W_2-W_1 because I have reversed the current coil. I have to take this reading as negative. So, this will be the net power. So, let us say I have noted down after doing all the jugglery what is V_0, what is I_0, and what is W_0. These I have noted down. Please note the no load current of induction motor will be still as high as 30 percent of its rated current.

So, I have to write $W_0 - 3I_0^2 R_1 = W_{NL}$. This is the no load loss of the induction motor. This will be actually equal to the mechanical losses incurred by the induction motor because the motor is running close to the synchronous speed plus the core losses incurred by the induction motor. So, this is consisting of both these losses.

We can assume that these losses are fairly constant because the induction motor is going to run almost at a constant speed and core losses will be constant as long as applied at rated voltage and rated frequency. Now, that I have $\frac{W_{NL}}{3} = W_{rL}^1 = \frac{V_0^2}{R_c}$.

All these things have to be per phase values. If it had been a delta connected induction motor, I can say V_0 whatever I read is directly line voltage as well as phase voltage whereas I_0 whatever I am reading current. So, I have to divide by root 3 to get the per phase current. So, all these values have to be per phase values. Now, that I have $\frac{V_0^2}{R_c}$. Once I determine R_c I can say $\frac{V_0}{R_c} = I_c$ that is actually the core loss component current per phase.

I already have I_0, so I can say $\sqrt{I_0^2 - I_c^2} = I_m$ which is the magnetising current. Now, I have I_m, I have V_0 with me, so I should be able to write this as $\frac{V_0}{I_m} = X_m$. So, I have got R_c value I have got X_m value. I have also got the losses which are corresponding to mechanical losses and core losses. So, I have got all that I wanted to know all those from open circuited test of an induction motor or free running test of an induction motor.

So, I will be able to determine the parallel parameters. So, now I had to go on to the blocked rotor test to look at the series parameters of the induction motor. So, now we will start looking at the block rotor test of a 3 phase induction motor.

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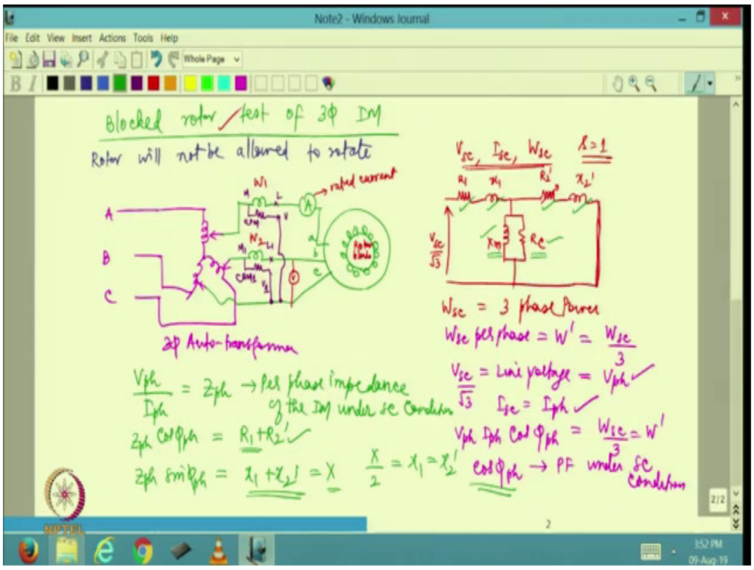

We had seen the open circuit test of the induction motor. We have to look for the next one which is known as blocked rotor test of 3 phase induction motor. So, as the name indicates in this particular case rotor will be blocked or it will not be allowed to rotate. We are going to have the rotor completely blocked. So, when the rotor is blocked we are essentially looking at let me first draw the diagram corresponding to this.

Let us say these are A, B, and C phase inputs. I am going to have a 3 phase auto transformer here. So, I am going to connect the 3 phases here like this. Now, from each of the phases through the variac this is the auto transformer. From the variac I am going to connect it to the 3 phase induction motor. So, let us say this is my 3 phase induction motor. Let me just show it like this a circle and then I am going to show the rotor here. Let me assume this is a squirrel cage induction motor.

