Fundamentals of Electrical Engineering
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Lecture – 51
Magnetic Circuits

So, we are back again. So, far we have studied DC circuit, then single phase AC circuits along with you your what you call that regulance as well as your maximum power transfer theory you have seen, and also the three phase circuits.

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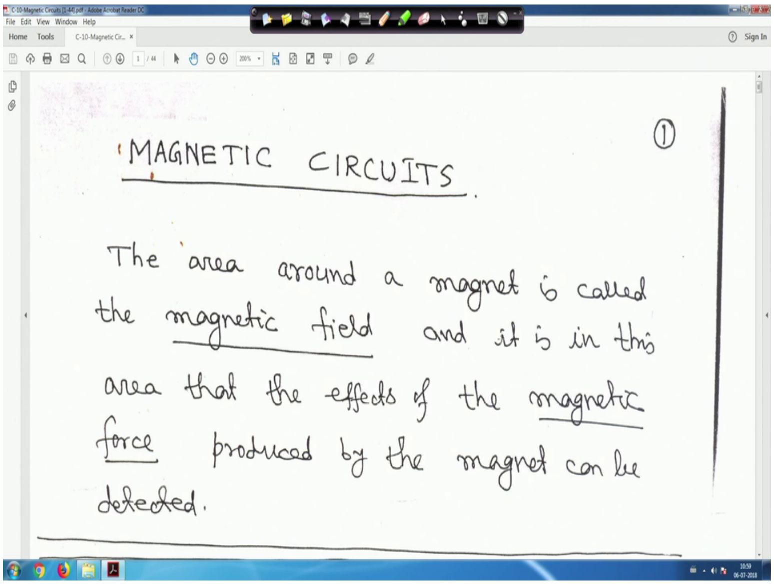

MAGNETIC CIRCUITS

①

The area around a magnet is called the magnetic field and it is in this area that the effects of the magnetic force produced by the magnet can be detected.

Now, we will start Magnetic Circuits right. First thing is that magnetic circuit we will find things are very simple, only one or two things we have to understand. And next we will find things are easy, particularly in magnetic circuit with coupling right, so mutual coupling. So, and we have to understand that, and we will find things are very easy.

So, just a magnetic circuit actually, the area around a magnet is called the magnetic field right that you know and it is in this area that we are what you call that the effect of the magnetic force produced by the magnet can be detected right.

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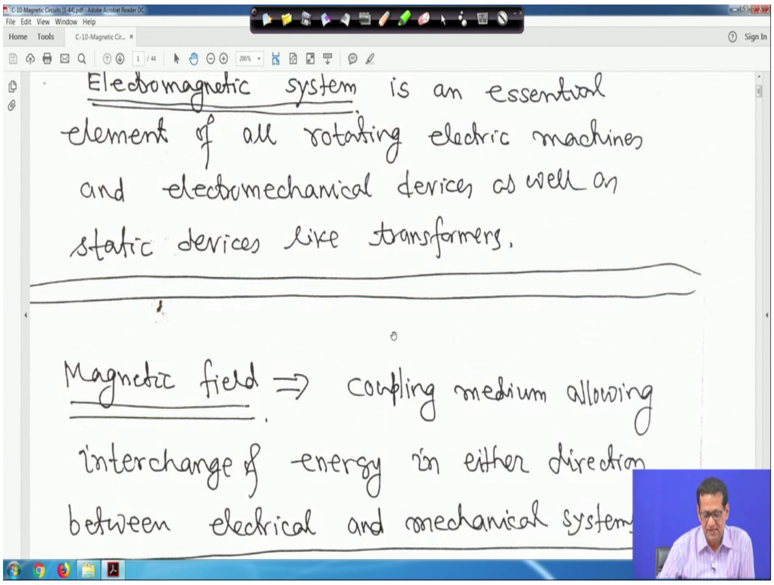

Electromagnetic system is an essential element of all rotating electric machines and electromechanical devices as well as static devices like transformers.

Magnetic field ⇒ coupling medium allowing interchange of energy in either direction between electrical and mechanical system

So that is your now and another thing is the electromagnetic system is an essential element of all rotating electrical electric machines in our electrical engineering we see, and electro mechanical devices as well as static devices like transformer right. So, and our magnetic field actually is a coupling medium allowing interchange of energy in either direction between electrical and mechanical system right, so that is your what you call that at your it is what a actually magnetic field.

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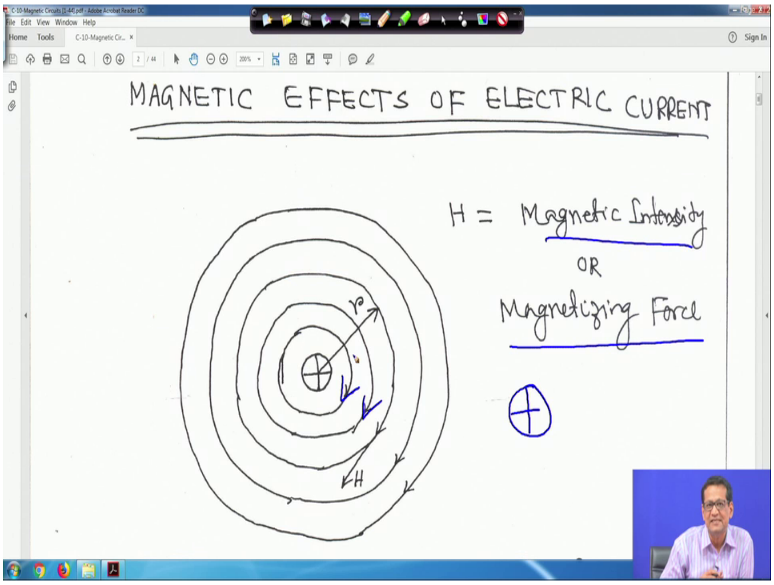

MAGNETIC EFFECTS OF ELECTRIC CURRENT

H = Magnetic Intensity

OR

Magnetizing Force

So, next is your the magnetic effects of electric current. Now, this is suppose here now H is actually called magnetic field intensity or magnetic force, and first let me tell you, this is a conductor right, this is a conductor circular conductor. And flux means just try to understand that your flux line and this thing right. This flux line means you take a paper, and current is entering into the plane or into the paper right.

So, if the if this is the direction of the current, if my thumb is the direction of the current, then flux line will be the curling this curling finger right. So, this is this is the direction of the current, this flux means that your current is entering into the into on the on the paper right that mean in the plane, and this direction this is the direction of the flux.

So, if I say this current is entering into the plane right or in the paper your notebook say it is entering, then this is the direction of the flux right that is clockwise direction. And that is why this one that is why this is the flux line, and this is that is why this is the flux line, it is clockwise direction, this is actually right hand rule right. So, I just we have to understand one or two few things right. And this is any from here to here, it is taken some distance are right, this is your what to call the magnetic flux line.

So, H is actually magnetic field intensity or sometimes we call magnetizing force right. And your what you call and this is a r is this a we later will come to that r, it is radius right. So, in this case, you are just let me clear it. So, then H actually it is uniform this magnetic field is uniform around the conductor, so, it is basically tangential to this point, and it remains constant right.

