Electrical Machines - I
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Lecture - 13
Hysteresis Loss

Welcome to lecture number 13.

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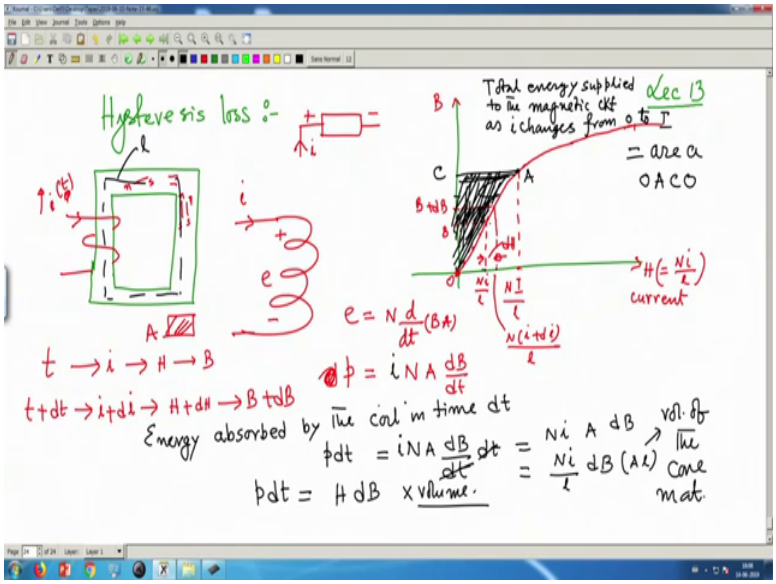

And we started discussing on Hysteresis Loss, why it takes place some physical reasoning only I gave. And now to understand why hysteresis loss takes place we have understood something, then we will try to see on what factors it will depend, as we did in case of eddy current loss. But before that you I have told about the beach characteristics of a magnetic material.

Suppose you have a magnetic circuit like this let it be like this it does not matter [FL] and you have a coil wound over it exciting coil. Here I will pass current i function of time. Now so, far I have drawn the B H characteristics generally it will be like this, this is H which is equal to you know N i by l; l is the mean length of the flux path these we know and this is your B.

Now, this is how I draw and if you increase this current i starting from 0 initially it was not magnetize. So, as I go on increasing the current you will find B is increasing almost

linearly in the initial phase. Then after sometime it becomes saturated that is further increase in H here will not cause any practically any increase in B the regime once again is we can understand the tiny magnets which are north-south etcetera.

As you are increasing H external magnetizing force you are forcing the tiny magnets to be aligned in a particular direction and after all the magnets are aligned south north; south north like that whatever way. Then further increase in H what further to align everybody has become a discipline soldier and they are in line, that is why these saturation zone takes place that way you can think.

Now, suppose I am increasing the value of H, but this we will see that what is the effect of hysteresis? As you go on increasing the current B increases starting from 0 it goes like this here. Before I tell you about that hysteresis loss or hysteresis loop let us try to understand one important thing because I have to after all estimate the hysteresis loss. Suppose this coil this current is increased from 0 value to a particular value here say some value I, this axis can be treated also as current H or current because N l are constant.

Suppose we have increase the value of the current I, as we have increased how much energy I have supplied to the coil that I want to study. Since this current we have increased from 0 to capital I or 0 to some H which is to be multiplied by n. So, N I by l this H value I want to know how much energy I have supplied?

First of all have I supplied any energy to it the answer is yes. See because of the fact this is the coil, I am increasing the current here therefore, flux linking with the coil is changing gradually increasing therefore, it will become a seat of emf, just like transformer plus minus e and it will try to oppose the cause what is the cause, because current was increasing. So, it will its polarity will be such that it this induced voltage is allowed to act it will try to reduce the value of the current that is why you we got plus minus.

Now, in any circuit if an element has a voltage across it of this polarity if current is entering through the positive terminal of that element, then we say it is absorbing energy. As in the case of a charging a battery to the plus terminal of the battery you have to inject current then only battery gets charge.