Now, I am going to connect this through let us say a watt meter to the phases of the induction motor along with an ammeter and second phase let me say again I am connecting through a watt meter to the second phase of the induction motor, third phase I am going to connect it directly.

So, these are a, b and c phases of the induction motor. Now, as far as the watt meter is concerned let me draw the potential coil. So, the potential coil is connected like this. This is also the potential coil for the second watt meter.

This is connected like this. Let me write this as M, L common point and this is the V. let me call this as M_1 this is L_1, this is common 1 this is V_1. So, these are the points of the watt meter. So, let me call this as W_1 and W_2. These are the 2 watt meters that have been connected here. Now, this rotor is blocked. Now, what we are going to do is increase this voltage slowly until this current reads rated current. It should not exceed rated current because we do not want to make the copper losses greater than rated copper losses and we are going to measure the voltage across 2 lines.

So, what we measure here V_{sc}, I_{sc} and W_{sc}. I call this as short circuit test because if you recall the equivalent circuit of the induction motor this is going to be R_1 this is going to be X_1. This is going X_m and this is going to be R_c, per phase equivalent circuit. Here, is what I am applying as V_{sc} and if I look at this is $\frac{V_{sc}}{\sqrt{3}}$ in fact if I assume this is a star connected induction motor and I am going to have this as normally R_2^l/s but s is 1. So, I can write it to be R_2^l and this as X_2^l and rotor is already short circuited. So, is not it very similar to the short circuit test of a transformer that is why the block rotor test is also known as short circuit test of the induction motor.

Now, I am calling this as short circuit test. Now, I have written these values as Vsc, Isc and Wsc. Now, whatever is Wsc this is the 3 phase power. So, if I want per phase quantity I should say Wsc per phase which I am call as $W^l = \frac{W_{sc}}{3}$. Now, I can write Vsc that is the line voltage during short circuit condition let me get what is the phase voltage which maybe $\frac{V_{sc}}{\sqrt{3}}$ if it is a star connected induction motor. So, V_{ph} is available with me if it is star connected $I_{sc} = I_{ph}$. So, phase current is also available with me. So, I can say $V_{ph} I_{ph} \cos(\phi_{ph}) = \frac{W_{sc}}{3} = W^l$.

So, these are available with me. So, I should be able to get what is $\cos(\phi_{ph})$. This will actually be the power factor under blocked rotor condition or short circuited condition. Now, that I have a power factor I should be able to write $\frac{V_{ph}}{I_{ph}} = Z_{ph}$ that is the per phase impedance of the induction motor under short circuit condition. Now, I can say $Z_{ph}\cos(\phi_{ph}) = R_1 + R_2^l$. If I know R_1 already is should be able to get R_2^l without any difficulty.

Similarly, $Z_{ph}\sin(\phi_{ph}) = X_1 + X_2^l = X$. Where, $\frac{X}{2} = X_1 = X_2^l$. So, block rotor test will allow me to get R_2^l and X_2^l whereas the open circuit test or no load test or free running test which we discussed earlier will allow me to decide what is Xm and Rc. So, both will allow me to decide these things now. So, based on this let me try to work out 1 problem on this or the induction motor performance characteristics.