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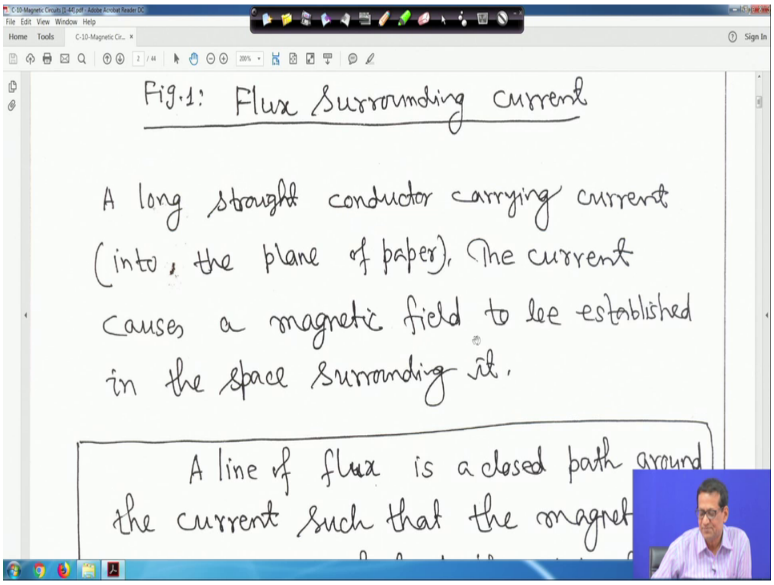

Fig.1: Flux Surrounding current

A long straight conductor carrying current (into the plane of paper). The current causes a magnetic field to be established in the space surrounding it.

A line of flux is a closed path around the current such that the magnet

So, this is that your flux surrounding current right. So, a long straight conductor carrying current it whatever I said it is written here right into the plane, the current causes a magnetic field to be established in the space you are surrounding it right.

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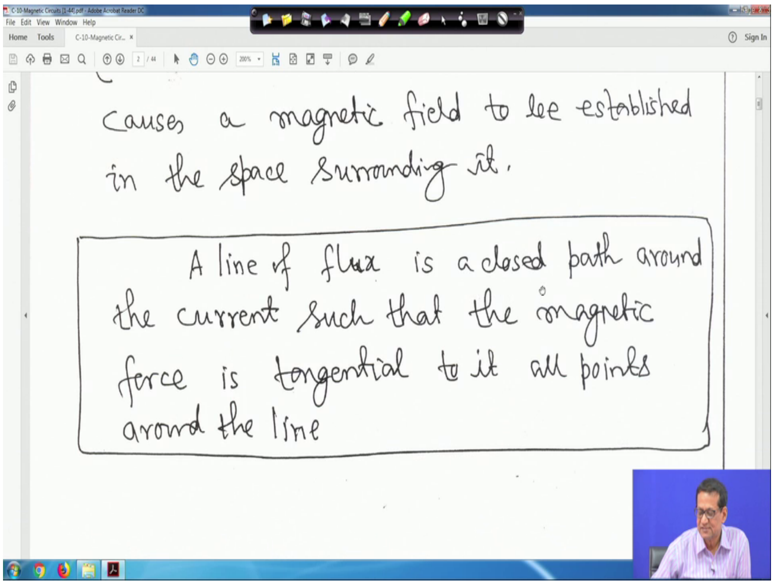

causes a magnetic field to be established in the space surrounding it.

A line of flux is a closed path around the current such that the magnetic force is tangential to it all points around the line

A line of flux is a closed path around the current such that the magnetic force is tangential to it is all point around the line. This is H right, this is a H right, H is the magnetic intensity or magnetizing force right.

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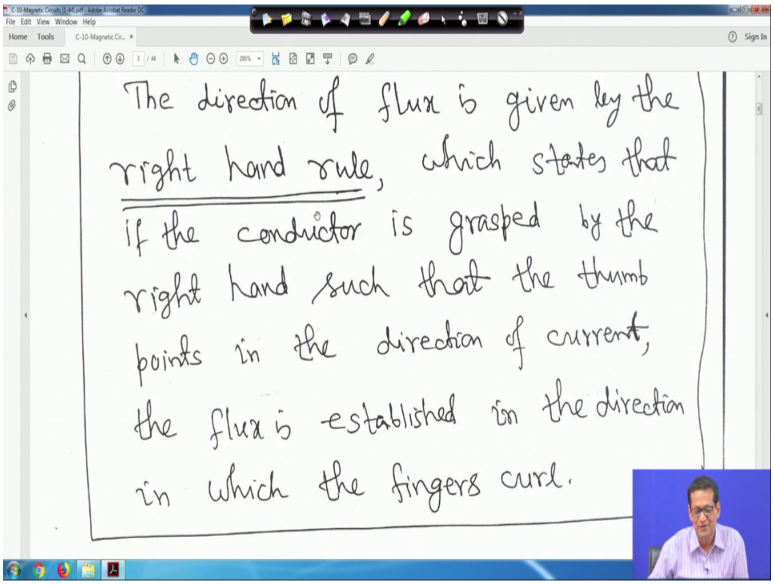

The direction of flux is given by the right hand rule, which states that if the conductor is grasped by the right hand such that the thumb points in the direction of current, the flux is established in the direction in which the fingers curl.

So, the direction of flux I told you the right hand rule, I will just explain you, you go through it whatever I said, same thing it everything it is here.

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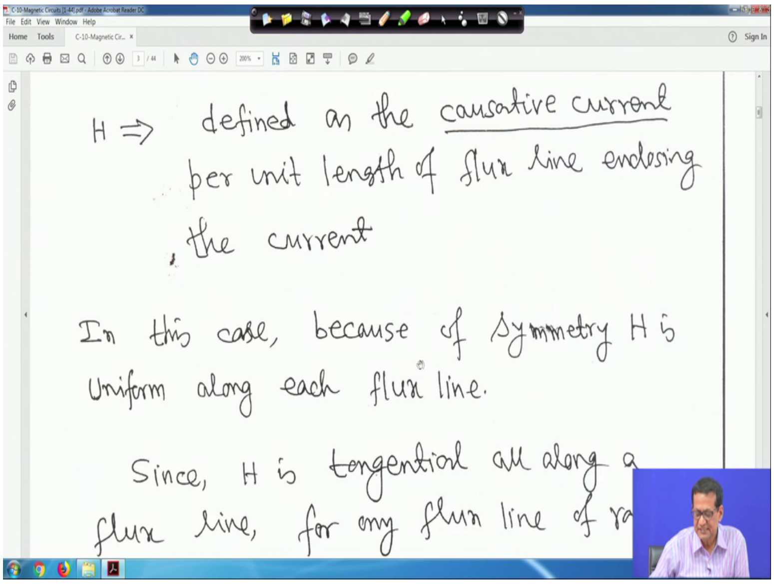

H ⇒ defined as the causative current per unit length of flux line enclosing the current

In this case, because of symmetry H is uniform along each flux line.

Since, H is tangential all along a flux line, for any flux line of ra

So, now H defined as the causative current, we will come to come later what is causative current, per unit length of the flux line you are enclosing the current right. Now, in this case because of symmetry H is uniform along each flux line. So, this is actually if you look into that, this flux line is you are called your concentric right and uniform. So, H actually at every flux is tangential and uniform right. So, this is your what you call so, in this case because of symmetry, H is uniform along each flux lines.

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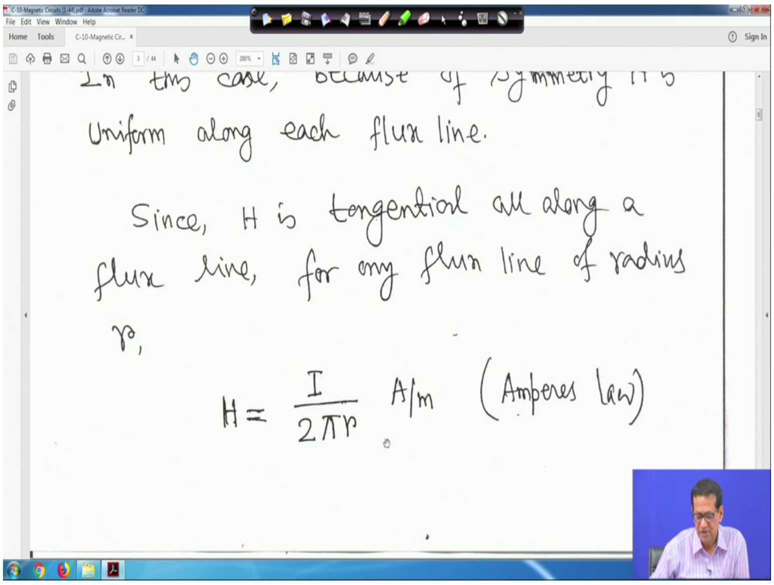

In this case, because of symmetry H is Uniform along each flux line.

