Electrical Machines
Professor G. Bhuvaneswari
Department of Electrical Engineering
Indian Institute of Technology Delhi
Lecture 40
Single Phase Induction Motors

One of the topics we have left over already is single phase induction motor. This is one of the motors which is extensively used in household applications.

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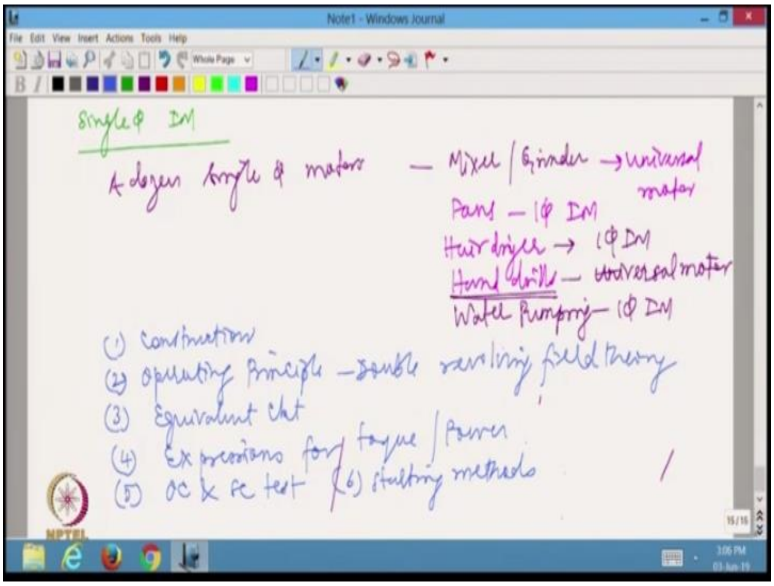

Single φ IM

A dozen single φ motors — Mixer / Grinder → universal motor
Fans — 1φ IM
Hair dryer → 1φ IM
Hand drill — universal motor
Water Pumping — 1φ IM

(1) Construction
(2) operating Principle — double revolving field theory
(3) Equivalent ckt
(4) Expressions for torque / Power
(5) OC & SC test
(6) Starting methods

If you look at any household normally at least a dozen single phase induction motors or single phase motors are used in any household. So for example, if you look at mixer grinder, we use a single phase series motor which is actually known as universal motor. Then all the fans that we use. They are all single phase induction motor. If you look at actually hair dryer or some of the shavers and so on, hand drills many of them, hand drills generally are universal motor, whereas these are all generally single phase induction. Lawn mowers if you look at rest of water pumping motor those are all single phase induction motor.

So this is very competitive market. Generally, if you look at the normal market price because even if you increase the efficiency tremendously, but if the price increases even slightly nobody will be willing to buy this kind of single phase induction motor. So it is really a competitive market in that sense. Now, let us try to look at how the single phase induction motor works. So we are going to look at the topics as follows.

First we will look at construction, then we will look at the operating principle based on double revolving field theory. We had seen already the revolving field theory when we were discussing three-phase induction motor. Then we will look at the equivalent circuit. Then we will be looking at expressions for torque, power, etc. After this, we will be looking at OC and SC test, how to determine the parameters of the machine. Finally, we will look at some starting methods. So we are just looking at the glimpse of single phase induction motor nothing more than that. So these are the topics that are going to be covered during this lecture.

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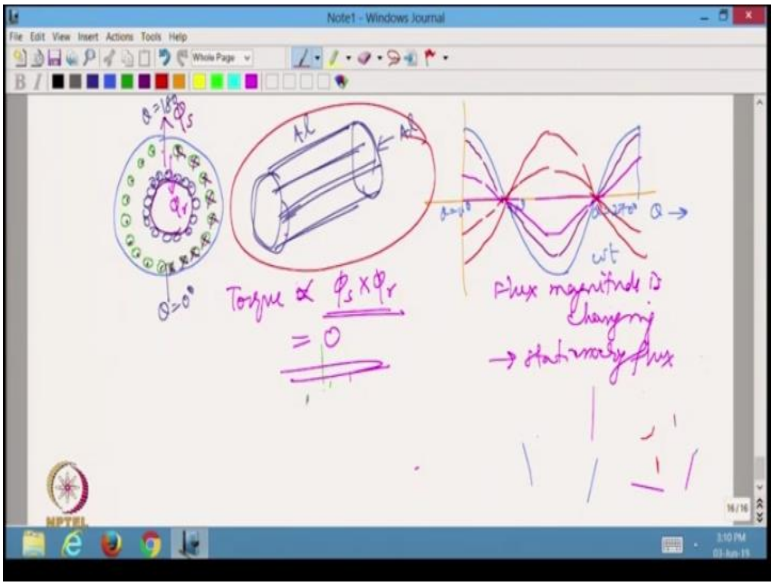

As far as the construction is concerned, normally the winding we have in the stator is a single phase distributed winding. So I am probably going to have, if it is a two pole construction. I am going to have the winding distributed all over the slots like this. So this side let us say is carrying dot current and this side is going to carry cross current. Now I am showing a 2 pole construction. Now because it is dot current and cross-current, I am going to have the stator flux. Rather looking at it in this direction, I had a rotor here. The rotor is very similar to the squirrel cage rotor of the 3 phase motor.

So I am going to have the squirrel cage bar arranged around the outer periphery of the rotor and it is going to be short circuited the same way. I may have basically the short circuiting end rings which are actually sitting here. So these are all generally made up of aluminium hardly ever we use copper in single phase induction motor because copper is more costly. So normally we use aluminium and this can work very well whether it is 3 phase, 2 phase, single phase, 4 pole, 2 pole, 8 pole anything it can work very well. So we are going to have this construction the cross sectional view I have shown here.

Now, very clearly because it is a pulsating MMF. What I mean by pulsating MMF is, if I say this is $\theta = 0$ clearly this is $\theta = 180^0$. So, if I actually draw I am going to have actually the MMF looking somewhat like this. This is how it is going to be. So let us say this is $\theta = 0$, this is $\theta = 90$ and this is going to be $\theta = 270$ and this is $\theta = 360$. So this is what we have drawn. So this is the kind of MMF or flux we are going to look at a particular ωt. Now, if I look at another ωt the current might have decreased in magnitude.

When it decreases in magnitude I am going to have the same flux, but looking like this and I will have further reduction in the flux as time goes by right because it is a sinusoidal current. Please remember it is a single phase current. At some point it will become completely 0. After some time, the current will start reversing so we may see something like this as the flux. Then it will become higher. Basically the flux magnitude is going to change so flux magnitude is changing but it is stationary flux. This is a stationary flux, which is not rotating basically.

