Electrical Machines - I
Prof. Tapas Kumar Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 02
Magnetizing Current from B-H Curve

Welcome to the second lecture on the Electrical Machine - I course, where we will be primarily discussing about transformers and DC machines. So, we started in our first lecture about transformers.

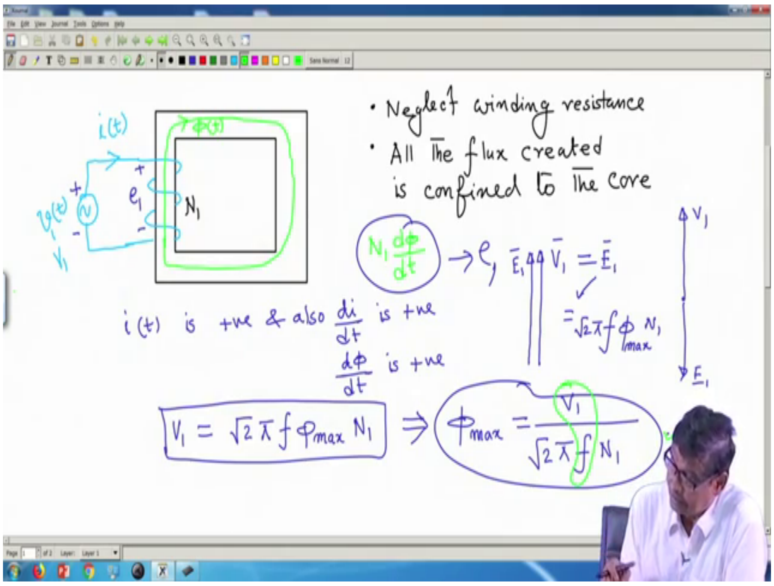
Transformer essentially is nothing but at least two coupled coils, wound on a common magnetic circuit and one coil will be excited with alternating source and will get voltage in the other coil. Details will discuss. But before that we told you in the last class that a magnetic circuit essentially comprises of a magnetic core which is a ferro magnetic material and it is wound by coil, may be by several coils. One of the coil is suppose carrying current we discussed in our last lecture what will be the flux and what will be its direction.

If you pass DC current, in case of DC magnetic circuit then we say it is a DC magnetic circuit, you excite the coil with some constant current and what will be generated is a constant amount of flux in the core. The amount of flux can be calculated from the equation phi is equal to NI by reluctance if it is a linear magnetic circuit. And also, the deduction of the flux whether it will be clockwise or anticlockwise can be figured out by knowing the direction of the current in the coil.

So, in case of DC magnetic circuit you excite it with a DC current and there will be flux produced and to calculate the flux there are two options you can use that formula that is NI by reluctance or alternatively if the B H curve is available which also encompasses the non-linearity case. Then you calculate first NI, then calculate NI by l that is H from the geometry of the magnetic circuit, you get the mean flux length and from the B H curve corresponding to that H read what is reproduced and B multiplied by the cross sectional area of the magnetic circuit will give you the flux, that was in DC.

Also in DC if you want to create a definite amount of flux you can go in the reverse way that is if the flux to be generated is this much then calculate first B then from the B H curve you get the value of H corresponding to that B and from that H is nothing, but NI by l I will be able to calculate the mmf required.

(Refer Slide Time: 03:52)



In case of AC magnetic circuit that is what we were talking about the interesting thing is you will excite the coil with a suppose this is the core of the magnetic circuit, this is the core material and over which there is winding ok. Only one coil let us first understand. And what I am telling is this coil I will excite it from a sinusoidally time varying voltage say v 1 t which has got an rms value of V 1, say V 1, V 1 is the rms voltage. And suppose the number of turns of the coil is N 1 and this is the core of the material. See it is time varying current and also, we neglect winding resistance which is suppose vanishingly small winding resistance.

And also let us assume that all the flux; all the flux created is confined to the core only, is confined to the core that is in other words that is no leakage flux. So, all the flux that will be produced will be confined to the core. And there will be several lines I have just drawn. I am so sorry, I forgot to do that.

Student: (Refer Time: 06:19).