Since, H is tangential all along a flux line, for any flux line of radius r,

$$H = \frac{I}{2\pi r} \text{ A/m} \quad (\text{Amperes law})$$

Since, H is tangential all along a flux line, for any flux line in radius r right, so H is equal to I upon 2 pi r ampere per meter that means, this is the radius of a flux line of r say here in the diagram.

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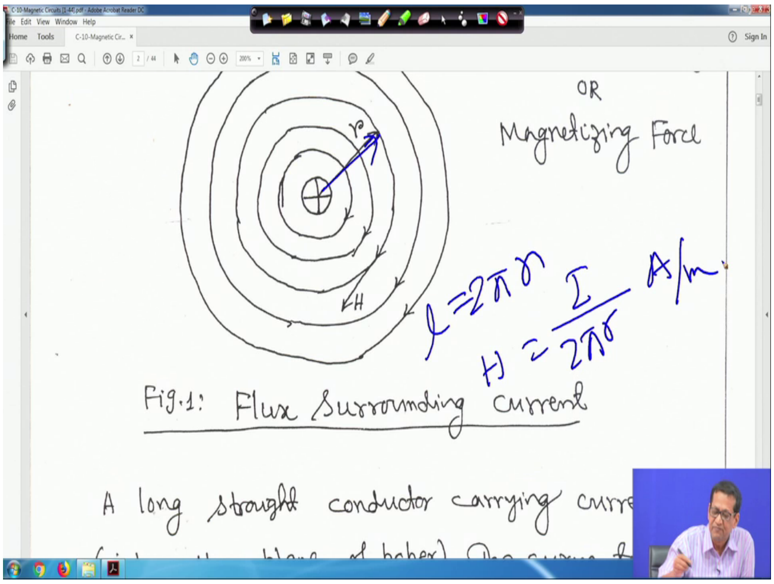

OR

Magnetizing Force

$$l = 2\pi r$$

$$H = \frac{I}{2\pi r} \text{ A/m}$$

Fig.1: Flux Surrounding Current

A long straight conductor carrying curr

This is the radius of the flux line your r right, this is your radius of the flux line is r right and your this is uniform, it is a circular. So, it is circumference is 2 pi r that is actually length l is equal to 2 pi r. Therefore, H is equal to it will be I upon 2 pi r, it is ampere per meter is Ampere’s law right so, let me clear it. So, this is actually your what you call H is equal to I upon 2 pi r ampere per meter that is Ampere’s law.

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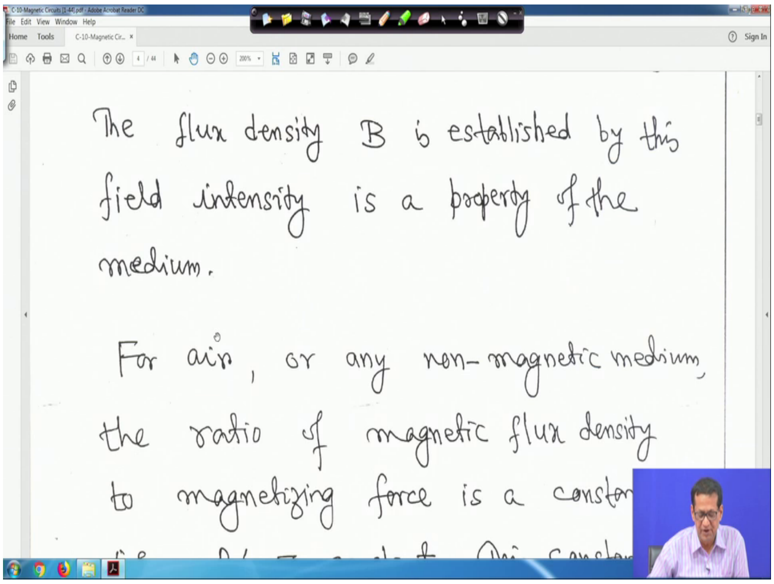

The flux density B is established by this field intensity is a property of the medium.

For air, or any non-magnetic medium, the ratio of magnetic flux density to magnetizing force is a constan

Now, the flux density B is established by this field intensity right is a property of the medium. So, for air or any non-magnetic medium, the ratio of magnetic flux density to magnetizing force is a constant, that is if your B is the flux density, it is Tesla or Weber per meter square it is unit right. And H right the magnetic field ampere per meter or we will later we will see it is ampere tons per meter that B by H is constant, then its flux density by magnetizing force ratio is always constant right.

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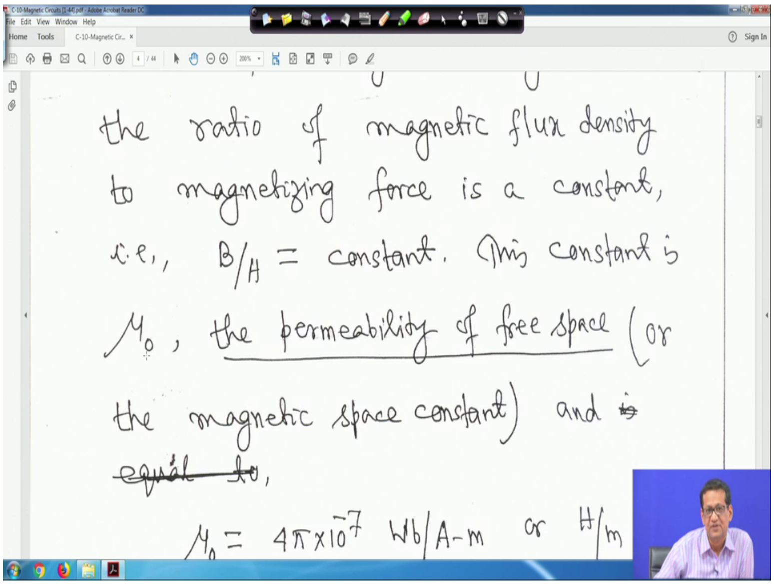

the ratio of magnetic flux density to magnetizing force is a constant, i.e., B/H = constant. This constant is μ_0, the permeability of free space (or the magnetic space constant) and ~~is~~ ~~equal to~~,

$$\mu_0 = 4\pi \times 10^{-7}\ Wb/A\text{-}m \text{ or } H/m$$

And this constant is defined as mu 0, so the permeability of free space or the magnetic space constant right, it is called permeability of free space or the magnetic space constant.

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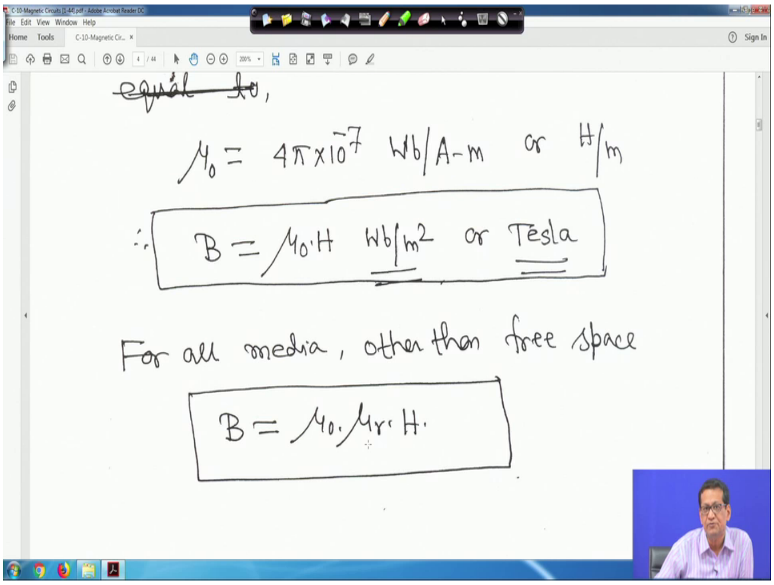

~~equal to~~,

$$\mu_0 = 4\pi \times 10^{-7}\ Wb/A\text{-}m \text{ or } H/m$$

$$\therefore \boxed{B = \mu_0 \cdot H \ \ \underline{Wb/m^2} \text{ or } \underline{\text{Tesla}}}$$

For all media, other than free space

$$\boxed{B = \mu_0 . \mu_r . H.}$$

And mu 0 is equal to either 4 pi into 10 to the power minus 7 Weber per ampere meter or it is Henry per meter either this unit or this unit Weber per ampere meter or Henry per meter. So, B is equal to mu 0 into H, B is the flux density, it is mu 0 into H and it is

Weber per meter square or Tesla it is unit is right. So, for all media other than free space, actually B is equal to mu 0 mu r into H right.