Now, as far as the rotor is concerned, the rotor is seeing this pulsating MMF because of which this will also have induced and that induced flux will be opposing whatever is the original flux, so we will have the rotor flux in the opposite direction, but if you look at the angle between these two, it is 180 degrees. So, if I try to look at what is the torque produced, $Torque\ \alpha\ \phi_s \mathrm{X} \phi_r$ and that means sine of angle between them will come into picture.

So that will be 0 when I look at the starting of the machine, so I will not be able to get any starting torque in a single phase induction motor as such if I do not make any arrangement for starting. That is because I have a pulsating flux in the stator, I have a corresponding pulsating flux in the rotor, which is exactly opposite. So the angle between them will be only 180 degrees so I will not be able to really get any torque. So much so as far as the construction of this particular single phase induction motor is concerned, one major point I want you to notice is there is no difference between the cage rotor construction of single phase motor and 3 phase motor.

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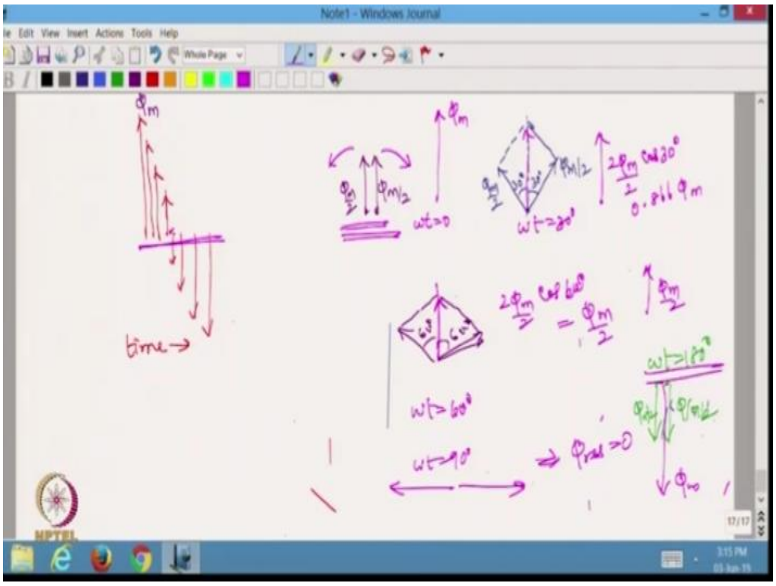

Now, if I actually look at this pulse, the MMF or flux I said that it is probably going to have a magnitude like this. Then it is going to decrease, decrease and decrease further and it will become 0, then it will start increasing in the opposite direction. This is what I said with respect to time. If I look at time this is how it is going to change. If this is the way, it is going to be I can imagine it somewhat like this. If this total magnitude is some ϕ_m, I can imagine that there are two $\frac{\phi_m}{2}$ fluxes available with me, and 1 is rotating in, say, clockwise direction, the other one is rotating in anti-clockwise direction.

When both are at stationary position, currently the resultant of this will be double this value something like this. This is going to be ϕ_m at let us say t=0 or $\omega t = 0$. If I look at what happens at $\omega t = 30$, I am going to have these displaced by 30 degrees and this also displaced by 30 degrees because it is rotating in opposite direction. This is 30 degrees and this is also 30 degrees. So, what I am going to get is, this is $\frac{\phi_m}{2}$ and this is also $\frac{\phi_m}{2}$, so I am going to get $\frac{\phi_m}{2}\cos 30$ and $\frac{\phi_m}{2}\cos 30$, both of them added together, the resultant will be along this.

This is how it is going to be so the resultant will be only this much. This is going to be the result. So at 30 degrees what I am going to get is $2\frac{\phi_m}{2}\cos 30 = 0.866\phi_m$. Now, if I try to look at this is at $\omega t = 30^0$, if I look at $\omega t = 60^0$, I can similarly write I am going to have this as the mid position. I am going to have this side actually having 60-degree displacement, this side also having 60-degree displacement. So the resultant if I try to look at it, I am going to get something like this.

So the resultant will be along this, like this. So this will be $2\frac{\phi_m}{2}\cos 60 = \frac{\phi_m}{2}$. Now, if I look at 90, please note both these things are exactly opposing each other. This is at $\omega t = 90^0$ so the resultant will be 0. So, what we talked about is coming true if I try to look at the fluxes 2 of them each magnitude having $\frac{\phi_m}{2}$ rotating in opposite senses. One in clockwise, one in anti-clockwise. You can also see that when Φ becomes 180 both of them will be actually looking down. Both of them will be $\frac{\phi_m}{2}$ like this. This is actually at $\omega t = 180^0$.

So the resultant will be phi M itself along negative direction. So that is corresponding to this particular period. So you can very well see that if I consider two revolving magnetic fields each having a magnitude of half the original magnitude of the magnetic field, peak of the magnetic field then it will be equivalent to a single phase pulsating field.

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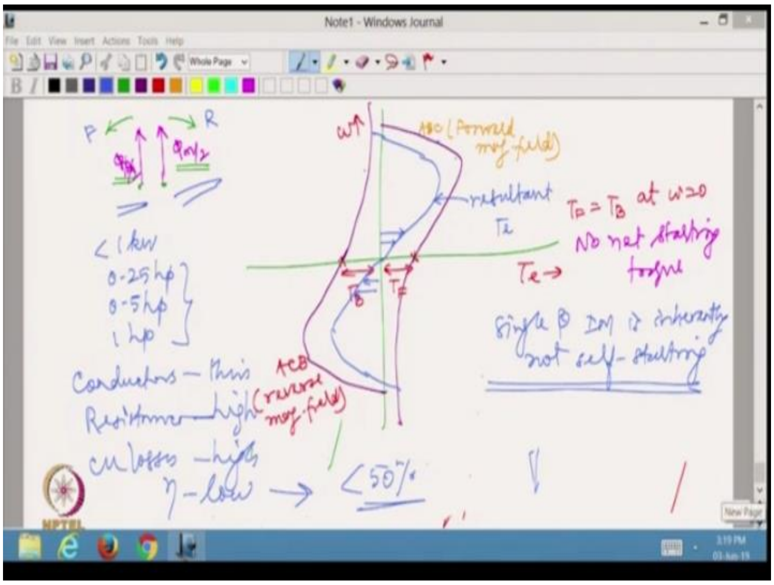

So when we analyze the single phase induction motor, we will analyze it as though we take two revolving magnetic field each of $\frac{\phi_m}{2}$ magnitude and we are going to consider this as though we have connected two three phase induction motors each having $\frac{\phi_m}{2}$ magnitude in the opposite direction and how the rotor will react to that. So you can imagine if I look at three phase induction motor characteristics, normally we draw it like this.

