Electrical Machines
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Module 2
Lecture 3
Magnetic Circuit -III

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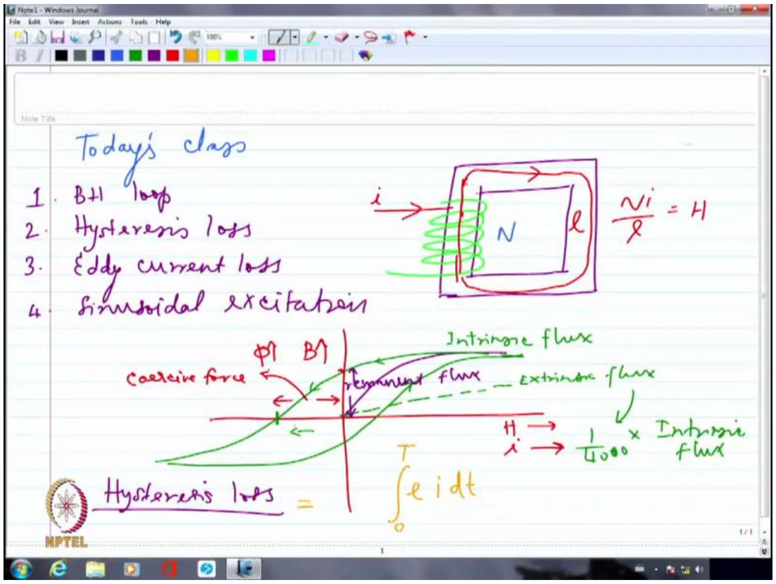

Today's class

1. BH loop
2. Hysteresis loss
3. Eddy current loss
4. Sinusoidal excitation

$\frac{Ni}{l} = H$

Hysteresis loss $= \int_0^T e\,i\,dt$

We were looking at the BH loop in a ferromagnetic material, we said that when we are exciting it several times with an alternating current repeatedly, it is not going to come down to zero flux density very easily, it will retain some amount of magnetism whether you like it or not because of the inherently available domains that are there in any ferromagnetic material. So what we were looking at is something like this, maybe, we took a core like this, please imagine the three-dimensional core although I am showing it as though it is planar. It is definitely not planar.

We are going to have the windings around it somewhat like this and we are actually looking at a current I flowing through this with the number of turns being *N*. And this is essentially going to cause some amount of magnetic field intensity. So this is going to cause whatever is the length of the magnetic circuit that we are talking about, that is let us say this is the magnetic field line that we are associating with this particular magnetic circuit average length.

So let us say this length is *L*, so we are going to say that $\frac{Ni}{l} = H$. Now what we were plotting was that with respect to this *H* or with respect to the current, we were plotting what is the flux or flux density. That is what we actually called as the magnetization characteristics. So what we were having was something like this, this is the plot which is having H in its x-axis and B in its y-axis, I may say this is ϕ in the y-axis, whereas in the other case it may be *I*.

So I am trying to plot this, when I plot it like that, I am essentially looking at maybe if it had been a new sample of iron, it would have followed a plot like this, but from here when I am trying to reduce actually the current, it will follow a plot like this and it will and then it will go back. So we call this as the BH loop, if you may recall we actually said that the ferromagnetic material has domains already which are probably pointing or the magnetic moments are pointing in different directions.

So when you actually take a new sample of iron, the net magnetic moment is going to be 0 because all of them are arbitrarily pointing in all different directions. Whereas, when actually we are trying to you know subject it to an external magnetic field by passing the current, that is going to do some work on these domains and physically they are going to be aligned along with the external magnetic field. So if I try to plot the external magnetic field, I should probably show it with you know some kind of straight line like this.

I hope you understand, we are talking about this as extrinsic flux, whereas this is intrinsic flux. So extrinsic flux is essentially due to the air which is surrounding it and which is creating a very small amount of magnetism. This will be almost $1/4000$ whatever the intrinsic flux is. So the way I have drawn it looks as though that is also you know taken into consideration but definitely the extrinsic flux is going to be really small, that is the reason why when the saturation occurs, any little increase in the extrinsic flux is not noticeable at all.

It may still be increasing but because it is $1/4000$, it is not going to be noticeable. So on the whole, it looks as though the overall flux has reached saturation. Now when I am actually having you know some of the domains aligning further and further, it is traversing this portion of the curve. So at that point in time, whatever is the current that I am applying to this wire which is wound around the magnetic you know the ferromagnetic core. That current multiplied by whatever is the voltage that I am applying, that is the instantaneous power I am inputting to the circuit.