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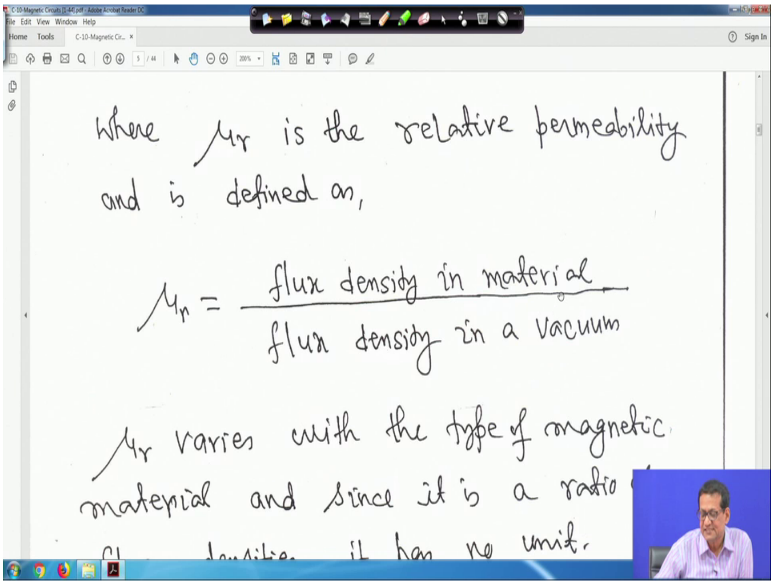

Where μ_r is the relative permeability and is defined as,

$$\mu_r = \frac{\text{flux density in material}}{\text{flux density in a vacuum}}$$

μ_r varies with the type of magnetic material and since it is a ratio

it has no unit.

So, mu where mu r is the relative permeability and is defined as mu r is equal to flux density in the material divided by flux density in a vacuum right. So, it is a dimensionless quantity, because numerator also flux density, denominator also flux density, so it is basically dimensionless constant. So, flux density in material, so flux density in a vacuum.

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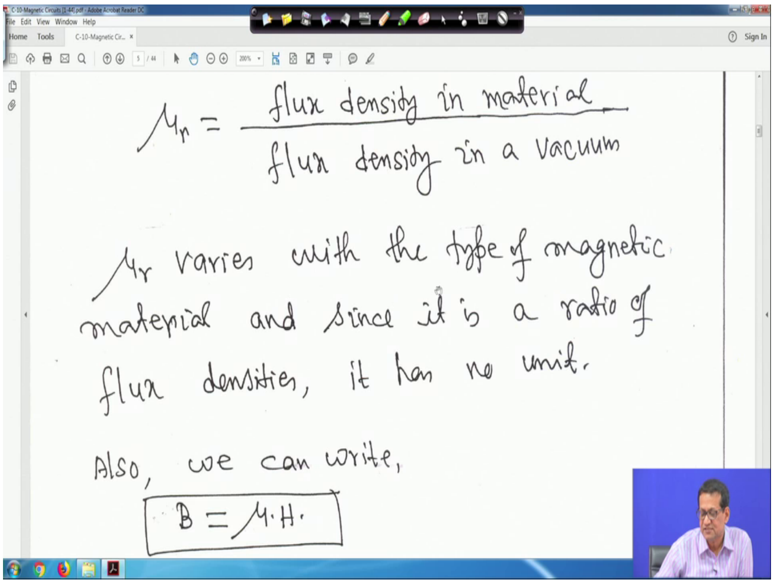

$$\mu_r = \frac{\text{flux density in material}}{\text{flux density in a vacuum}}$$

μ_r varies with the type of magnetic material and since it is a ratio of flux densities, it has no unit.

Also, we can write,

$$\boxed{B = \mu \cdot H}$$

So, mu r varies with the type of magnetic material, and since it is a ratio of flux densities I told you, it has no unit, it is a dimensionless. Also, we can write that B is equal to mu into H; instead of mu 0, we can write mu into H in any material right your what you call in any in a any particular you are what you call in material.

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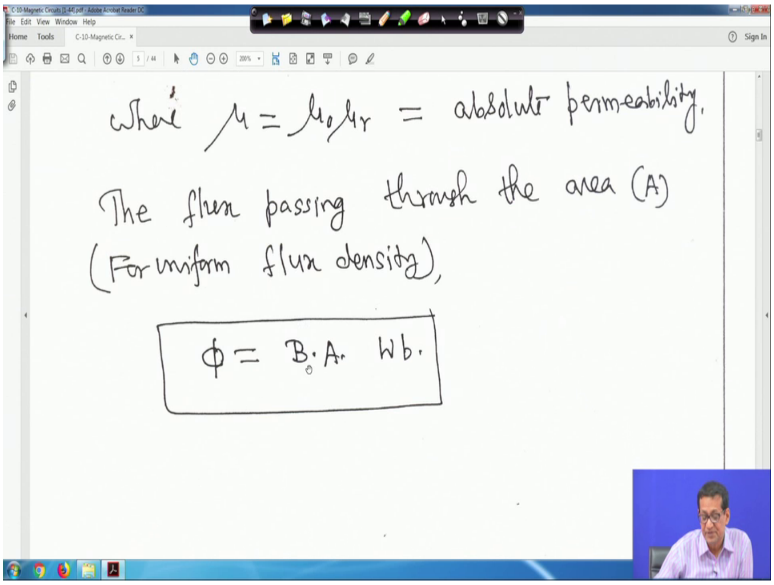

where $\mu = \mu_0 \mu_r$ = absolute permeability.

The flux passing through the area (A)
(For uniform flux density),

$$\boxed{\phi = B \cdot A \text{ Wb.}}$$

So, where mu is equal to mu 0 into mu r, it is called absolute permeability right. So, mu is equal to mu 0 into your mu r. And the flux passing through the area for uniform flux density phi is equal to B into A; B is the flux density. Suppose, Weber per meter square an A is the area, it is meter square so, phi is equal to B into A, it is Weber right. So, this is simple these are all these simple formula that B is equal to mu H, mu is equal to mu 0 mu r, and phi is equal to B into A.

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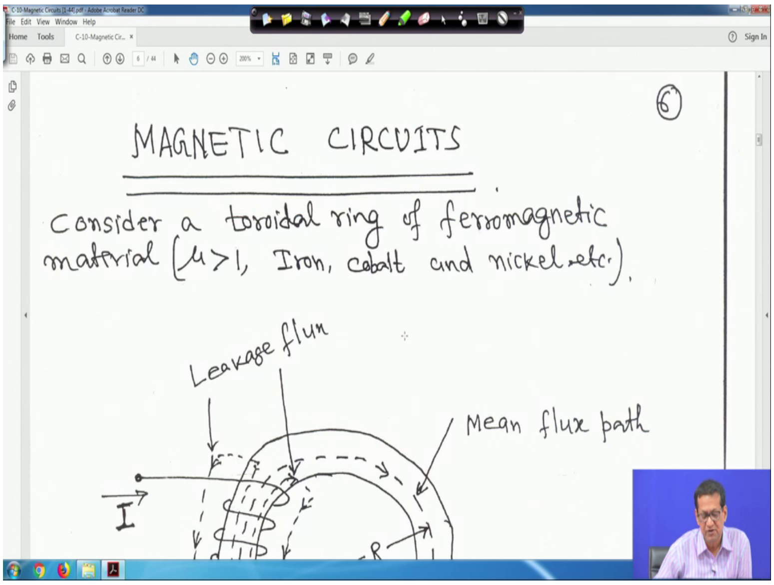

⑥

MAGNETIC CIRCUITS

Consider a toroidal ring of ferromagnetic material ($\mu > 1$, Iron, cobalt and nickel etc.).