So this is let us say corresponding to ABC phase sequence or forward rotating magnetic field clockwise or anti-clockwise and we are going to take the other one again starting from the other ω_s, but it is going to actually go like this which is reverse rotating magnetic field. This is ACB sequence or this is reverse rotating magnetic field.

Now, if I look at this is actually the speed axis and this is the torque axis. So, if I look at speed equal to 0 point, I am going to have both these torque exactly being equal to each other. If I may call this as T_f and if I may all this as T_b forward torque and reversed torque or backward torque, $T_f = T_b$ at $\omega = 0$. So I will not have any net starting torque because of which I will not have this machine so single phase induction motor is inherently not self-starting. It will not be able to start on its own.

This is what you would have seen many times in railway compartment and all. Many fans will not start running, but if you give it a push in one direction, it will start running. That means if you give an initial torque then it will be able to run that is because if I look at the resultant of these two torques, after all the single phase induction motor is having both these fields.

This is forward and this is reverse. Both are existing. So the net torque will be the resultant of these two. So, if I draw the resultant I have to subtract from forward the reversed and I can draw it somewhat like this. I am going to essentially get some torque somewhat like this.

So this is how the torque is going to be. So this is going to be the resultant torque. So you can see the moment I give a rotation either in forward direction or reverse direction I do have some amount of torque available because of which the motor will be able to pick up speed. Normally most of the single phase induction motors will be less than 1 kilowatt rating. Very standard ratings are 0.25 HP, 0.5 HP, 1HP and so on. Many of them are really small motors. So the conductors will be really thin. So which means resistance will be high. That means the copper losses are going to be high, which means efficiency will be low.

Most of the single phase induction motors will have less than 50 percent efficiency. Nobody cares too much about the efficiency of the single phase induction motor because if you want to improve their efficiency by making a better design, even if the cost increases slightly nobody is going to buy your motor. It is a very competitive market.

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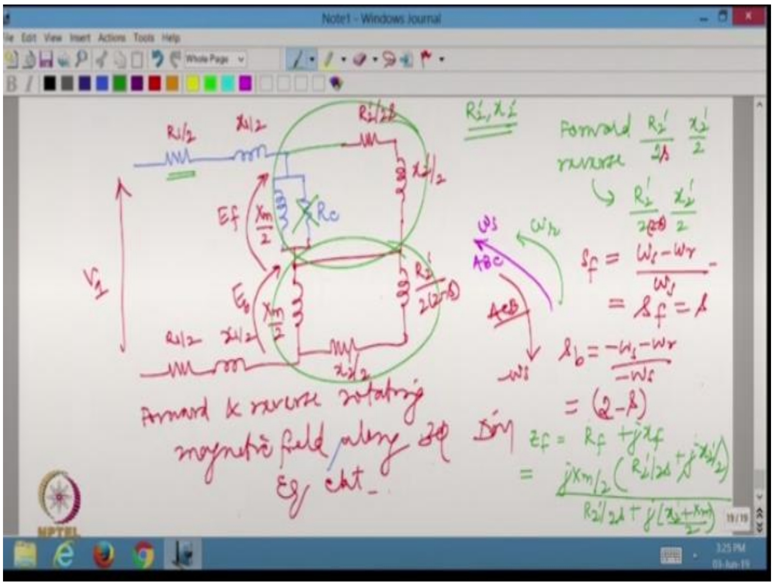

Forward & reverse rotating magnetic field along eq ckt

Forward $\frac{R_2'}{2s}$ $\frac{X_2'}{2}$

reverse $\frac{R_2'}{2(2-s)}$ $\frac{X_2'}{2}$

$$s_f = \frac{\omega_s - \omega_r}{\omega_s} = s_f = s$$

$$s_b = \frac{-\omega_s - \omega_r}{-\omega_s} = (2-s)$$

$$Z_f = R_f + jX_f = \frac{jX_m/2\left(R_2'/2s + jX_2'/2\right)}{R_2'/2s + j\left(\frac{X_2' + X_m}{2}\right)}$$

So when we actually analyze the motor it is exactly similar to induction motor I said. So in induction motor normally we have R_1, X_1, we will have X_m. We will have normally R_c also but most of the times we are going to neglect R_c in the case of single phase induction motor for the sake of simplicity and also because the resistance value that is connected in the stator is generally high, thin wires. That is the reason.

Now as far as rotor is concerned, the rotor has to be divided into 2 portions. One corresponding to forward, the other corresponding to reverse rotating magnetic field. So, if I say R_2 and X_2 are normally the rotor resistants and reactants or referred to the stator side it is R_2^l and X_2^l.

For forward let me take R_2^l /2 and X_2^l /2. Similarly, for reverse also let me take R_2^l /2, X_2^l /2 because both are equally influenced by forward and reverse rotating magnetic fields. Now, if my machine is rotating in this direction let us say it is rotating in this direction in ω_r . If I am looking at forward revolving magnetic field, it may be rotating at ω_s this is corresponding to ABC phase sequence. If I am looking at reverse rotating magnetic field, it will be $-\omega_s$ which is corresponding to ACB phase sequence.

So, if I try to calculate the slip corresponding to forward rotating field I should write $\frac{\omega_s - \omega_r}{2\omega_s}$ which is very similar to the normal flux of the induction motor, which is s_f itself. Let me call this as s for simplicity. If I try to calculate what is S_b which is corresponding to reverse rotating magnetic field that will be $\frac{-\omega_s - \omega_r}{-\omega_s} = 2 - s$. So I am going to have 2 different slips corresponding to each of them.

If you may recall what we wrote earlier in three phase induction motor, we used to write R_2^l/s. Here we have to write $R_2^l/2s$ and here we have to write $R_2^l/2(2-s)$. Now, I am going to divide X_m also into 2 portions. This is corresponding to forward flux and this is corresponding to reverse flux. Whatever I am drawing as the rotor parameter again I am going to draw corresponding to forward side and backward side. I can very well draw this also as R_1 and X_1. Otherwise I can write this as $R_1/2$, $X_1/2$. Similarly, here also I can draw this as $R_1/2$ and $X_1/2$.

So I should be able to draw it like this. Let me write here this is $R_2^l/2s$, this is $X_2^l/2$ which means this voltage is going to be corresponding to E_f or forward revolving magnetic field dependent induced EMF. Similarly, this is going to be E_b which is the revolving magnetic field induced EMF. Now this will be $R_2^l/2(2-s)$. Now this is going to be $X_2^l/2$. This is essentially the overall equivalent circuit of the single phase induction motor with the voltage V_1 being applied here.

We have derived this essentially from forward and reverse rotating magnetic field along with three phase induction motor equivalent circuit. Now, let us see how to get the power expressions. Now I can look at this entire impedance whatever I am getting here as the forward side impedance. Similarly, whatever impedance I am getting here as the reverse side impedance.