That is essentially aligning the core and hence does some work on these domains. So it is doing some work on the domains because of which forcefully, the domains are aligned in one way or the other. After that, when I am trying to actually reduce the current. The intensity of the current or the total power the time inputting decreases, but already aligned domains are not going to budge from their positions because if they have to budge, they have to do some work.

And intrinsically, any system is not going to be doing any work if you leave it to itself. Many of the domains remain in their position which are aligned in a particular way, they are not going to budge.

But when I try to increase the current in this direction further, this current is going to do some work on these domains because of which they are realigned in the opposite direction. So at this point if you look at it, some of the domains which are more obstinate, they are probably going to stay in the original direction. But some of the domains which have been coerced to some extent, they would probably realign along the reverse direction. So the net value of magnetic field becomes zero at this point.

The current is a non-zero value because this current has made some of the domains to align in the opposite sense but already whichever domains have been aligned in the forward sense or the previous sense, both of them essentially cancel out with each other, so the net magnetic field or flux available becomes zero at this point. So this particular quantity is known as coercivity or coercive force which is actually trying to coerce many of the domains to align into the opposite sense.

So we call this as the coercive force basically. And if you actually look at this point where I am having zero current but certain value of flux density left over from the previous alignment that is remaining, that flux is remaining. So we call this as the remnant flux. This is essentially remanent flux. So this is remanent flux whereas that other one is the coercive force, and every time when I align and realign these domains, I am doing some work physically or the current and voltage are doing some work physically on these domains which is actually manifested in the form of some amount of energy that is lost because this energy is just useless.

It is just doing basically aligning and realigning of these magnetic domains. So it is manifested in the form of a loss, energy loss which is known as the hysteresis loss. So hysteresis loss is actually due to the fact that we are having a ferromagnetic material in the form of a core and it has certain domains which are obstinate and we are spending enough amount of energy in aligning and realigning them over every cycle. So that is really not going towards any productive or useful work but it is establishing the magnetism in one direction and the reverse repeatedly.

That is all it is doing. So this is unavoidable as long as we use a ferromagnetic material because it has its inherent property of flux lagging behind the current. So this hysteresis property gives rise to a loss called hysteresis loss. If I try to calculate really what the hysteresis loss is, I should say it should be equal to $\int_0^T (ei)\,dt$ if I calculate this loss over one cycle. This is going to be the energy loss.

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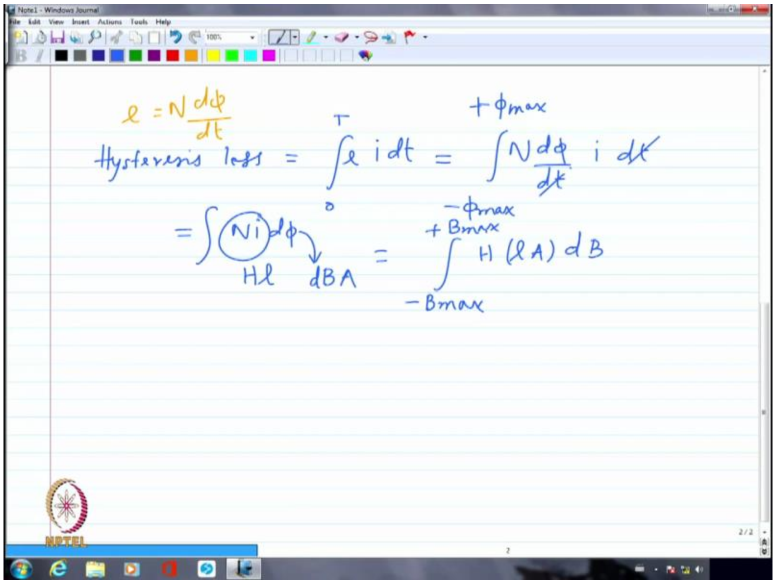

$e = N\frac{d\phi}{dt}$

Hysteresis loss $= \int_0^T e\, i\, dt = \int_{-\phi_{max}}^{+\phi_{max}} N\frac{d\phi}{\cancel{dt}}\, i\, \cancel{dt}$

$= \int \underset{Hl}{\boxed{Ni}}\, \underset{dBA}{d\phi} = \int_{-B_{max}}^{+B_{max}} H\,(lA)\,dB$

But we can also say in this particular case that $e = N\dfrac{d\phi}{dt}$ where N is the total number of turns. So I can say hysteresis loss is equal to $\int_0^T (ei)\,dt$. The same thing can be written as $N\dfrac{d\phi}{dt}(i\,dt)$. So, I can simply write this as $\int_{-\phi_{\max}}^{+\phi_{\max}} Ni\,d\phi$, if I may write it for the entire flux, if I plot ϕ versus I, rather than plotting B versus H.