So, thank you. So, this is the flux path and suppose let us also assume the instantaneous current is i t ok. So, with winding resistance is neglected without going thinking too much about it I can only say this much look there is a coil, having no resistance and therefore, this coil will perhaps act as an ideal inductor and therefore, it will draw some current 90 degree lagging ok. The value of the current will be decided by the inductance of the coil. That way one can think, but I will tell the same thing in slightly different way.

Suppose, it draws current and this current will be also sinusoidal. Why not it will be sinusoidal because your supply voltage is sinusoidal there cannot be anything else. Now, the moment this sinusoidal voltage is applied, the flux developed direction of the flux will be also time varying.

When I is I max phi will be phi max, when I is 0 phi will be 0, because current is expected to be sinusoidal why not and therefore, it will be like this. But one should also remember in this circuit this flux is time varying therefore, this coil will become, this coil means coil with N 1 turns will become a seat of EMF that is N 1 d phi dt because of Faraday's law. And the polarity of this induced EMF will be such that it will try to oppose the very cause for which it is (Refer Time: 08:56).

Let us also tell about one thing about i t, let us consider this to be the instantaneous direction of the current and not only that di dt is positive that is d phi dt is positive, it is increasing, ok. So, i t is positive and also di dt is positive. That is current is increasing and also having a positive slope ok. Therefore, d phi dt in the direction shown is also positive that is what we are attributed to time ok; d phi dt may be negative, but these will be taken care of by the equation. But this is the two things I have attributed to i t, i t is positive that is what I have assumed and not only that di dt is also positive and that is done.

Therefore, d phi dt is also positive; that means, at this instant flux linkage with turns N 1 is positive number it is increasing, d phi dt is positive. And what is the cause of this induced voltage in this coil N 1? Because i t is increasing, therefore, polarity of this induced EMF will be such it will try to oppose this increase in current i t. That is why it will oppose the supply voltage, mind you I have assumed supply voltage like this. So, this is the thing a single coil excited by AC will have some induced voltage here E 1 and this without writing any equations I can tell instantaneous value of this induced voltage ok.

Therefore, applied voltage and induced voltage. And as I told you it is a magnetic circuit only thing coil is excited by a voltage source AC voltage source. Now, in this case what happens second argument was that ok, there is expected to be current is varying sinusoidally therefore, flux will also vary sinsusoidally, d phi dt fellow will be also sinusoidally it will be changing therefore, induced voltage E 1 too has to be sinusoidal.

What will be the nature of this induced voltage in relation to V 1? This two will be in same time phase because k V l is to be satisfied only thing this since in which E 1 is acting is opposite to this sense of V 1 applied to this circuit that is if V 1 was allowed to drive current alone it would have driven current from right to left.

So, this is the (Refer Time: 12:29) law that is the induced voltage will oppose the supply voltage essentially. But nonetheless this two voltages will have same with respect to time I if you draw the phasor diagram I will draw this is V 1 and this is also equal to E 1 has to be, that is both V 1 and E 1 are in phase. In books many of the books they will show V 1 is like this, E 1 is in opposition to indicate that E 1 acts in opposition with V 1, but I will not do that, because I know time phasor means what with respect to time how V 1 is changing and how E 1 is changing. When V 1 will be maximum e 1 2 will be maximum and so on. So, there in time phase.

So, I will go by this way of looking at the things, because time phasor I know if there are two quantities I 1 t and I 2 t, some currents into different branch and if there in time phase there is when I 1 attains maximum I 2 also attains maximum they are in phase. So, draw along same line why not. So, mind you this is the thing.

In this loop in this coil loop k V l is to be satisfied therefore, the rms value of the applied voltage at rms value of the induced voltage they are to be same and has to be we have seen that. Therefore, what is known to me? V 1 is the rms value of the applied voltage. In my last class I show the rms value of this induced voltage is nothing, but root 2 pi f phi max into N 1. What is phi max? Phi max is the sinusoidally varying flux big value of that. So, this is the equation Therefore, your this equation is true.