Now, magnetic circuits, now, you consider let us consider a toroidal ring of ferromagnetic material, where mu greater than 1, it maybe iron, it maybe cobalt, and nickel etc right. So, it is consider a toroidal ring.

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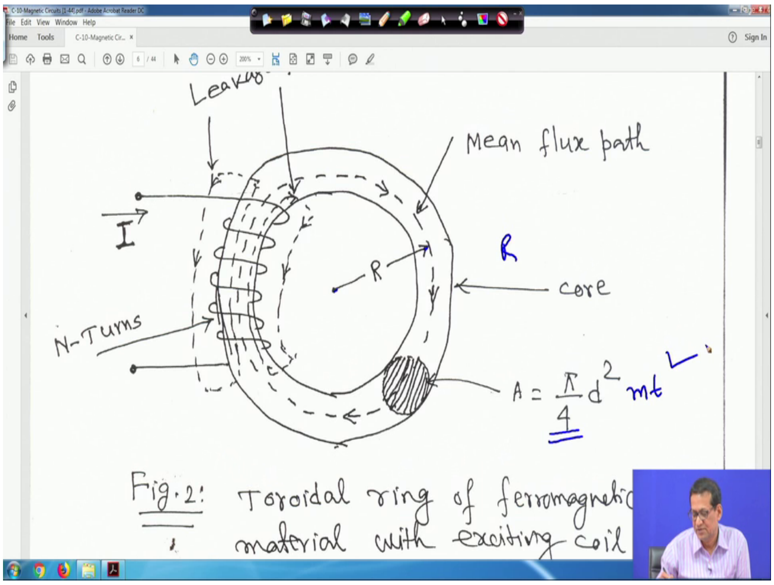

Fig.2: Toroidal ring of ferromagnetic material with exciting coil

Now, this is a circular ring so, what we will do is we will take your what you call that you are mean path, this is actually mean flux path, we will take the mean distance right. So, from here to your mean radius is capital R right, and this is the core circular core, so it is diameter is d right. If it is diameter is d, so area will be pi by 4 d square. If it is a meter, then it will be your meter square, if d is in meter. This is that cross sectional area right, this is circular one. This is the mean flux your what you call mean your flux path. Now, let me clear it let me move little bit up right.

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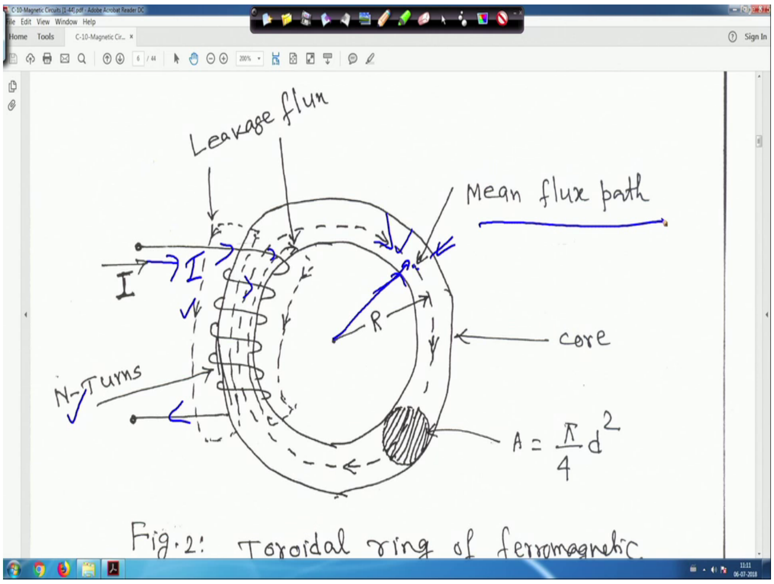

Fig.2: Toroidal ring of ferromagnetic

Now, if you look into this if you look into this diagram, this is the coil wound on this you are what you call on this toroidal ring. Now, current actually entering it, this current is entering this ring has N number of turns right. So, whenever, now here we have to understand your I cannot revolve this 1 to 90 degree, I will tell you that first thing is that this is the leak[age] leakage flux part is also solve, and then this is the mean flux path.

Now, question is that it is a coil, if you have a coil, you wrap the coil like this, you grabs the coil like this, and this is the current is entering right, this is the current entering, this is the curren, and finally the current is leaving.

So, if you grabs the conductor like this, then this will be your the direction of the your mean flux path, this is the direction of the flux path right. If I for example, this is your what you call if you grab it this conductor, this coil this right if you grab it like this, then this will be the direction of the flux path. So, if I make it like this, so this that is why this is my the dire[ction] this is the I mean in the direction of the current, you grabs it right, and then this thumb will be your direction of the flux path right.

So, in this case if you make it like this by right hand, if you grab this way your what you call this winding by right hand, then thumb will be the direction of the flux path. So, this is the mean flux path, and there will be some leakage so, this line also so some leakage flux path right. So, it is actually coming it is actually direction will be like your in the direction of the thumb, if you grabs it right hand. So, this is actually I, and this is N-turns, and this is the only thing need to understand the direction of the flux path. So, and this is you call mean flux path whatever core will take, we will take the your what you call the mean radius or mean length.

Suppose, for example, suppose from here, suppose the thickness of this one, suppose if you take your what you call thickness of this one whatever it is, you take the mean path, you would calculate from here to here the mean path right. Because, we will go for mean your what you call assuming that is uniform cross section, so your mean follow the mean flux path. So, this is my mean flux path. So, direction of the you are what you call flux line later we will show you that is analogy to DC circuit voltage current resistance to your what you call magnetic circuit what are those quantity for analogous to that right.

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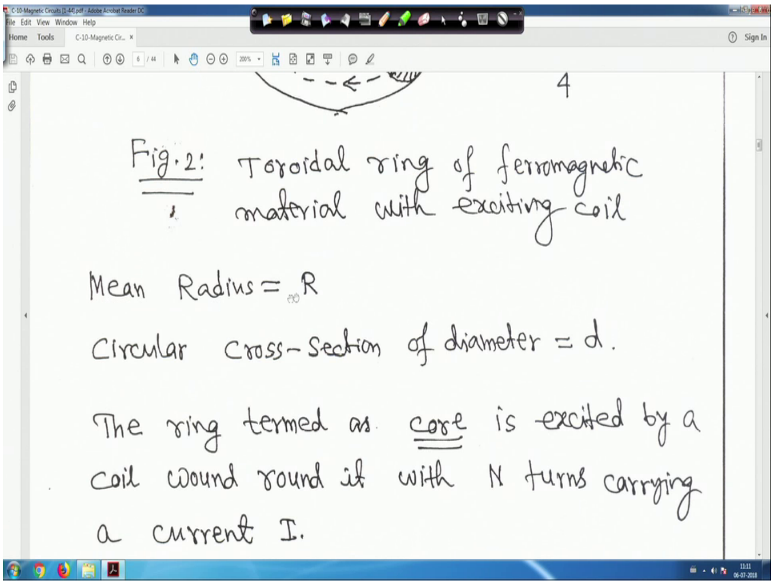

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Fig. 2: Toroidal ring of ferromagnetic material with exciting coil

Mean Radius = R

Circular Cross-Section of diameter = d.