So, energy will be absorbed and voltage across this coil; so, how much energy is absorbed in the process when I increase the current from 0 ampere to some capital I ampere, that is the goal of the first part ok. What I will do is this as I is increasing during this process I is the function of time you know; so, induced voltage at any instant suppose the current is N i by l and the B value is B.

So, the and then the induced voltage will be N d d t of phi; phi is B into A; A is the cross sectional area, is it N d of d t, this is the voltage. And the polarity I have taken Lenz's law into account do not under the confusion that minus N I have written N d B A dt is positive and polarity I have very correctly put on this diagram. So, this is the induced voltage.

Therefore, instantaneous power absorbed by the coil this I am just writing d p; why p, instantaneous power absorbed by the coil will be N, A is constant d B dt, why A is constant? A is the cross sectional area, B is changing. So, at any instant this is B ok, so N A dB dt. Then energy supplied, so what I am essentially doing is let me write it like this at time t current is i, at time t plus dt which means a particular H, a particular B at time t plus dt suppose some time elapses current has I have increased from i to di.

So, that H has increased from H to dH and B has increased from B to dB and all these changes have taken place over a time interval dt and that dt I can assume to be very small. So, B it has become B plus d B, here it was N i by l this point is N i plus d i by l n so on.

So, this is dH is not this is dH, therefore, this is how things are going. Therefore, in time dt energy supplied I am write in black energy supplied, energy absorbed by the coil in time dt will be simply p into dt and that will be equal to NA dB dt into d t this is the thing.

Student: (Refer Time: 10:33) sir.

Hm?

Student: (Refer Time: 10:36) full (Refer Time: 10:37) I at i.

So, p is this into i correct power is voltage into current. So, here there is current this will be the thing [FL], this dt can be struck off and you will be left with Ni A dB dt it not,

then what I sorry dt is not there dt has already gone Ni A dB and then what you do, you multiply this with this mean length of the magnetic circuit l.

So, multiply and divide, so you will be getting Ni by l dB into A into l this is what you will get, A l becomes the volume of the core material cross sectional area into the average length. So, this is volume of the core material this will be the case. So, energy supplied during this same. So, p d t then becomes equal to H into dB into volume that will be the case, but what is H into dB; H into d B is nothing but this area; this area is this H into dB.

So, as you have increase the current from i to i plus d i or H from H to H plus dH this is dH this one, energy absorbed by the coil has become H into dB. Therefore, what is the total energy supplied then; total energy supplied to whom? Supplied magnetic circuit as you have increase the current as i changes from 0 to some value capital I, that is up to this point will be nothing, but this whole area are you getting this whole area now H d B; H d B this strips you have to add.

So, these area; so, if I write it 0 some A this point let us called C, then as total energy supplied to the magnetic circuit as I changes from 0 to I will be equal to area O A C O this; this; this; this is the area shaded area that much energy you have supply. This we will be utilize to find out more about hysteresis loss in the next one.

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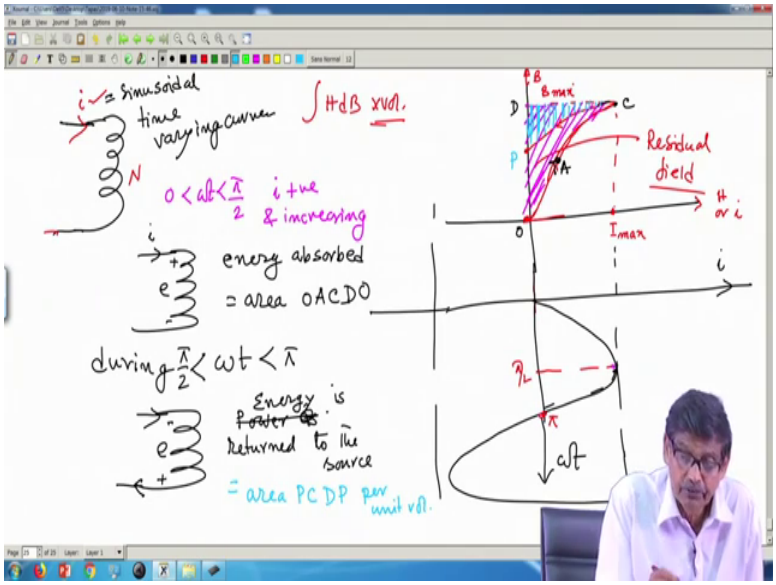