So if I write like this, then I can simply write this as $Ni\,d\phi$, so I can replace this *NI* by *Hl*. Similarly I can write phi as B multiplied by A. So I can write AdB, so I am essentially going to replace this by $HlAdB$, which means I can integrate it from $-B_{\max}$ to $+B_{\max}$.

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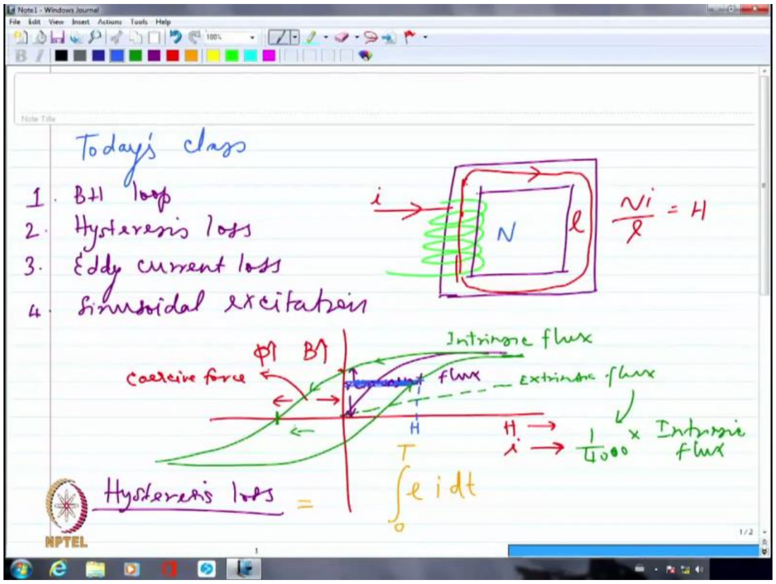

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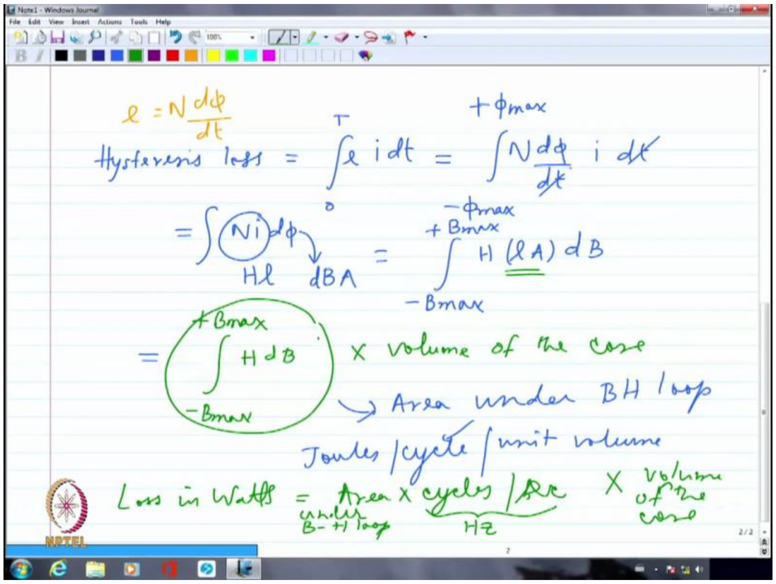
Hysteresis loss = $\int_0^T e\,i\,dt$



$$e = N\frac{d\phi}{dt}$$

$$\text{Hysteresis loss} = \int_0^T e\, i\, dt = \int_{-\phi_{max}}^{+\phi_{max}} N\frac{d\phi}{\cancel{dt}}\, i\, \cancel{dt}$$

$$= \int \underset{Hl}{\boxed{Ni}}\, \underset{dBA}{d\phi} = \int_{-B_{max}}^{+B_{max}} H\, \underline{\underline{(lA)}}\, dB$$

$$= \boxed{\int_{-B_{max}}^{+B_{max}} H\, dB} \times \text{volume of the core}$$

→ Area under BH loop

Joules / cycle / unit volume

$$\text{Loss in Watts} = \underset{\text{under B-H loop}}{\text{Area}} \times \underbrace{\text{cycles / sec}}_{\text{Hz}} \times \text{volume of the core}$$

If I go back to the curve earlier what I have. If I take a particular value of H, probably I can just take some particular value of H, I can look at what is dB here. So $\int H\,dB$ gives me whatever is the area that is covered by this particular curve. Because this is the B axis. So if I traverse the entire loop and I try to look at what is the overall $-B_{\max}$ to $+B_{\max}$, it will give me the complete area under this particular loop.