The ring termed as core is excited by a coil wound round it with N turns carrying a current I.

So, that means, your this one, your the radius mean radius R, circular cross section the of the diameter is d. So, in this case, the ring termed as core is excited by a coil wound, it with N-turns carrying the current I told you right.

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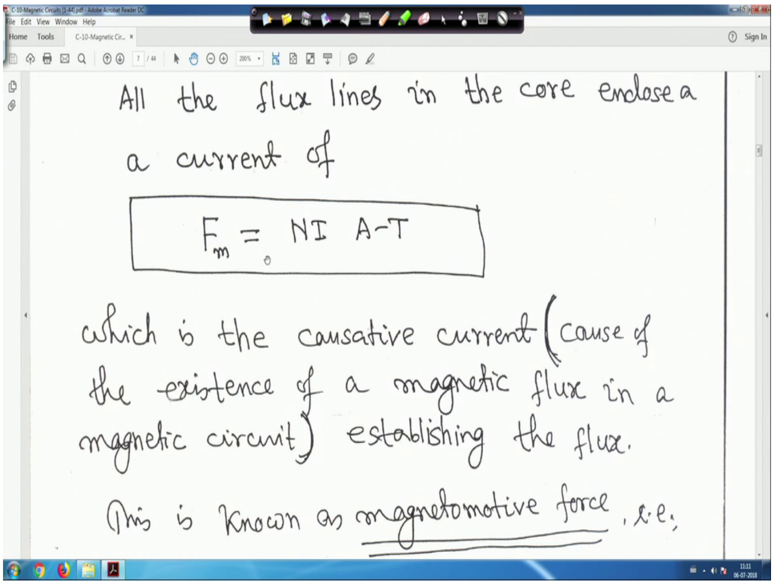

All the flux lines in the core enclose a

a current of

$$\boxed{F_m = NI \text{ A-T}}$$

which is the causative current (cause of the existence of a magnetic flux in a magnetic circuit) establishing the flux.

This is known as magnetomotive force, i.e.

So, that means, the flux lines in the core enclose a current of F m is equal to N I right. So, this is actually here it is number of turns is N, it is I right. So, your magnetizing force or sometimes we call m m f that is your F m is equal to say N I ampere turns; if I is ampere and N is turn, so its unity call ampere turn.

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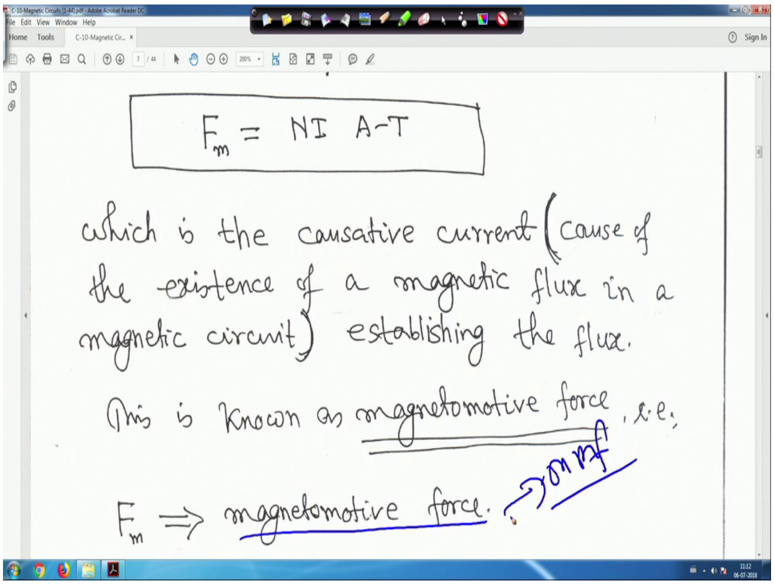

$$\boxed{F_m = NI \text{ A-T}}$$

which is the causative current (cause of the existence of a magnetic flux in a magnetic circuit) establishing the flux.

This is known as magnetomotive force, i.e.

$F_m \Rightarrow$ magnetomotive force. or mmf

Now, which is the causative current I told you, this causative current means cause of the existence of a magnetic flux in a magnetic circuit right that is why we call it is a causative current, so establishing this flux. So, this is known as magnetomotive force, sometimes we call it is m m f right, so magnetomotive force. So, F m is actually magnetomotive force, sometimes we call it is at m m f.

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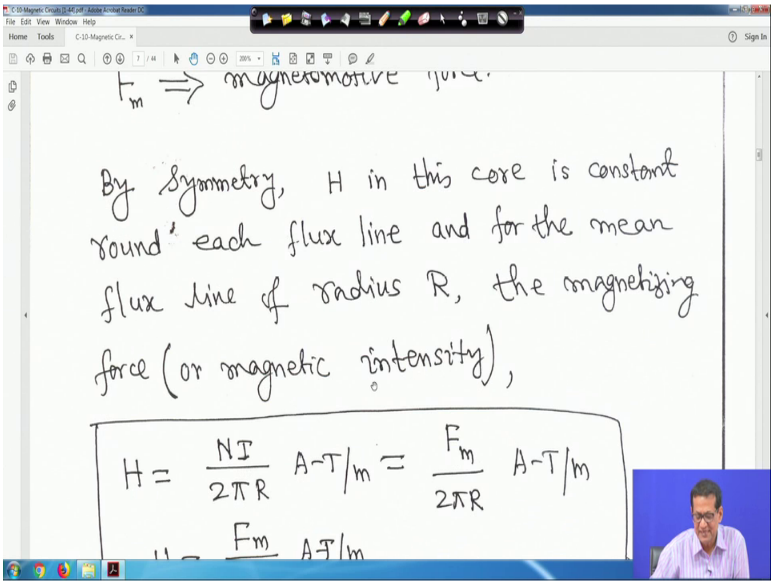

$F_m \Rightarrow$ magnetomotive

By Symmetry, H in this core is constant round each flux line and for the mean flux line of radius R, the magnetizing force (or magnetic intensity),

$$\boxed{H = \frac{NI}{2\pi R} \text{ A-T/m} = \frac{F_m}{2\pi R} \text{ A-T/m}}$$

F_m A-T/m

So, by symmetry, H in this core is constant, because it is a right round each flux line and for the mean flux your mean flux line of radius capital radius capital R, the magnetizing force or magnetic intensity right, it can be written as H is equal to N I upon 2 pi R. Earlier you are writing I upon 2 pi r, but here you have N number of turns, so H is equal to N I upon 2 pi R. So, N I is ampere turn, and this the length, so ampere turns per meter and then N I is equal to F m, here we have define F m is equal to N I right.

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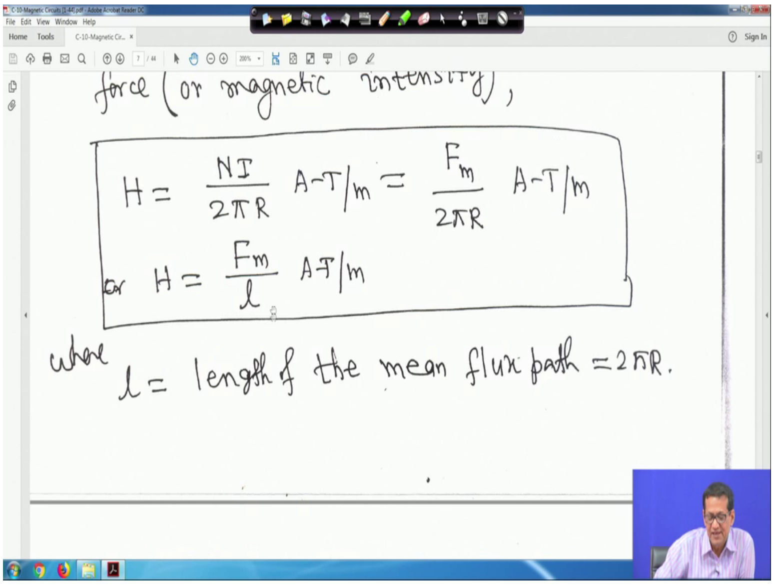

force (or magnetic intensity),

$$\boxed{\begin{aligned} H &= \frac{NI}{2\pi R}\ \text{A-T/m} = \frac{F_m}{2\pi R}\ \text{A-T/m} \\ \text{or}\quad H &= \frac{F_m}{l}\ \text{A-T/m} \end{aligned}}$$

where l = length of the mean flux path $= 2\pi R$.