This phi t can be expressed in terms of say phi max cos omega t differentiate that last time we did that. So, the rms value of the applied voltage is equal to rms value of the induced voltage which I got from N 1 d phi dt this thing is your E 1 rms value of that. How did you get? Put phi equal to say phi max cos omega t differentiate it and big value of that divided by root 2. So, this is the thing. This equation implies that this is this a most important statement that phi max is equal to V 1 by root 2 pi f into N 1.

In other words, what I am trying to tell, in case of DC circuit excite with DC current NI is known then calculate flux, but in case of the same coil which is excited from an rms voltage sinusoidally varying V 1 the value of the peak value of the flux is fixed V 1 by root 2 pi f N 1. That is no question of trying to calculate current then calculate mmf, then flux unlike DC circuit. Phi max gets decided, decided by whom? Decided by this two numbers, rms value of the supply voltage and applied frequency. Of course, this is the peak value of the flux. How flux is changing? Sinusoidally.

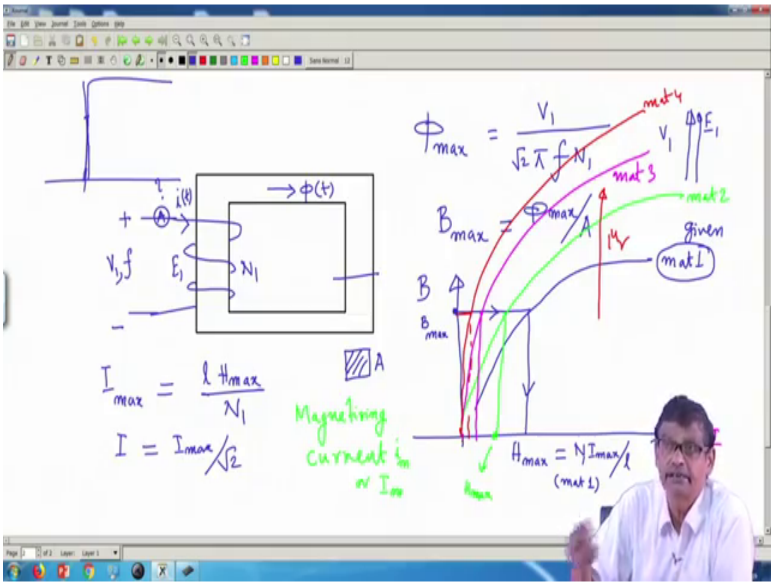
If you want to describe it as phi max as a sine function then write it phi sine omega t or cos omega phi max cosine omega t whichever is convenient to you. And this flux is also sinusoidally varying with the same supply frequency f. Therefore, to describe a sinusoidal function completely what you need is its peak value and the frequency, so phi max. So, we say that if a coil is excited from a sinusoidal voltage source the value of phi max gets fixed means the value of flux gets fixed in the core of the machine ok. So, this is the thing one should remember very carefully ok.

Now, let us go to a new page after learning these. So, a in this a magnetic circuit once again a this is the thing, so we now know this is what is going to happen ok. Now, I will ask you I will refer to back these once again re-drawing is not necessary. Now, what I am telling is suppose I want to know and what is the another important implication of this equation, that is if this core material is replaced by another core material other things remaining same, that is same voltage you apply with same number of turns only thing replace these magnetic material with another magnetic material, then also phi max will remain same.

In other words, if mu were changes change it by a different magnetic material phi max you cannot alter, it is solely decided by this V 1 and the supply frequency. They say the last word about the strength of the flux which will be created inside the core, nobody else definitely not the relative permeability of the core material. Supply voltage and frequency is fixed phi max is decided.

Then how to apply the magnetic circuit problem; then rather relevant question will be if that be the case, I would like to know what will be the current drawn, suppose you connect an ammeter in series with this line. And I ask you that, it is a magnetic material which has got a B H characteristics and I want to know what is phi max. So, let us not make this page too dirty. Let us go to new page.

(Refer Slide Time: 20:26)



So, if necessary let me draw once again. So, suppose once again the same coil with N 1 turns. Now, I ask I will apply an AC voltage with rms value V 1 and frequency f to this two points with this side plus this side minus and I will connect an ammeter here. I am asking you what will be the reading of this ammeter? That is the question I am asking.