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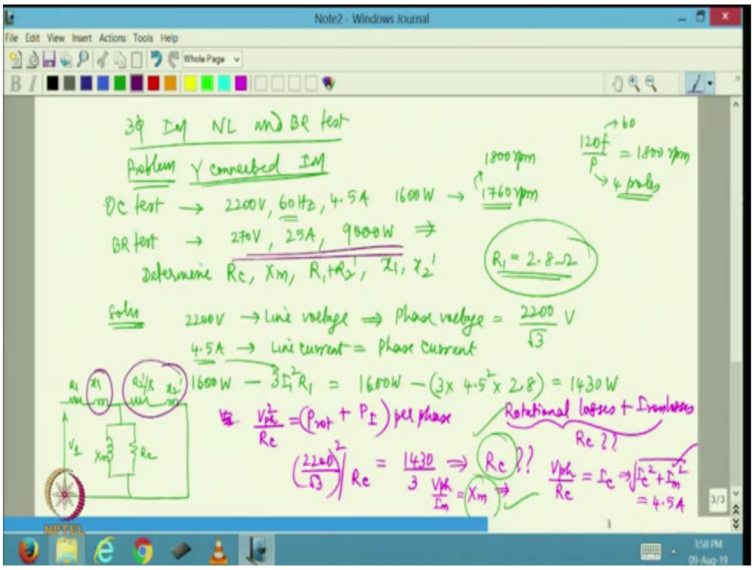

So, 3 phase induction motor no load and blocked rotor test let me try to work out 1 problem. So, the problem statement goes somewhat as follows. So, I am going to have basically for open circuit test for a 3 phase induction motor the readings are somewhat like this it is 2200 volts, 60 hertz, 4.5 ampere and I am essentially getting a wattage reading of 1600 watts and when it is freely running let us say it is running close to a speed of 1800 rpm let us say 1760 rpm. Please understand if I am going to have 1760 rpm and 1800 rpm will be the synchronous speed whatever is the closest.

It is a 60 hertz machine. So, $\frac{120f}{p}$, f is 60 so if I say that the closest synchronous speed is 1800 rpm then p has to be 4 poles. So, already we have deduced the poles have to be 4 poles then block rotor test reading is somewhat like this. It has 270 volts as the line voltage and I am going to have 25 amperes as the line current and about 9000 watts is the reading. Now, what is being asked is determine Rc, Rm, $R_1 + R_2^l$ then X_1 and X_2^l.

Now, 2200 volts is given as the line voltage and 1 more things that is given is R_1 is given as 2.8 ohms. This is going to be the line voltage and if it is given as y connected induction motor. Phase voltage is going to be $\frac{2200}{\sqrt{3}}$. Now, 4.5 ampere is given as the current. This has to be line current as well as phase current because it is star connected.

So, first of all I should say $1600W - 3I_1^2 R_1 = 1600 - (3 * 4.5^2 * 2.8) = 1430W$. This will give what is the value of the losses which can consist of actually rotational losses because the motor is rotating very clearly plus iron losses. So, iron losses and rotational losses corresponding to this I should be able to get what is Rc. So, for Rc let me try to $\frac{V_{ph}^2}{R_c} = (P_{rot} + P_l)$.

So, very clearly this also should be per phase voltage so I should say $(\frac{2200}{\sqrt{3}})^2 / R_c = \frac{1430}{3}$ so from which I would be able to get what is Rc without any difficulty. Now, I have to get what is Xm. To get Xm all I need to do is if I have $\frac{V_{ph}}{R_c} = I_c$ and I can also say $\sqrt{I_c^2 + I_m^2} = 4.5A$ from which I should be able to determine what is Im.

Now, I can say $X_m = \frac{V_{ph}}{I_m}$. So, I have got what is the value of Xm, I have also got what is the value of Xc. So, when I draw the equivalent circuit I should essentially draw R_1 which is already given. I will have to find out what is X_1, I have to get what is X_m which I have got exactly from this value I have got Rc which is also from this value what I have got. Now, I have R_2^l / s and I have to get X_2^l and this is the equivalent circuit completely which is V_1. So, I am yet to get this value. I am yet to get R_2^l and X_2^l for which I should be using the blocked rotor test data.