So I can say that $Z_f = R_f + jX_f = \frac{j(X_m/2)((R_2^l/2s) + j(X_2^l/2))}{(R_2^l/2s) + j(X_2^l + X_m)/2}$. So this is going to be my Z_f.

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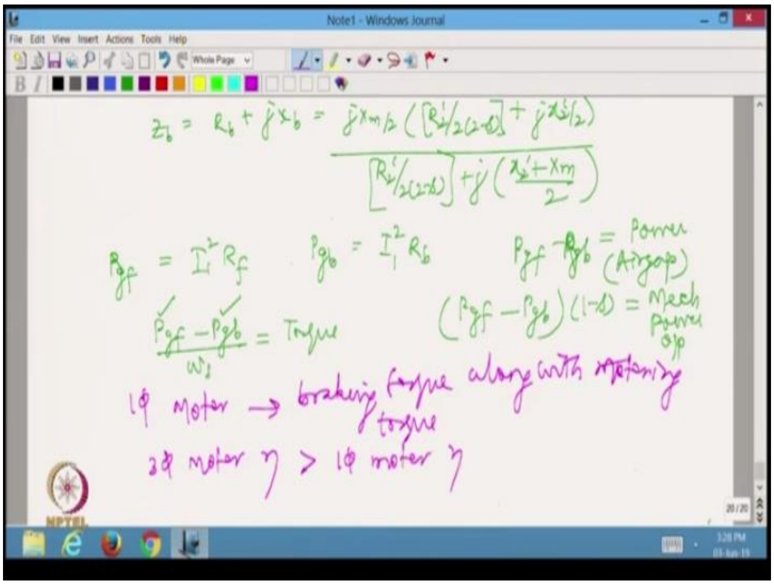

$Z_b = R_b + jX_b = \frac{jX_m/2\left(\left[R_2'/2(2-s)\right] + jX_2'/2\right)}{\left[R_2'/2(2-s)\right] + j\left(\frac{X_2'+X_m}{2}\right)}$

$P_{gf} = I_1^2 R_f$ $P_{gb} = I_1^2 R_b$ $P_{gf} - P_{gb}$ = Power (Airgap)

$\frac{\overset{\checkmark}{P_{gf}} - \overset{\checkmark}{P_{gb}}}{\omega_s}$ = Torque $(P_{gf} - P_{gb})(1-s)$ = Mech Power o/p

1φ Motor → braking torque along with motoring torque

3φ motor η > 1φ motor η

So similarly, I should be able to write what is Z_b.

$$Z_b = R_b + jX_b = \frac{j(X_m/2)((R_2^l/2(2-s)) + j(X_2^l/2))}{(R_2^l/2(2-s)) + j(X_2^l + X_m)/2}.$$

Now if I say that the motor is drawing a current of some I_1. The same current flows everywhere. So I should be able to say $P_{gf} = I_1^2 R_f$ be the power that is taken by the rotor corresponding to forward revolving magnetic field. Similarly, P_{gb} which is actually the reverse rotating or backward rotating magnetic field input power that will be $P_{gb} = I_1^2 R_b$.

Now, $P_{gf} - P_{gb}$ is actually what is available as the power through the air gap or power which is available in the air gap. So air gap power I can call it like this. Now, $(P_{gf} - P_{gb})(1-s)$ will be the mechanical power that is available. Now I can talk about this $\frac{P_{gf} - P_{gb}}{\omega_s} = Torque$.

Now, very clearly this is going to be a breaking torque whereas this is going to be the motoring torque. So single phase induction motor will always have breaking torque along with motoring torque. I cannot help it. It will be always there because of which I am not going to have really a good efficiency in this motor. So three phase motor efficiency which has only forward torque, no breaking torque at all. So the three phase motor efficiency is always going to be greater than single phase motor efficiency as a rule.

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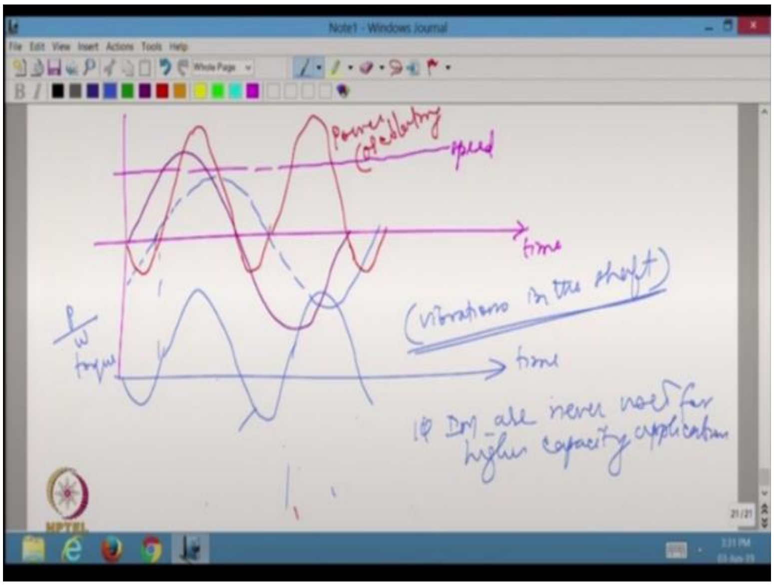

And one more thing I should be able to say is after all, in the case of single phase motor we are looking at actually voltage somewhat like this. This is the applied voltage. The current is going to be probably lagging behind by certain angle. So, if I try to multiply V and I, I am definitely going to get some negative power here. I am going to get positive power here, again negative power here, positive power here and negative power here. This will be the power. So, if this is the power, the power is oscillating. It is not a constant power.

Now, if I look at the speed because it is having mechanical time constant, speed is almost like a constant. Within this 20 millisecond period if I try to look at it, speed will be almost like a constant. So, if I try of get what is the torque $T = \frac{P}{\omega}$. So that will definitely have oscillations. So, if you look at the torque, torque will have some positive component, negative component like this. This is how the torque is going to be. The torque is not a constant torque because of which there will be huge vibrations in the shaft.

So normally we will never tolerate such vibrations in bigger power capacity motors so single phase induction motors are never used for higher capacity applications because first of all the efficiency is very low, it is not self-starting and also because I am going to have vibrations continuously in the shaft which is definitely not tolerated in higher capacity applications.