So if I go back to what I was writing earlier, I can say that this will be equal to I can start from $-B_{\max}$ to $+B_{\max}$, A multiplied by *l*, which is volume of the core because I am looking at the overall length of the magnetic circuit which is actually the complete circumference of the core, average circumference of the core and *A* is the cross-sectional area through which the flux is flowing. So that is assuming that it is uniform cross-section, $A \times l$ will give me volume of the core.

So I can simply say, it is $H\,dB \times \text{Volume of the core}$. So this $\int H\,dB$ whatever we have written here, that is the area under BH loop. This is the area under the BH loop. So I can say that the hysteresis loss what I get will be given by the area under BH loop but the quantity what I get as the area under the BH loop, I have to definitely make sure that the flux density is plotted in Tesla and similarly whatever H, I am plotting, that will be A/m.

So, area in the BH loop will give me Joules per cycle because for one cycle, it will traverse one BH loop. So if I go through the cycle again, it is going to again lose so much of energy which is covered under the area of the BH loop. So it is loss in Joules per cycle per unit volume.

So if I really want the losses, for example in watts, so if I want the loss in watts, then I have to multiply this area by cycles per second. So I have got here is hertz. So this is cycles per second, I have to multiply this by volume of the core. So if I want the overall you know the total amount of loss in watts in a ferromagnetic core, I have to multiply that by whatever is the frequency with which I am exciting the coil and I also have to multiply that by the volume in m^3, that is the reason why hysteresis losses would increase as the frequency is increased further and further.

So this is area under the BH loop, this is area under BH loop. So whatever I get as the area under BH loop, I have to multiply that by the frequency with which I am exciting the coil and also I have to multiply that by the volume of the core. Then I would get the hysteresis loss in watts. So if I am talking about 400 Hz or 600 Hz which is being generated in a particular system, I am definitely going to have more and more hysteresis loss.

That is the reason why very high frequency transformers which are used in some of your switched mode power supplies and so on, they will not use a ferromagnetic core. Rather than that, they might use some cores which are rather viable for high-frequency operations. For example, if I have a lot of iron filings, you know what is filing. If I have a lot of powdered iron, I just you know deposit into another non-magnetic hollow you know core, then all of them would have lost their domains already because you have powdered them.

So they would not really have the hysteresis property much. So invariably, when we use some high-frequency transformer, the core will be made up of some amorphous iron or powdered iron material. Then you would essentially lose out on the hysteresis property because of which, there will be not any hysteresis loss. So we cannot use a normal ferromagnetic core for these kinds of transformers which are working at kilo hertz frequency.

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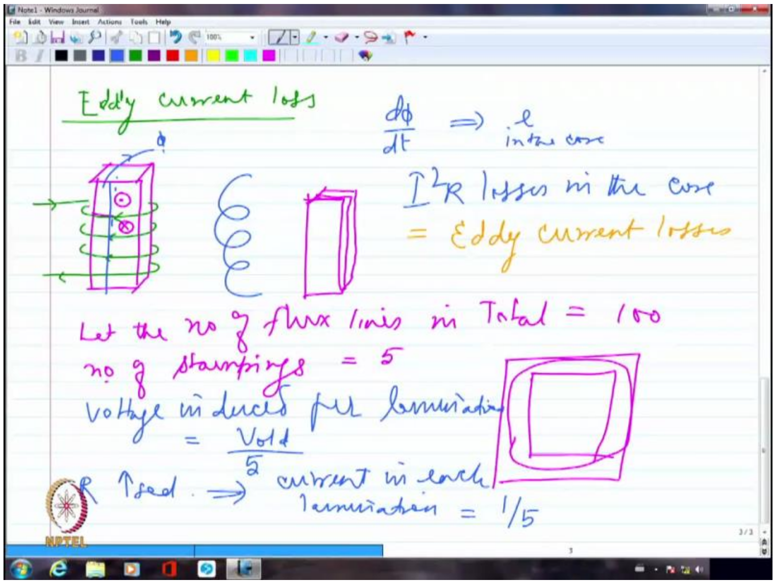