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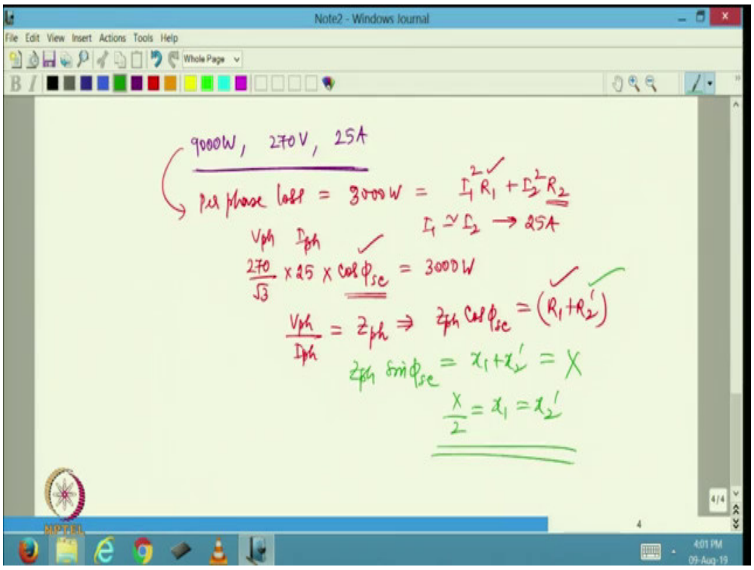

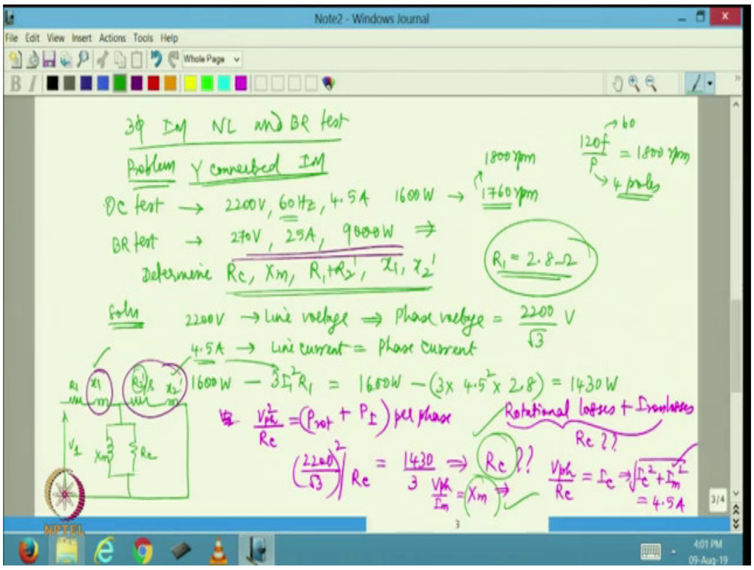

So, let me try to look at the blocked rotor test data. Again let me write down in the next page that was actually 9000 watts was the power, 270 volts was the voltage and 25 amperes was the current. This is what was the data of the blocked rotor test. So, I can say very clearly per phase loss is equal to 3000 watts because 9000/3. This is essentially corresponding to $I_1^2 + I_2^2$.

I know already R_1. I am going to assume $I_1 \cong I_2$ which is actually 25 amperes. So, I should be able to get what is the value of R_2 so that so let me write the value like this. Our voltage is $\frac{270}{\sqrt{3}} * 25 * \cos(\phi_{sc}) = 300W$ from which clearly I should be able to get $\cos(\phi_{sc})$. once I get $Z_{ph}\cos(\phi_{sc}) = R_1 + R_2^l$ so this is $V_{ph} I_{ph}\cos(\phi_{sc}) = 3000W$. Now, I should be able to get $\frac{V_{ph}}{I_{ph}} = Z_{ph}$.

Once I get Z_{ph} I can say $Z_{ph}\cos(\phi_{sc}) = R_1 + R_2^l$. R_1 is already given as 2.8 ohms because of which I will be able to determine what is R_2 without any difficulty. So, I should be able to get R_2^l. Now, I can say $Z_{ph}\sin(\phi_{sc}) = X_1 + X_2^l = X$. Now, $\frac{X}{2} = X_1 = X_2^l$. So, I think from this test data we should be able to get the complete equivalent circuit parameters namely X_1, R_2^l as well as X_2^l. So, we have determined all these things. So, you guys will complete the calculation, you should be able to do it. It should not be a problem.