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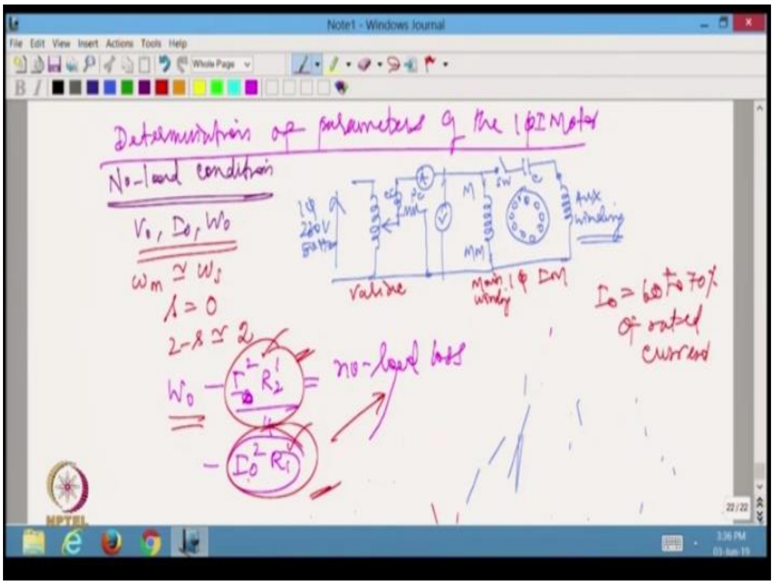

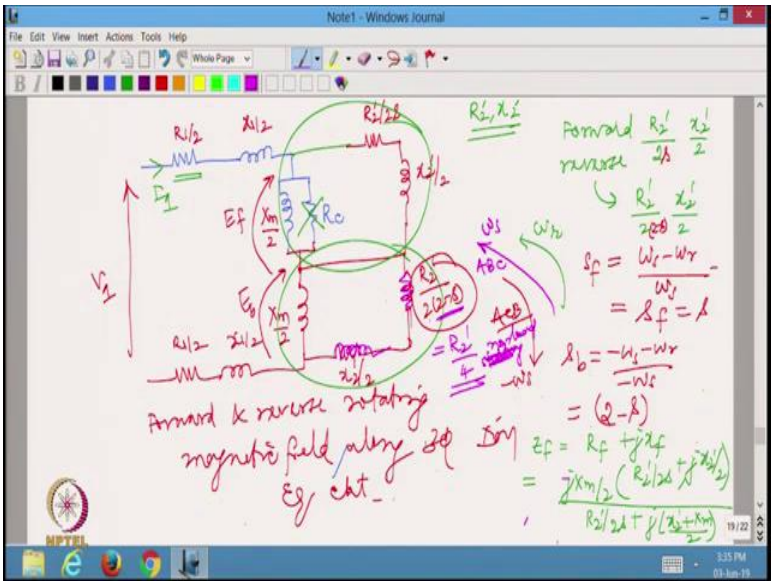

Now, let us try to take a look at how to determine the parameters of the single phase induction motors. We had already done for three phase induction motor this in detail, so hopefully we should be able to do it quite fast. Let us say I have basically under the no load condition somehow I have started the motor, I have still not talked about starting methods. I have started the motor, after starting the motor I am just running it on no load, I am trying to measure V_0, I_0 and W_0. Let me show the circuit diagram also. I am going to have a single phase supply which is actually 230 volts, 50 hertz, single phase supply. This is the variac I am going to have.

From the variac I am going to feed it to the single phase induction motor. The single phase induction motor normally is shown somewhat like this. There is a main winding. I am going to show this as M and MM simply. I definitely have to connect a voltmeter and ammeter which I have not shown right now. So I have to show ammeter and I can connect a voltmeter across this. Of course I have to have a wattmeter also. So this wattmeter I am showing it somewhat like this. So wattmeter is here, this is the pressure coil, this is the current coil.

Now, I have to definitely show the rotor also, here is my rotor. Normally induction motor will have something called auxiliary winding. We will talk about this within a short while, but this is the auxiliary winding or starter which is meant for starting the machine that will normally have a switch and the capacitor as well. The capacitor is meant for creating some phase shift in the auxiliary winding current and this is the switch which will be opened once the motor starts.

I do not have to have the auxiliary winding eternally in the circuit. Initially only for starting I will need this. Later on I can open it out. Now, this is the circuit diagram corresponding to the single phase induction motors no load test. So this is the main winding. Now, what I have got is V_0, I_0 and W_0. Under this condition we are going to assume that the speed is close to synchronous speed which means $s \simeq 0$ but $(2-s) \simeq 2$.

So, if you actually look at the equivalent circuit once again very clearly this portion is going to definitely carry, sorry this is the resistance and this is inductance. I have just drawn it the other way round, does not matter, but this is essentially going to have the resistance which is R_2^l /2(2-s) and $(2-s) \simeq 2$ because $s \simeq 0$. So I am going to have $R_2^l/4$ as the quantity here. So this is under starting condition when I am talking about no load condition. So under no load condition I am going to have this had to be $R_2^l/4$.

So, the first thing I need to do is unless I have the R_2^l value I cannot say how much is dissipated in among W_0, how much is dissipated in the backward revolving magnetic field circuit. So I have to actually say $W_0 - I_0^2 \frac{R_2^l}{4}$ is what is the no load loss. In fact, I should also subtract $I_0^2 R_1$ because this is also not a small quantity. I have to subtract both these quantities from W_0 to get what is the no load loss because I_0 itself will be a good chunk of the total rated current. I_0 will normally 60 to 70 percent of rated current. So I cannot completely neglect this or this. That is the reason we are taking into account.

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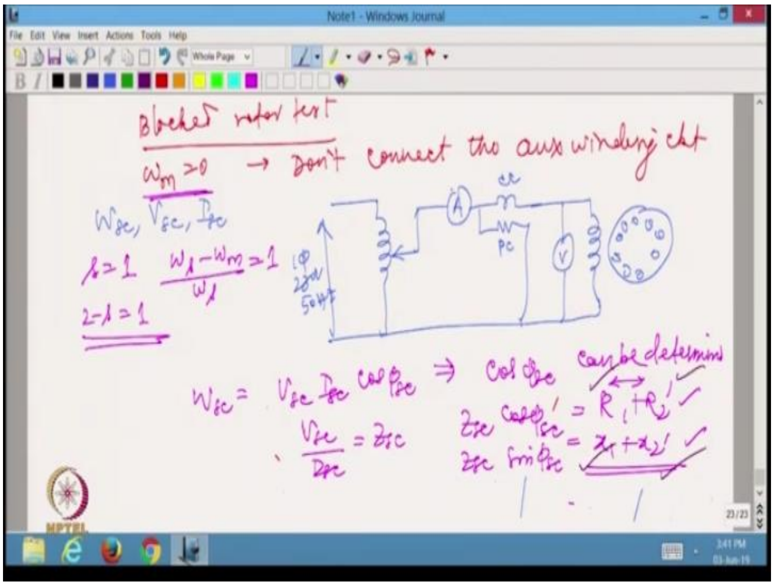