Eddy current loss

$\frac{d\phi}{dt} \Rightarrow e$ in the core

I^2R losses in the core

= Eddy current losses

Let the no of flux lines in Total = 100

no of stampings = 5

Voltage induced per lamination

$= \frac{V_{old}}{5}$

R ↑ sed. ⇒ current in each lamination = 1/5

There is one more property which probably we will need to look at when we use a ferromagnetic core which is actually known as Eddy current loss. So let us try to take a look at again the ferromagnetic core. So let us say this is basically what I am talking about as a three-dimensional core I am showing it as a solid limb of a transformer core. So if I am having this as my core and I am going to wind some wire like this.

So I am just showing it as though it is wound like this and I am going to take out the wire here and one more let me show it as though is going like this. So I am essentially having a wire like this. So let us say the current is going in here, so it will go like this and come out like this. So I am going to have definitely the flux line perpendicular to this.

Now the iron of the ferromagnetic material which is used to make the core, that is also not a non-conductor that is definitely a conductor. So when we say that we have probably another winding wound on another side, maybe I have another core or another limb of the core, I am going to have some induced EMF and if I connect a load, it will have an induced current, that is what transformer action is.

But the core which is a conductor, that is also not going to keep quiet, that will also definitely have an induced EMF. So I will have an induced EMF in the ferromagnetic core as well because of the rate of change of flux it is being subjected to. So if I have let us say $\frac{d\phi}{dt}$ as the rate of change of flux, I am going to have definitely that much of induced EMF even in the core. And core is not having really a very high resistance. Let us say it is made up of a metal and it is a solid metal, so the currents can go in all sorts of directions there.

Because the resistance is a small it will just have all sorts of different directions of current flowing all over the core which is called as the Eddy current. So if I have essentially a solid core which is wound with a piece of coil and then you are passing an alternating current through that, you are going to have currents induced in the core itself which is generally known as the Eddy current. And that Eddy current is going to cause a huge amount of I square R losses in the core.

So this is known as the Eddy current loss. This is unavoidable whenever I have a core which is made up of a metal, which is going to have lower resistance basically and which is going to be thick, so obviously it is going to offer very less resistance, I want to minimize this loss. To minimize this, what I can do is rather than making this core just out of a solid piece of iron, I can just have a rectangular piece like this.

Behind that, I can again stick one more rectangular piece, behind that, I can stick one more rectangular piece. I am essentially looking at very thin rectangular sheets, each of them stuck to another rectangular sheet behind that, all of them will have the same dimension, only thing what I will ensure is between the first sheet and the second sheet, I put an insulator layer. So I may just apply some varnish, then I will apply some resin, then I will stick these two together.

So the varnish will ensure that the two layers of these thin rectangles are insulated from each other. So if I actually look at the induction of EMF here, because the plane of actually the flux line is along the plane of this paper or the surface, so the current would be perpendicular to that. So it will be going into the paper or it will be coming out of the paper. That is how it is going to be. So I will have the current actually, you know I can specify this as a dot or I can specify that as a cross depending upon whether it is in the positive half cycle or negative half cycle or increasing flux or decreasing flux, that is how it is going to be.

See, the flux line what I have shown in blue, that is along the plane of this paper or this screen itself and the current will always be perpendicular to that. The two will be at right angles to each other stuff so I should say that the plane of the current flow if I may call it, it will be at perpendicular it will be perpendicular to the plane of the flux lines. The plane of the flux line is parallel to the plane of this paper, so it will be perpendicular to that.

So if I can interrupt the flow of current you know I have to probably interrupt it which cannot flow directly as a thoroughfare into the paper. So what I am going to do is, I have put one behind the other, the current cannot flow into this because I have put varnish. So obviously, the current will be kind of interrupted and it will be forced to confine itself to only one particular stamping, I may call this as lamination or stamping. So it has to confine itself to only one stamping.

There is no other way that is how it will be. So because of which, I am going to reduce the amount of current. So what is happening is if I say that there are 100 flux lines overall, I am just arbitrarily taking a number. So let the number of flux lines in total be on 100, let us say, I have number of stamping or laminations to be 5. So per stamping, I will have only 20 flux lines, so when I look at $\frac{d\phi}{dt}$ obviously for every stamping, I am going to have reduced amount of voltage induced.