So, what I will do is this, I will simply draw this coil now, but in my mind it is there it is wound on a core material things like that and here I will draw the BH curve. So, what we have seen as I increase the current it will go like this. So, B H curve now the game starts about hysteresis loss suppose I am increasing the current to this value. So, this axis can be treated as H or i, suppose you have increase the current to a level of I max and this axis is your B and suppose it reaches some B max ok. What is this i? This i is here, this is the coil having number of turns N it will be like this.

Now, for the first time when I am doing let us imagine that this current I will make it SC Sinusoidal Current. So, current starts rising, current increases with time suppose I say let me draw that current waveform also in this axis, this is i this is I max and here it will be minus I max. So, suppose current is moving like this and this axis is your omega t, the variation of current against time sinusoidal suppose. So, current increases from 0 it reaches maximum at that time it is B max, after this current decreases with this current I t which is sinusoidal varying sinusoidal current sinusoidal time varying current suppose.

Now, after these the moment current starts decreasing, the beach curve does not trace back the same path through which it went it will be in fact, doing like this now. This is while current was increasing it will go like this, but while tracing back when you are decreasing the current it will follow another path above this that is the molecules will be sluggish after they have reach that you are applying a negative H, then they will follow that instruction they will try to follow, but in a sluggish manner and this is called hysteresis it will lag behind ok.

The way they went up while you are decreasing H it will be sluggish sort of inertia or whatever, it is you call it will go like this. So, this is your pi by 2 and this is pi so, between 0 to pi by 2 it went like this, then from pi by 2 to pi current has become 0, but you will find it has come here and even when H has become 0 it is having some field retained and it is called you know residual field. If somebody stops everything here, it comes here only one pulse of current passes you will find this iron piece will become a sort of permanent magnet retentivity and it will have a residual field like this.

This positive pulse of the current let us talk about ok, when the current increased from 0 to I max how much energy I have supplied to the coil, I know the energy supplied to the coil is the area between this curve and the ordinate H d B integral H d B into volume is

not energy supplied. So, as the current increase from 0 to I max energy you have supplied is nothing, but this area; this whole area the pink shaded during these to this part pi by 2 to pi.

So, during 0 to omega t to pi by 2 i was positive and increasing is not. So, during this zone if you draw the coil this is i; i was increasing and positive the induced voltage must have been like this plus minus this is induced voltage and current is really positive. So, it was absorbing power and what is the amount of power that it has supplied if I call it 0, if I give them name this point suppose some name I give A, this point is C, this point is D and O.

So, I will say energy absorbed during this interval; energy absorbed is the area which area 0AC and D and O back to O this whole area. During this interval what is happening? Omega t pi and this is pi by 2. During this interval i is still positive no doubt, but i is decreasing d i dt is negative therefore, or dB dt is negative therefore, polarity of the induced voltage has reversed here. What this coil is doing now? It is then delivering power to whom to the source, earlier it was absorbing power between 0 to pi by 2 this region di dt positive it was absorbing power from the source now it will keep back power to the source.

So, power is returned during this interval power or energy, energy is returned to the source; energy is returned to the source because polarity has decreased. Now, the question is which area gives me the energy this is now your BH curve you do not have to take these because now when you are decreasing current as I told you because of hysteresis the BH curve will be traced by this path. Therefore, area enclosed by this and this y axis gives you the energy enclosed and this area is this area, this blue sketched area if you call this point as P, energy is returned to the source and must be given by the area PC DP is it, PC DP this area.