Blocked rotor test

$\omega_m = 0$ → Don't connect the aux winding ckt

W_{sc}, V_{sc}, I_{sc}

$s = 1$ $\quad \frac{\omega_s - \omega_m}{\omega_s} = 1$

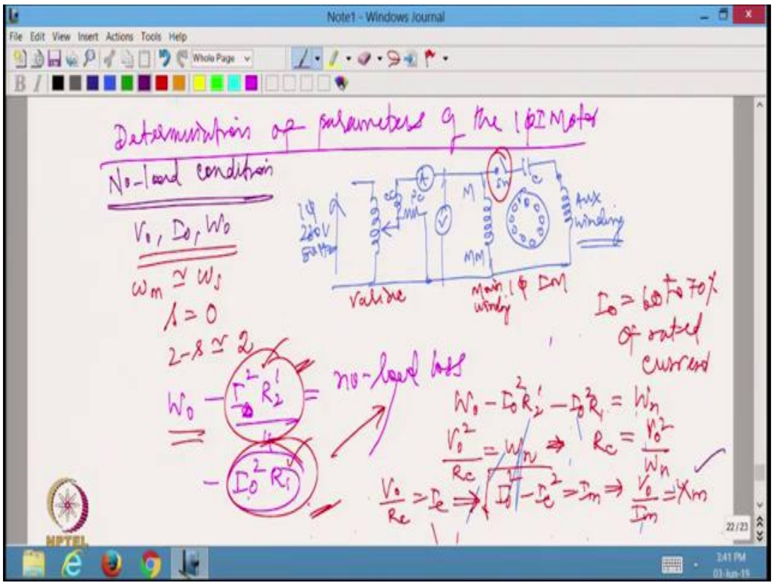
$2 - s = 1$

$W_{sc} = V_{sc} I_{sc} \cos\phi_{sc} \Rightarrow \cos\phi_{sc}$ can be determin

$\frac{V_{sc}}{I_{sc}} = Z_{sc}$

$Z_{sc} \cos\phi_{sc}' = R_1 + R_2'$

$Z_{sc} \sin\phi_{sc} = x_1 + x_2'$



Determination of parameters of the 1φ I Motor

No-load condition

V_0, I_0, W_0

$\omega_m \simeq \omega_s$

$s = 0$

$2 - s \simeq 2$

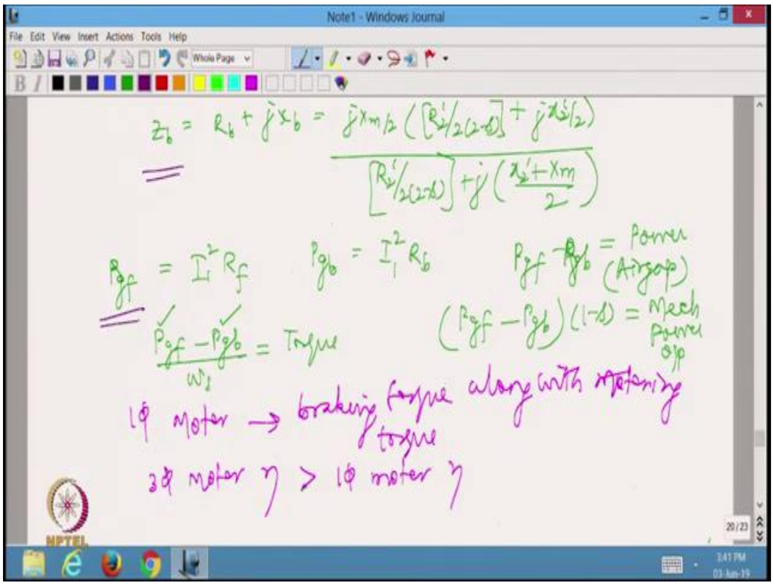
$W_0 - I_0^2 R_2' - I_0^2 R_1$ = no-load loss

I_0 = 60 to 70% of rated current

$W_0 - I_0^2 R_2' - I_0^2 R_1 = W_n$

$\frac{V_0^2}{R_c} = W_n \Rightarrow R_c = \frac{V_0^2}{W_n}$

$\frac{V_0}{R_c} = I_c \Rightarrow \sqrt{I_0^2 - I_c^2} = I_m \Rightarrow \frac{V_0}{I_m} = X_m$



$$Z_b = R_b + jx_b = \frac{j x_m/2 \left(\left[R_2'/2(2-s) \right] + j x_2'/2 \right)}{\left[R_2'/2(2-s) \right] + j \left(\frac{x_2' + X_m}{2} \right)}$$

$P_{gf} = I_1^2 R_f$ $\quad P_{gb} = I_1^2 R_b$ $\quad P_{gf} - P_{gb}$ = Power (Airgap)

$\frac{P_{gf} - P_{gb}}{\omega_s}$ = Torque $\quad (P_{gf} - P_{gb})(1 - s)$ = Mech power o/p

1φ motor → braking torque along with motoring torque

3φ motor η > 1φ motor η

This R_1 and R_2 will be actually determined only from the short circuit test or block rotor test. I will come back to the other calculation shortly. So in block rotor test the speed will be 0. I need not connect, do not connect the auxiliary circuit at all or do not connect the auxiliary winding circuit, then automatically if I open the switch whatever I had shown, if the switch is open I am going to essentially not allow the machine to start. So in this particular case also we are going to have essentially the circuit similar.

I am going to have the variac here. This is the single phase 230 volts, 50 hertz supply. I am going to have an ammeter, I am going to have a wattmeter and I am going to connect it to the main winding. Of course my rotor is here sitting idle. It is not going to rotate. Now this is the current coil, this is the pressure coil and I am going to measure the voltage here. So what I get here is W_{sc}, V_{sc} and I_{sc}.

Under this condition, block rotor condition because $\omega_m = 0$, $s = 1$ which is essentially $\frac{\omega_s - \omega_m}{\omega_s} = 1$. So $2 - s = 1$. Both of them are 1. So you can see that the two equivalent circuits can completely be merged $\frac{R_2}{2(2-s)} = \frac{R_2}{2s}$. So I can simply draw this as a single equivalent circuit, like what we do in the case of a three-phase induction motor.

So I should be able to say that whatever I get as $W_{sc} = V_{sc} I_{sc} \cos\phi_{sc}$. So from which I should be able to say what this $\cos\phi_{sc}$. Once $\cos\phi_{sc}$ is determined $\frac{V_{sc}}{I_{sc}} = Z_{sc}$. So $Z_{sc}\cos\phi_{sc} = R_1 + R_2^l$. Similarly, $Z_{sc}\sin\phi_{sc} = X_1 + X_2^l$. I can assume almost both of them are equal to each other so I can say $\frac{Z_{sc}\cos\phi_{sc}}{2} = R_1$. $\frac{Z_{sc}\cos\phi_{sc}}{2} = R_2^l$. So I should be able to get the values directly.