See, you want to have the flux lines intact, so if the flux lines have to be intact, if I say that the overall core is somewhat like this, I want maybe these 20 flux lines which are flowing, they will all flow through this like this. I want to have the flux lines intact I do not want to interrupt them. Whereas, I want to interrupt fundamentally only the current. So that is the reason why we are essentially dividing the number of flux lines confining to every lamination, that will be one Nth of the total number of flux lines if I have N such laminations.

So obviously, the voltage induced in each of the lamination will be one fifth of the overall voltage induced it would have been induced if there had not been laminated core, if it had been a solid core. So I am going to have the voltage induced per lamination will be equal to whatever is the voltage induced divided by phi but overall, I have increased the resistance because I have not given a thoroughfare for the current.

So I have essentially made sure that the current is somewhat interrupted. So I am going to have resistance increased overall because of which I am going to have the current in each lamination will be decreased by a factor of first of all 1 by 5 and also by a factor of how much the resistance has increased. So I am going to have definitely the overall current decreased. If the overall current has decreased to at least one fifth or even more, I am definitely going to have I square R losses also decreased without interrupting the flow of flux lines.

The flux lines are still flowing through every lamination without any problem. So basically, we are looking at reducing, not completely eliminating, reducing the Eddy current losses by making the core made up of several stampings or laminations which are separated from each other with the help of some kind of insulator like varnish. So invariably, you would see that all our 50 hertz Transformers what we use in the laboratory or use in the substations, distributions, power transformer, all of them will have laminated cores.

They will not have solid cores at all. Similarly, any high-frequency application you will see amorphous core. It will hardly ever be iron core. It will not be an iron core.

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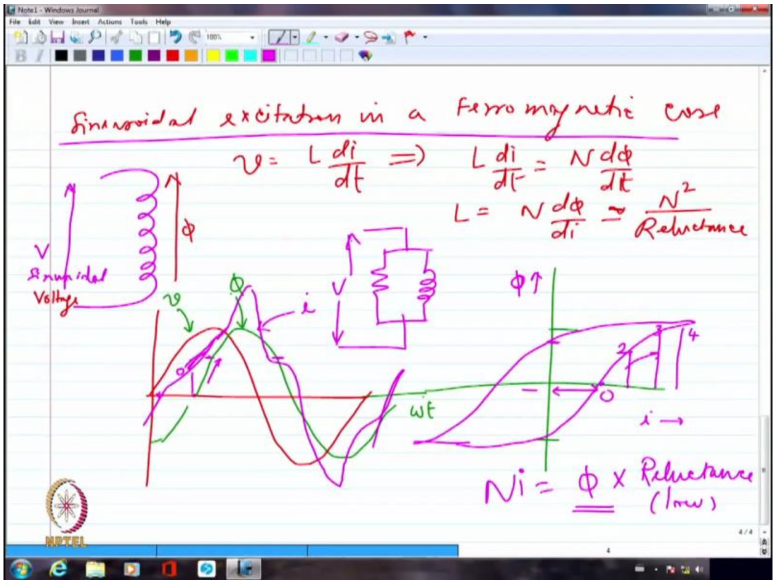

Sinusoidal excitation in a Ferromagnetic core

$$v = L\frac{di}{dt} \Rightarrow L\frac{di}{dt} = N\frac{d\phi}{dt}$$

$$L = N\frac{d\phi}{di} \simeq \frac{N^2}{\text{Reluctance}}$$

$$Ni = \underline{\underline{\phi}} \times \underset{(\text{low})}{\text{Reluctance}}$$

The last discussion in magnetic circuit further to some extent I am infringing into transformer because these things we could have discussed in transformer but I thought let me do it along with magnetic circuits. So the last discussion that we are going to have is sinusoidal excitation in a ferromagnetic core. So I am looking at basically a ferromagnetic core around which I have wound a coil and I am essentially looking at exciting that with a sinusoidal voltage.

Invariably in any power apparatus, you would see normally sinusoidal waveform being given. Sinusoidal waveform is one of the most beautiful waveforms and naturally existing waveform which hardly has abrupt rise or abrupt fall, you differentiate it, integrate it, summation, subtraction, multiplication, anything ultimately yields only sinusoid. So this is one of the major advantages of probably the sinusoidal waveform.