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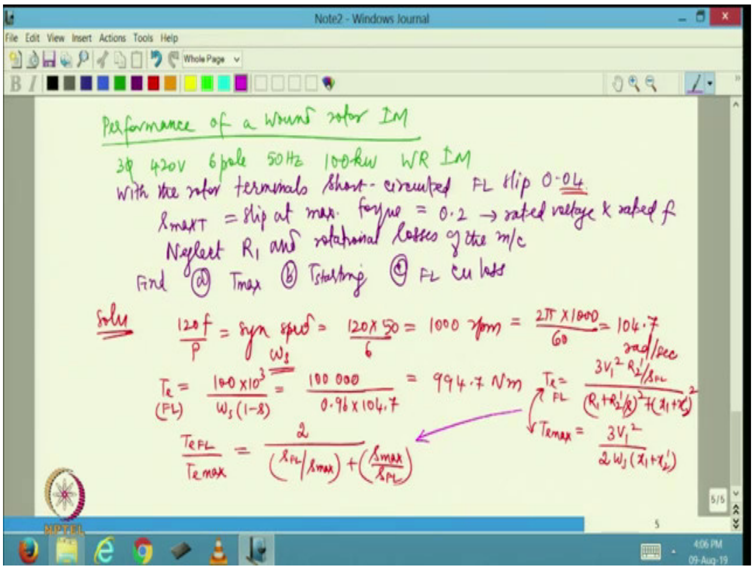

Let me work out 1 more problems on the performance of a wound rotor induction motor. The problem statement goes as follows it is a 3 phase, 420 volts, 6 pole, 50 hertz, 100 kilo watt wound rotor induction motor. What is written is with the rotor terminals short circuited we are going to have the full load slip to be 0.04 and slip at maximum torque that is $s_{max\ T}$ is given to be 0.2 when it is running at rated voltage and rated frequency.

Neglect stator resistance R_1 and rotational losses of the machine. Now you are being asked to calculate what is T_{max} what is $T_{starting}$ and what is the value of full load copper loss. This is what is being asked. So, let us see it is a 6 pole, 50 hertz induction motor. So, $\frac{120f}{p}$ is synchronous speed. This is going to be $\frac{120*50}{6} = 1000rpm$. So, if I want to convert it into radians per second I should say $\frac{2\pi*1000}{60} = 104.7rad/\sec$.

Now, I should be able to write what is the full load torque. So, this is 100 kilo watt. So, $T_{e(FL)} = \frac{100*10^3}{\omega_s(1-s)} = \frac{100000}{0.96*104.7} = 994.7Nm$.

Now, $\frac{T_{eFL}}{T_{e\max}} = \frac{2}{(\frac{s_{FL}}{s_{\max}}) + (\frac{s_{\max}}{s_{FL}})}$. This expression you can derive very clearly if you have

$$T_{eFL} = \frac{3V_1^2 \, R_2^l / s_{FL}}{(R_1 + R_2^l / s)^2 + (X_1 + X_2^l)^2}.$$

Let us say I am talking about this as full load and I can also write this as $T_{e\max} = \frac{3V_1^2}{2\omega_s(X_1 + X_2^l)}$.

This is another expression. So, if you combine these 2 expressions you should be able to derive this expression.