The answer to that question will be you have applied V 1 f 1 then I will say this will be time varying flux and the peak value of the flux is phi max which is equal to V 1 by root 2 pi f into N 1, this I know. Then what I will do is these I will calculate B max which is equal to phi max by the area, cross sectional area of the core, suppose it is uniform constant, this is A, this is the cross sectional area. Then I will I have to calculate the value of the current, I will ask what is the B H characteristics of this material, B H characteristics of the material as you know it remains linear then it goes like this. This is the B H curve of the material.

Then what I will do. So, what is I? That is the question asked. So, I will calculate phi max, then B max and B H characteristics is given to me, given. Then what I will do this B max I will come here whatever it is B max and corresponding to this B max I will note down how much H is necessary that I will call the H max and this is nothing but NI max by l. What is l? L is the mean length of the flux path which I am not drawing I have shown in the previous. And from this I will say that I max is equal to l into H max by N, I am sorry N 1 it is. So, maximum value of the rms current is current drawn is known and then ammeter reading if it is MI meter I will say I rms will be equal to I max by root 2, this is the thing.

So, this the now tells me that if a single coil is excited from an alternating voltage source of frequency f and this coil is wound on a magnetic material whose B H characteristics is like this. This is known to you; I hope from magnetic circuit analysis. This portion is saturation zone it is initially linear things like that. But the moment you apply a known voltage and frequency flux peak value of the flux gets fixed and I am asking you what is the current drawn?

So, what I will do is this I will phi max I will first calculate then I will calculate B max, if B max is known then I will calculate H max and from that I will be able to calculate I max that divided by root 2 will be the rms value of the current. This you must understand.

Therefore, in AC magnetic circuit everything is sinusoidally varying time varying thing, phi is time varying, instantaneous quantity is i t is time varying, only thing is i t and y t will be in same phase, when I is maximum, phi is maximum and so on. But the rms voltage induced in this coil E 1 they will be in phase with this supply voltage. When V 1 is maximum E 1 2 will be maximum and so on ok.

Now, suppose this part if you understand then we really can discuss much more about an ideal transformer, although I have not used the term ideal yet at least in today's lecture. Suppose, I say that this magnetic material and its B H characteristics is this one. So, this is suppose material 1, material 1 for which B H characteristics is known.

Suppose, I say this material I will replace it by a newer magnetic material which is whose B H curve is like this. So, material 2, B H curve is this. Then I apply same voltage and frequency to this coil, then how much current this coil is going to draw. Then if this is the material 2 now phi max is fixed no matter whether it is material 1 or material 2.

So, same B max you read, but now you have to read the value of H max this is for material 1, this is for this is material 1. If it is material 2, I will say it will take it will draw current this much only is not corresponding to these that is H max material 2, this green color is H max corresponding to material 2. And H max is lower therefore, current drawn will be lesser. Therefore, you see this current which establishes the flux in the core will use now another term is called magnetizing current, usually denoted by instantaneous value y i m or rms value y I m, no maximum it is magnetizing current.

We see that if you go on replacing this core material by better and better material current drawn ammeter reading will then become smaller and smaller, because another material if you choose suppose somebody says, I will replace these by another material whose B H curve is like these material 3. So, this axis is H or also I, let us forget about this constant N by l, this axis also represents the current drawn. Therefore, current drawn because phi max remains same, so current drawn can be further reduced.

In other words, to establish a given flux if you use better and better material current needed will be smaller and smaller. So, more efficient way of creating flux provided you use better and better material. Suppose there is no restriction plenty of better materials are available, suppose some material is like this very steep material 4, then current needed will be only this much. Further, you can reduce the magnetizing current. What is this better material? Better material means this slope of d B d H is mu r, it is a measure of mu r. So, we are increasing relative permeabilities for this different curves essentially I mean.

Therefore, suppose mu r is very high tending to infinity what does that mean, it means that B H curve will be something like this very high value of. Therefore, to create flux you require very little current. Therefore, the magnetizing current can be reduced to any extent provided you have got very good magnetic material. So, we will continue with this in our next lecture.

Thank you.