So normally the voltages generated in any power station will be sinusoidal you know wave shape. Now let us say I have a core and I am just showing that with a coil, I am showing it as an air core, it is not an air core. Imagine that there is a core inside. And I am essentially applying some voltage here. And this is a sinusoid, sinusoidal voltage, this is going to be a sinusoidal voltage.

Now definitely there will be a flux that will be set up, there will be a flux setup in one direction or the other and that is definitely going to cause a rate of change of flux because I am having an alternating voltage, the current will be an alternating current, the flux will be an alternating flux and I will have an induced EMF. So when I have an induced EMF, this induced EMF should be balancing whatever is the applied voltage normally. If I neglect the resistance. So I am going to have essentially $v = L\frac{di}{dt}$ if I may call the inductance of this coil as L, we already wrote the inductance has an expression because we wrote basically $L\frac{di}{dt} = N\frac{d\phi}{dt}$ from which we said $L = N\frac{d\phi}{di}$.

If you manipulate it, you will get this to be N square by reluctance, please manipulate this and find out whether you are getting this expression, N square by reluctance will be the inductance. So if the reluctance is changing because the permeability is changing due to saturation, the inductance will not be a constant any more, this we already discussed. So we are not going to have this as a constant, fine. So this is the inductance so I can say that the voltage applied will be balanced by whatever is the induced EMF in the coil inductance, $L\frac{di}{dt}$. So if I say that I am having probably my voltage somewhat like this. So I should be able to say because this $v = L\frac{di}{dt} = N\frac{d\phi}{dt}$, I should be having the flux which will be corresponding to 90° lagging, clearly because current will be 90° lagging in the case of an inductance.

So definitely the flux will also be 90° lagging. So if I say for example the flux $\phi = \phi_m \sin\omega t$, I will have the voltage to be $\cos\omega t$. So it will be voltage will be leading the flux that is all we are trying to say. So I should draw the flux somewhat like this, let me probably draw it with a little different color, so I should have a sinusoid they need not be of same magnitude I have just drawn it like that, they need not be because the two are in different quantities, one is Wb, the other one is in terms of volts.

So this is how the flux would be. So I can say this is flux whereas this is the voltage and I am drawing this with respect to time or ωt. I want to know how the current is going to be. So if I want to look at the current waveform, how it is going to be when I have a ferromagnetic core, what I am going to do is to draw the BH loop corresponding to, so this is my $B_{\max}$ and I am going to have my hysteresis loop confining itself to $+B_{\max}$ and $-B_{\max}$ in this case.

So I should draw it as though, let me draw it like this, something like this. This is how it is going to be. So this is actually I can call that as flux and this is current for example. This is how it is going to be. I am looking at now increasing flux from this point, this is zero flux, correspondingly this is zero flux, this is the increasing direction of flux. Similarly, this is the increasing direction of flux as far as the sinusoidal wave shape is concerned.

Now let me call this point as let us say O, so corresponding to this, I can say the current value is probably some I_1 amperes. So at 0 flux itself, I am having some current of I_1 ampere here. So this is corresponding to point O. The next point if I consider, this is probably point 2 or point 1 let us say. So this flux corresponds to correspondingly I can say the flux is somewhere here, this is what is the flux but corresponding to that the current has increased slightly, so maybe I will have a curve like this.

So, I should say, as I travel along point 3, point 4 and so on, I may be able to draw the curve somewhat like this, but as I reach the saturation point. The increase in flux is not much but the increase in current will be more, I hope you understand at this point, the increase in flux is not much but the increase in current is quite a bit. So I will have a peaking of current around this point when almost I am going to have flat value of flux because here the maxima of the sinusoid, I do not have much of rate of change of the flux.

The flux is almost a constant but the current is increasing quite a bit because already, the ferromagnetic core has hit its saturation region. So I am going to have probably the current almost reaching the peak and after that it will probably drastically decrease also because if I look at this portion, the flux is still actually fairly constant, but I am trying to reduce the flux, but the current will actually decrease quite a bit of without making a dent on the flux.

So but if I try to look at this point for example, there is already a flux density value existing almost corresponding to this value, but by then the current has become 0. So you would see that the current abruptly falls or very quickly falls to 0 from its peak value and then I may increase the current actually in this direction. The current is actually increasing quite a bit without making much of change in the flux. So you may have a wave shape somewhat like this as far as the current is concerned because there is hysteresis property.