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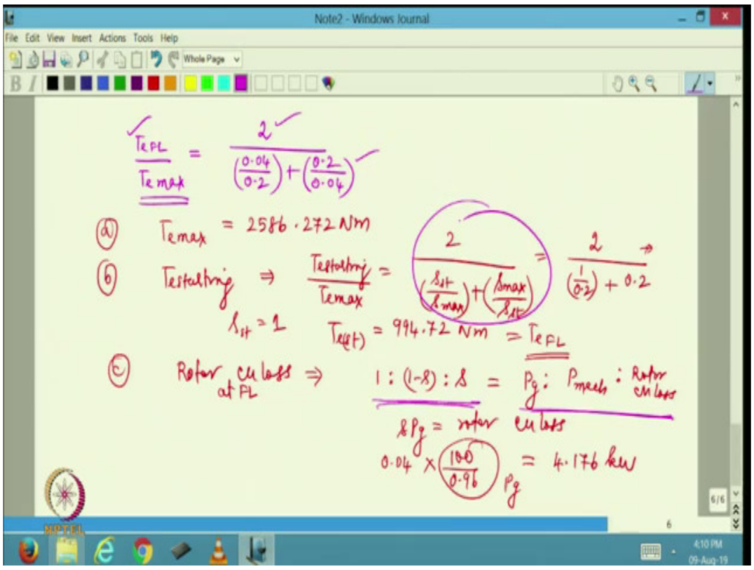

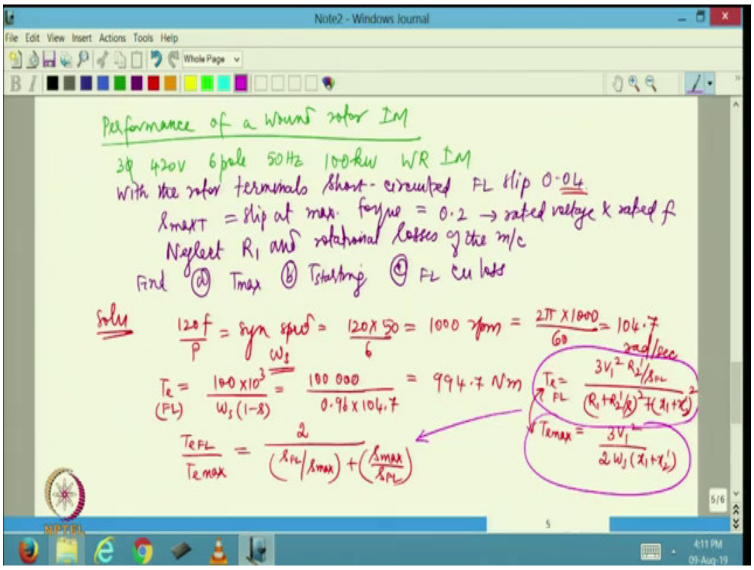

Now, using this we should be able to write $\frac{T_{eFL}}{T_{e\max}} = \frac{2}{(\frac{0.04}{0.2}) + (\frac{0.2}{0.04})}$. All these things are known only thing you need to calculate is T_{emax}. From this we can arrive at $T_{e\max} = 2586.272Nm$. Now, the second sub division that is being asked is what is $T_{e\ starting}$.

I can again write this expression $\frac{T_{estarting}}{T_{e\max}} = \frac{2}{(\frac{s_{st}}{s_{\max}}) + (\frac{s_{\max}}{s_{st}})} = \frac{2}{(\frac{1}{0.2}) + (0.2)} = 994.72Nm$. Which is same as that of full load.

The third one that is being asked is rotor copper loss. So, rotor copper loss how will you get it. Please remember the equation we derived $1:(1-s):s = P_g : P_{mech} : P_{cu}$. So, I can say sP_g is rotor copper loss, at full load. So, this is $0.04 * \frac{100}{0.96} = 4.176kW$. So, this equation is a very, very important equation which we should remember all the time for the induction motor.

Similarly, this is another important equation whatever is the condition at which we are talking about the slip. This is another important equation and one more important equations which we normally talk about is this and this is another equation corresponding to maximum torque. So, these are really important equations. So, you should actually know how to derive this but also know how to use it. So, with this we have concluded basically open circuit short circuit test as well as couple of problems on induction motor.