Therefore during 0 to pi by 2 we supplied so much area, but while the material was having reduced value of B tracing back here when you are decreasing the current the amount of energy returned is less, this must be understood per unit volume. So, let us go to the next page and let me now draw this once again.

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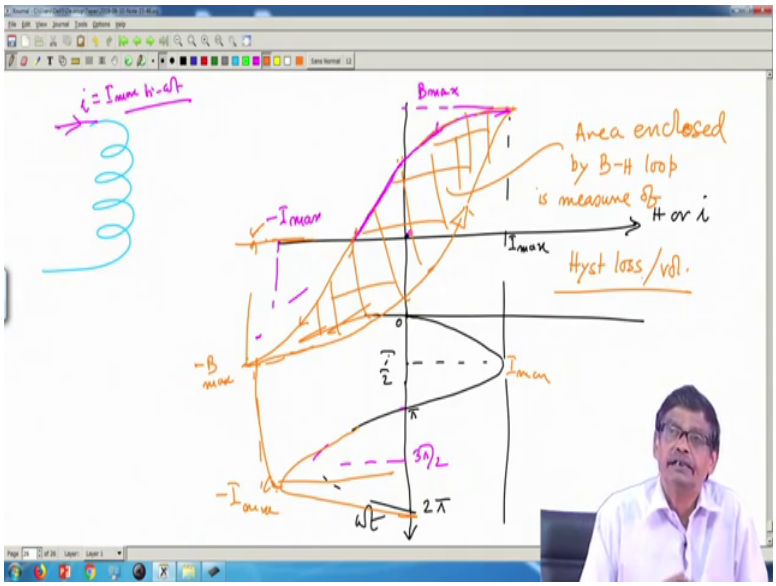

So, here was my coil mind you it is wound on a magnetic circuit we are not try. Now, what I will do is this, what I have done last time (Refer Time: 26:11) mean do it like this. So, this was the B H curve which I will draw with this color and while tracing back here it will be like this. So, this is my positive direction of i, but suppose this i is I max sin omega t suppose this current is this, then I also draw the current, you can always draw current this is my omega t axis variation of current I am showing.

This axis as I told you can be treated H or I, this is your I max and this was the current only one cycle I am showing that is got enough 0 pi by 2 pi. And suppose I have started the game when there was no magnetic field present in the core. So, H here as current was increasing came up to I am so sorry this is pi by 2 and this is pi and this is 2 pi correct it. And of course, the cycle repeats only one cycle have.

So, it has gone like this it has increased, then it reached a B max corresponding to I max and suppose I do not stop here I allow the current to flow in the opposite direction then pi to 2 pi what is happening here, pi and this is 3 pi by 2 is not. So, if you do that you will see it will be like this and I think this length should be slightly I mean whatever is B max has same modernity if you come it will come here.

So, it will be somewhat like this, it will go like this reach say minus I max this is not correct later on this is D max I mean it goes, this is suppose minus I max this point. And

then once again it will go it will be always lagging it is like this. See after it is tracing the following the currents I think this is I max.

So, slight this way I should correct this is suppose I max, this is the negative current I max are you getting not a very good diagram, but it tells you the picture this is I max this is minus I max. Therefore, when you are decreasing the current; current reaches 0 residual field is there, then you further need negative current to make it 0 B and then go on increasing the current up to minus I max then it will reach this minus B max this level. And after that no looking back so, this part this initial part is of no consequence now except after the first quarter.

After that as current changes the locus of BH values will become confined here; here only it will trace like this go, go, go like that. So, we will continue with this because it will take some more time, but I will request you to try to go through this lecture hysteresis thing a little bit carefully particularly a drawing this curve nicely.

You will be perhaps drawing it much better and we will next time show that the hysteresis loss per unit volume is nothing but the area enclosed by the path that will show that is my target is this area enclosed and this is called hysteresis loop in area enclosed by B H loop is a measure of hysteresis loss per unit volume. We will continue with this next time.

Thank you.