The hysteresis property ensures that wherever I have the saturation playing a role, the current is varying very fast without flux varying much, and wherever I am going to have the increase or decrease in the flux taking place, those are the linear regions, I am going to see that probably the current is not making so much of change as much as what I saw earlier during the saturation. So if I look at the current, the current will not be sinusoidal any more.

The flux is sinusoidal all right but the current is definitely not sinusoidal because the hysteresis loop or the BH loop introduces a nonlinearity in the relationship between the current and the flux. And that is going to cause the current waveform deviating from the normal sinusoid. So I am going to have this as the flux waveform whereas this is going to be the current waveform, the current is definitely not sinusoidal.

But most of the times, when we actually look at the transformer functioning, for example initially when the flux is established, the current drawn by the transformer is known as the magnetizing current. It is magnetizing basically the core and it is establishing the flux. That magnetizing current is really small because of the permeability of the iron being so high. We said already that *Ni* equal to flux multiplied by reluctance, reluctance is really low for an iron core.

So to establish a finite amount of flux, I will require only less amount of current assuming that the number of turns is fairly large. So I am not going to require a large current in my transformer. So the magnetizing current drawn by a transformer will be miniscule compared to what the load would demand later. So we do not see this non-sinusoidal quantity coming to the forefront in the case of a transformer because if I am going to have 100 amperes as the load current, this particular magnetizing current may be 2 amperes or 3 amperes, nothing more than that.

So when the 100 ampere is sinusoid and this 1 or 2 ampere, this cannot make a dent on the overall current shape, that is the only reason why in a transformer, when you look at the loaded transformer, that is when load is connected to the secondary of a transformer, the current looks fairly sinusoidal because the magnetizing current is not able to create any aberration in the waveform of the overall transformer current.

So generally, when we represent a ferromagnetic core, we represent this by two specific parameters in its equivalent circuit, one is the current is actually lagging behind by certain angle because of which, we call this particular ferromagnetic core to be acting like an inductance. So obviously, I have to represent the ferromagnetic core by an inductance. The second thing I would represent this by is a resistance, so we are going to represent the ferromagnetic core by a resistance and inductance in parallel with each other.

The inductance actually represents the fact that the current is lagging behind. I think I made a mistake, I should show it as though at least it is lagging by some quantity. So I should actually erase this portion, and I am showing it as though basically, you know it is lagging behind at least by certain angle. Clearly even here, it should probably go through this. So it is essentially going to go somewhat like this, sorry, I did not mean to do that but this is the way it will be.

The waveform will be somewhat like this. So I am going to have essentially the waveform will be lagging behind definitely the voltage waveform and we will have definitely there will be some amount of loss in the form of hysteresis loss and Eddy current losses, so those will be represented by the resistance and the lagging current which is flowing through the entire ferromagnetic core wound coil, that will be represented by an inductance. So I will have both of these in parallel with each other.

One thing I have to mention is, we put them in parallel because both of the quantities that is the flux established as well as the losses due to hysteresis and Eddy current, both of them depend upon the voltage that I am applying. So if the voltage is affecting both these quantities, I should necessarily have them in parallel. If the current is affecting both the quantities, I should have had them in series because the same current would flow through both of them.

Whereas, both of them essentially depend on the amount of flux established. Hysteresis loss clearly depends upon the BH loop. So what is the maximum amount of flux density or flux that has been established, the same way the inductance whatever I am showing, that is showing the amount of flux established. So both of them depend heavily upon the flux established, and the flux established is directly related to the amount of voltage.

So that is the reason why we are essentially representing both of them in parallel. So we will assume that the same voltage is being applied to you know both of them, the resistance as well as the inductance. So this is the representation of a ferromagnetic core you know in terms of electrical circuit parameters but this definitely does not represent the non-sinusoidal nature of the current, I hope you understand. The resistance will also draw a sinusoidal current, the inductance will also draw a sinusoidal current.

So we are not still representing the non-sinusoidal nature of the current although we know that the current drawn by the winding which is wound around a ferromagnetic core will be non-sinusoidal in nature. So this is an approximation without considering the non-sinusoidal nature of the current. So if I take a ferromagnetic core and I want to establish a particular amount of flux, the reluctance is very low.

Because the reluctance is low, I am going to require only a smaller amount of you know the ampere turns. The MMF required will be very small because the reluctance is low. So compared to that, generally the transformer will be designed for supplying a very large amount of load. So the overall load current will be you know if I say that is 100 percent, I am going to say that the magnetizing current will be only about 2 percent or 3 percent, nothing more than that. That is how it is going to be.