Once I get the values of R_1, R_2^l, X_1, X_2^l. I should be able to actually get what is the no load loss from this expression. So I can say $W_0 - I_0^2 R_2^l - I_0^2 R_1 = W_n$. Once I get the no load power P_n I can do rest of the things directly. Like I have V_0 so I can say $\frac{V_0^2}{R_c} = W_n$.

So I can get what is R_c. $R_c = \frac{V_0^2}{W_n}$. So R_c once we get it is a piece of cake to get X_m because I can say $\frac{V_0}{R_c} = I_c$ from which I can say $\sqrt{I_0^2 - I_c^2} = I_m$ and $\frac{V_0}{I_m} = X_m$.

So I have got everything, I have got X_m, I have got R_c and I have got R_1, R_2^l, X_1, X_2^l. All of them have been inferred using block rotor test and no load test. Once I have these things we should be able to calculate all the performance parameters using all these expressions without any difficulty.

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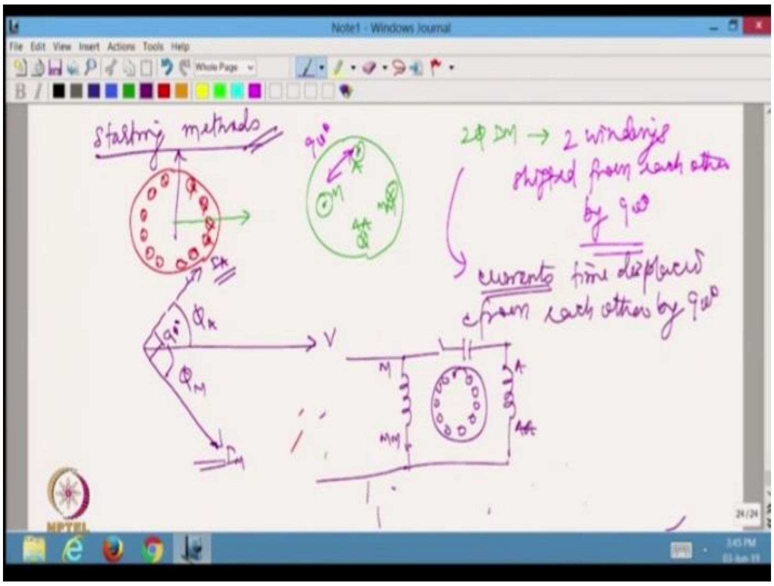

Now the last but not the least, we look at some of the starting methods of single phase induction motors. Although the load on the single phase induction motors will be small and the machine is also really miniaturized. We need to have some starting methods so that it starts on its own. So normally if you look at the auxiliary winding if I say that my main winding is going to have the axis like this. This is all dot and this is all cross. So I am going to have the main winding axis something like this the flux.

Auxiliary windings axis will be always at 90 degrees to that. So I should essentially show if I show it as a concentrated winding. If I am showing main winding like this. I should show the auxiliary winding as though this is like this. So this is M MM this is A AA. This is how it will be. They will be at 90 degrees, but what I want is I want to make this particular machine function like a two phase induction motor.

Two phase induction motor will normally have two windings. In three-phase induction motor there will be three different windings which are phase shifted from each other by 120 degrees. Here there will be two windings shifted from each other by 90 degrees. That is what we have done precisely here. These 2 are shifted from each other by 90 degrees, but we should also have the currents time displace from each other by 90 degrees. So we will normally have to provide maybe a capacitor which will actually if I say that if this is going to be my voltage of the induction motor.

If I am going to have this as the main winding current which is lagging behind by certain angle let us say ϕ_m, I would like the auxiliary winding current to exactly be at 90 degrees if it is possible. So this should be some I_a. If I am able to do this, then these two are actually displaced from each other by 90 degrees their fluxes will also be displaced from each other by 90 degrees. It will actually result in a revolving magnetic field. So I had to have this as ϕ_a. If I want this current to be leading maybe, I should put a capacitor but the capacitor cannot put inside the slots.

That is the reason why we normally what we do is if this is M and MM like this, I am going to have a capacitor externally connected along with auxiliary winding coming here. Now, I am going to have the cage rotor sitting here. This is the overall structure of the single phase induction motor along with starting arrangement. So the starting method, the major concept of the starting method is to displace the current in the auxiliary winding by certain angle as compared to the main winding current.

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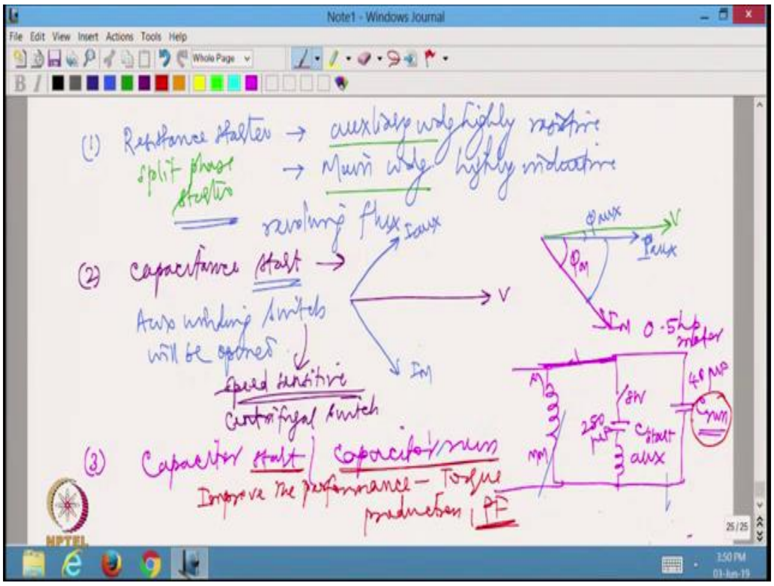

So I have different methods. The first method I would say is resistance starter. So in this case basically auxiliary winding is going to be highly resistive, whereas main winding is going to be highly inductive. This is generally called as split phase starter because you are essentially trying to split the phase angle between auxiliary winding and main binding, so I am going to have if this is the voltage, main winding current is going to be lagging quite a bit.

So this is ϕ_m, whereas I am going to have ϕ_{aux} lagging behind very slightly. So this is going to be I_{aux}, this is going to be I_M and I am going to have the ϕ_{aux} to be really small. So still there is a good amount of phase angle between these two which will actually create some amount of revolution as far as the flux is concerned. So starting will be possible. Although it is not exactly 90 degrees still there are 2 phase shifted winding and time shifted current. So it will be able to create some revolving flux. This is one of the methods.