So, here you substitute, it will be F m upon 2 pi R ampere turns per meter or we can write H is equal to F m upon l ampere turns per meter that l is equal to actually length of the mean flux path that is that circumference that is you 2 pi R. So, H is equal to F m upon l right.

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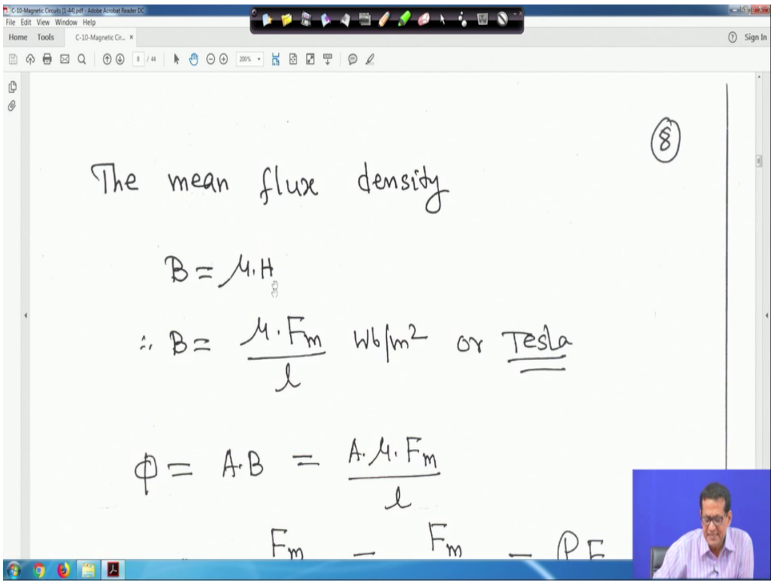

The mean flux density

$$B = \mu . H$$

$$\therefore B = \frac{\mu . F_m}{l}\ \text{Wb/m}^2 \text{ or } \underline{\underline{\text{Tesla}}}$$

$$\phi = A.B = \frac{A.\mu.F_m}{l}$$

So, next is the mean flux density, it is we know, B is equal to mu into H, so but H is equal to F m upon l. So, B is equal to mu into F m upon l Weber per meter square or Tesla either or mu this is the unit.

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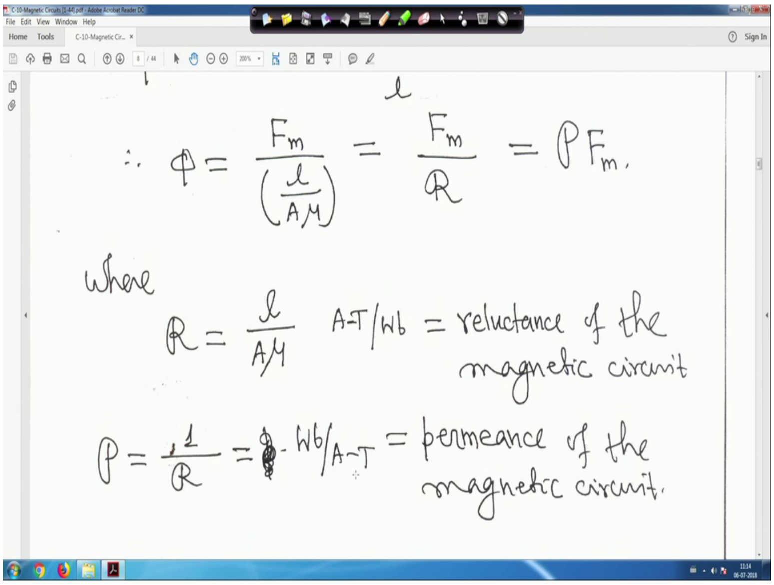

$$\therefore \phi = \frac{F_m}{\left(\frac{l}{A\mu}\right)} = \frac{F_m}{R} = P F_m.$$

where

$$R = \frac{l}{A\mu} \text{ A-T/Wb} = \text{reluctance of the magnetic circuit}$$

$$P = \frac{1}{R} = \text{Wb/A-T} = \text{permeance of the magnetic circuit.}$$

Now, flux is equal to A into B; A is the cross sectional area, and B is the flux density. So, A into B that is B is equal to mu F m upon l, so mu F m upon l right. So, that means, my phi is equal to we can write F m divided by l upon A mu right or we can write F m upon R or we can write is equal to P into F m right. So, R actually we call l upon A mu M it is ampere turns per Weber its unity, it is called reluctance of the magnetic circuit right, this is called the reluctance of the magnetic circuit; or P is equal to 1 upon R, it is called Weber per ampere turns right.

So, here it is R is actually ampere turns per Weber, and P is the reciprocal of R, the reluctance it will be just Weber, this unit will be Weber or ampere turns of this physical permeance of the magnetic circuit right. So, actually in the DC circuit, if you compare that F m actually like your what you call the voltage in DC circuit emf right, here it is m m f.

Now, phi actually in DC circuits say if it is a current, here analogous to magnetic circuit is a flux. And R is the resistance in DC circuit, whereas in your magnetic circuit is the reluctance right, it is just a analogy to that analogous to that right. And permeance in the DC circuit g is equal to 1 upon R, the conductance here the permeance that is 1 upon R that is Weber per ampere turns, so permeance of the magnetic circuit right.

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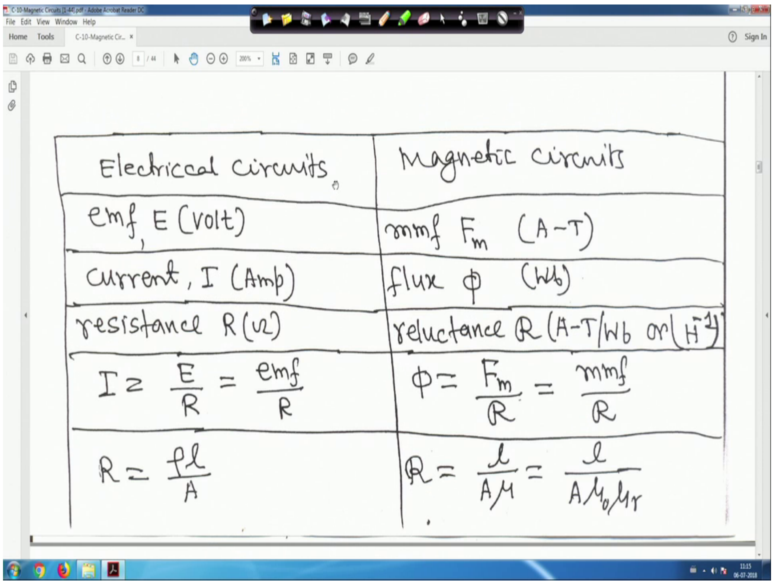

Electrical Circuits	Magnetic circuits
emf, E (volt)	mmf F_m (A-T)
current, I (Amp)	flux ϕ (Wb)
resistance R(Ω)	reluctance $\mathcal{R}$ (A-T/Wb or H^{-1})
$I = \frac{E}{R} = \frac{emf}{R}$	$\phi = \frac{F_m}{\mathcal{R}} = \frac{mmf}{\mathcal{R}}$
$R = \frac{\rho l}{A}$	$\mathcal{R} = \frac{l}{A\mu} = \frac{l}{A\mu_0\mu_r}$

So, that means, if I put it in a tabular form that analogue the analogous thing, electrical circuits say emf, E is a volt in magnetic circuit, it analogies F m right. Current here is I ampere in magnetic circuit in analogous is phi flux Weber. Now, resistance R ohm in electric circuit in per magnetic circuit, reluctance R ampere turns per Weber or Henry or your reciprocal right (Refer Time: 16:03) Henry to the power H 2 the power minus that means, 1 upon Henry right.