Then the second method is generally going to have capacitance start motor which is very commonly used in our ceiling fans which I have already explained so I am going to have the voltage along this and I am going to have probably the main winding current here whereas auxiliary winding current I would like to arrange it in such a way that I get the capacitance like this.

So in capacitance start, only during starting the capacitance will be used, after that auxiliary winding will be opened or auxiliary winding switch will be opened which means this switch will be some speed sensitive switch. The moment the speed reaches maybe 80 percent or 60 percent of the normal speed we are going to essentially make sure that that is opened. So centrifugal force is something will open it. So we will call this as a centrifugal switch. So this is very commonly used in many of the configurations.

The third one normally maybe capacitor start, capacitor run motor. So in which case here if I am going to have actually this as the main winding and I am going to have through the switch auxiliary winding I should show the switch here, rather I should show the switch here along with the capacitor and auxiliary winding. So this is the auxiliary winding, this is the capacitor which is the starting capacitor and this is going to be the switch.

Apart from this I am also going to have a running capacitor. So the running capacitor maybe something like 30, 40 micro farads if it is a 0.5 HP motor. Whereas, I am going to have quite a large value maybe 250, 300 micro farad for starting. So starting capacitor value will be larger, running capacitor value will be smaller, but having the running capacitor will enhance the torque that is coming up in this particular motor.

So this will improve the performance in terms of both torque production and the power factor as well. So that way this will be really good. Sometimes we may have only capacitor run motor. That is only one capacitor will be used in series with the auxiliary winding to make sure that it is going to be there in the circuit during running as well as starting. That may not give such a high starting torque like what capacitor start motor gives, but still it is manageable.

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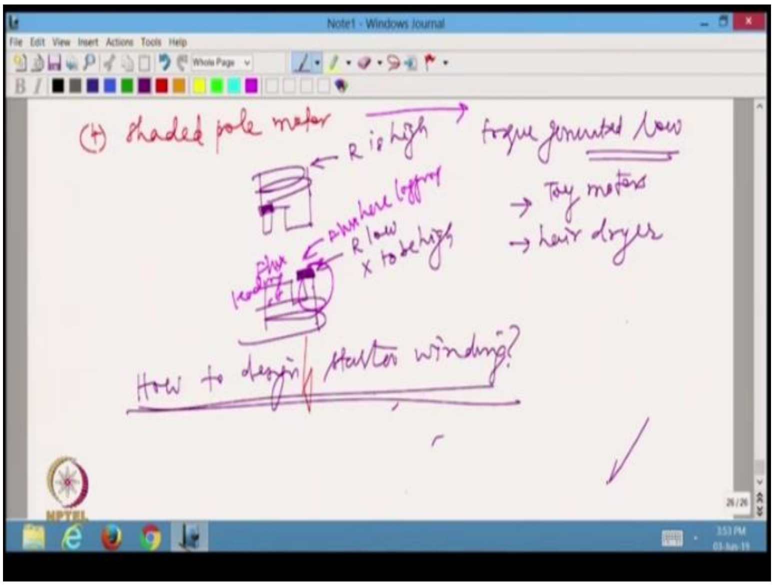

The fourth one which is a shaded pole motor. In shaded pole motor what happens is if this is one of the poles I am going to have a small protrusion in this pole. Similarly, I am going to have a small protrusion in this pole. This is the main winding. This is also the same main winding. Now, what is going to happen is this protrusion will have a small shading ring, which is very thick. It can be a copper ring. So this will have R to be low, X to be high, whereas this is going to have R is actually also high, but X is not too high.

They are comparable because of which it will look as though the flux here, because the current will be more lagging, the induced current will be lagging, flux will be lagging so this flux this flux is going to be leading as compared to the flux here. The flux here is lagging, whereas the flux is leading here. So it will look as though you are going to create a phase shift between these two. So it is like creating a revolving magnetic field but here the torque generated will be really low.

So typically in a hair dryer where the torque generated need not be very high, in those cases, or let us say there are toys where there may be a small fountain which is pushing the water up or down in those cases you may require these kinds of motors. So toy motors or we may use this normally in hair dryer in those cases, we may be using this kind of shaded pole configuration. So I am not really getting into the details of how to design the starter winding. I am not really getting into this because that will be very much beyond the purview of this course.

So, if anybody is interested, they should refer to any special book called single phase motor. So on the whole what we had done in this particular lecture was to go through an overview of single phase induction motor. So we actually looked at, we started off with basic principle of operation of the single phase induction motor after starting with the constructional features.

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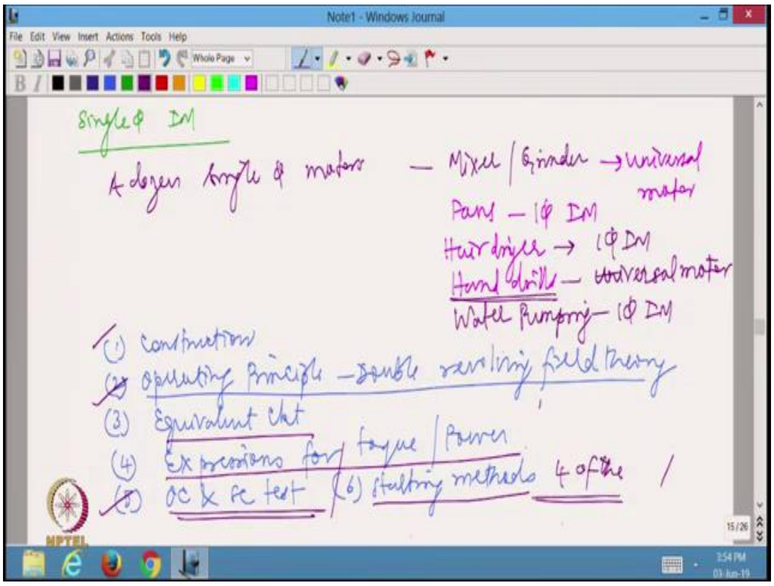

Single ϕ IM

A dozen single ϕ motors — Mixer / Grinder → universal motor

Fans — 1ϕ IM

Hair dryer → 1ϕ IM

Hand drill — universal motor

Water Pumping — 1ϕ IM

(1) Construction

(2) Operating Principle — double revolving field theory

(3) Equivalent ckt

(4) Expressions for torque / Power

(5) OC & SC test (6) starting methods 4 of the

Then we looked at the operating principle based on double field revolving magnetic field theory, then we looked at the equivalent circuit and how to really determine the equivalent circuit parameters. We looked at open circuit and short circuit test. We also got the expression for the torque and power and finally we looked at 4 of the starting methods. So that is all I have to say about the single phase induction motor and thank you very much for your attention.