And current I is equal to E by R that is you know emf upon R. And here flux is equal to also it is analogous to that F m upon R right, because F m is analogous to E and R reluctance R is analogous to resistance. So, phi is equal to F m upon R so, this is actually called mmf upon reluctance right. Here it is emf upon resistance that is mmf upon reluctance. And R is equal to you know rho l upon A right in the case of reluctance, it is l upon A mu right, so l upon A mu 0 mu r; mu is equal to mu this is your what you call this is the analogy from the electrical circuit and magnetic circuit.

When we will solve the magnetic circuit, we will follow the same way the way you do super position or now we will phi current. Here also we can draw the magnetic circuit, and we can solve like this right. So, things are very simple, only thing is that the right hand rule little bit you we probably apply for various purposes the right hand rule. So, the because the polarity why do you make this magnetic equivalent circuit like electrical, you have to know which will be the plus, I mean analogous to your electrical circuit will be plus and which will be minus that will actually from the right hand rule will be determinant we will see that.

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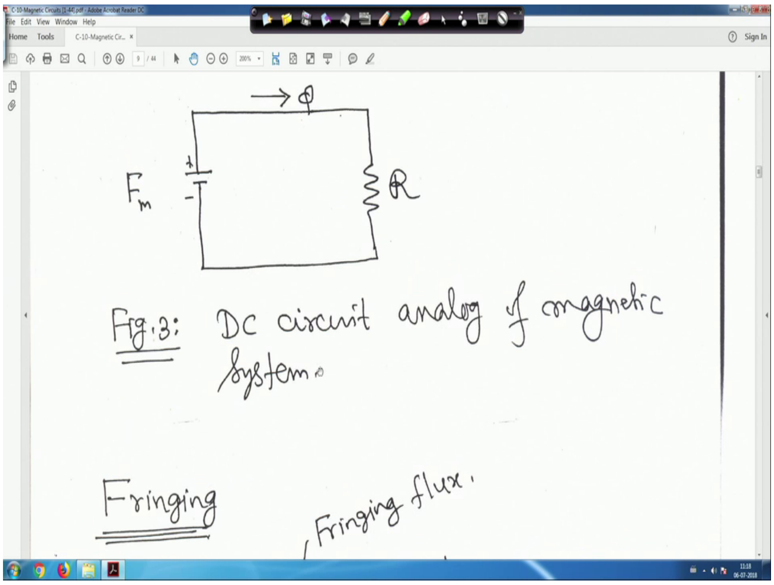

Fig.3: DC circuit analog of magnetic system.

So, now if we make the DC circuit magnetic circuit like this, so this is F m, and this is phi, this is R.

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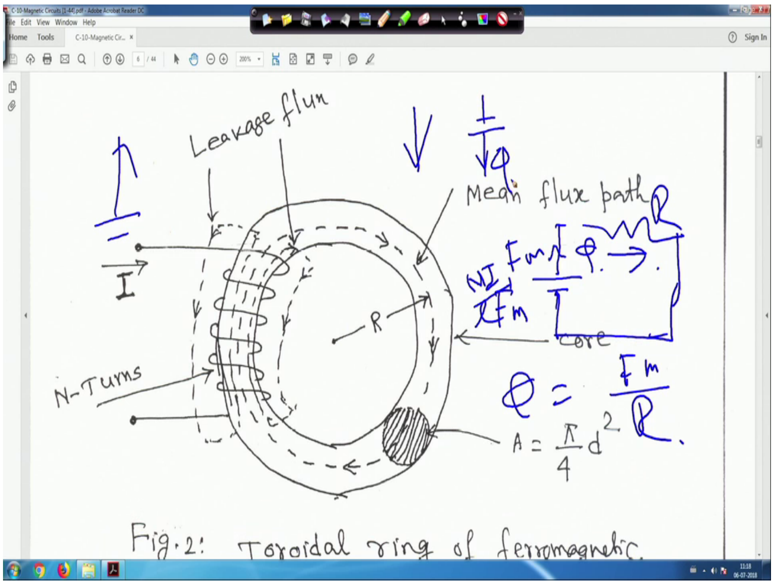

Fig.2: Toroidal ring of ferromagnetic

Actually, you how you have taken it that if you come to this your what you call this diagram, so if you look into that I could grabs the conductor and thumb will be direction of the flux right, so that means, flux line is suppose, this is my flux line, this is my flux.

So, as it is direction current actually leads the positive terminal for your (Refer Time: 17:50) your what you call for electric circuit say DC circuit right. For positive terminal that your what you call any take any voltage source that current actually living the positive terminal right that means, this is my plus, and then this is my minus.

So, this will be my F m, F m is equal to this N I right your what you call by your what you call l that is the ampere turns per meter, this is your that means, you have to see the whose direction you have to take the flux. So, if you grab the conductor, the flux is coming out, and then you put the reluctance and close the circuit, and this is your what you call the direction of the phi. So, phi actually is equal to your this is actually your F m. So, phi actually F m upon your reluctance right, and F m is equal to N I upon l.

So, whenever flux I mean whenever you take in a direction, you see that flux is leaving like this, then this will be your plus, this is minus for analogous. But, if you see in other way, if you can see direction of the flux is like this. Then this will be plus, and this will be minus, this is the direction of the flux got it, I think you have got it right so, this I will make it.

So, once you understand this, you will find magnetic circuit is very simple right. So that is why this circuit is drawn analogous to your say DC circuit say this is analogous to DC circuit so, your phi is equal to F m upon reluctance. So, this way you can draw the circuit, even you will see one or two problem that how to solve using this kind of circuit right. So, it is a DC circuit analogous of magnetic system right.

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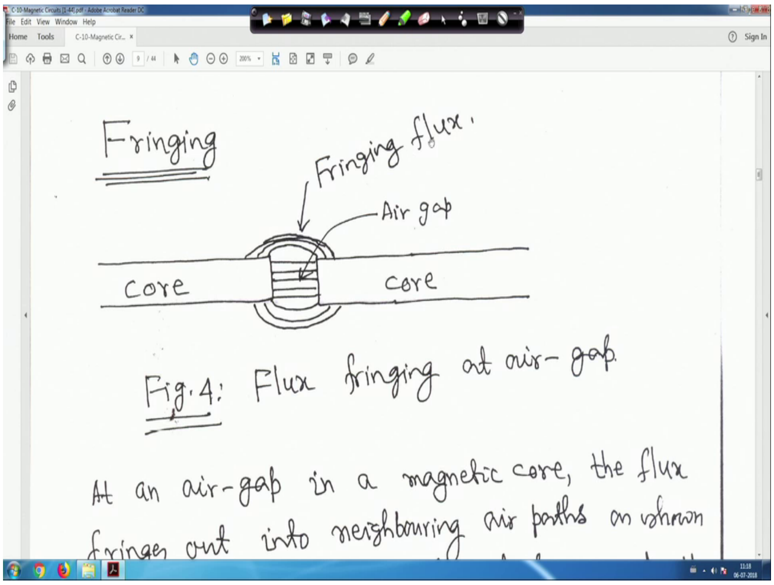

Fringing

Fig.4: Flux fringing at air-gap

At an air-gap in a magnetic core, the flux fringes out into neighbouring air paths as shown

Next is it is very simple thing next is fringing, it is fringing flux, which is air gap. And this one core, this is another core in between some air gap is there. So, it is actually if you look into that, the flux density is not uniform right, the particular the corner it will taking some different path, not directly going from this to that right, it is taking some different path.

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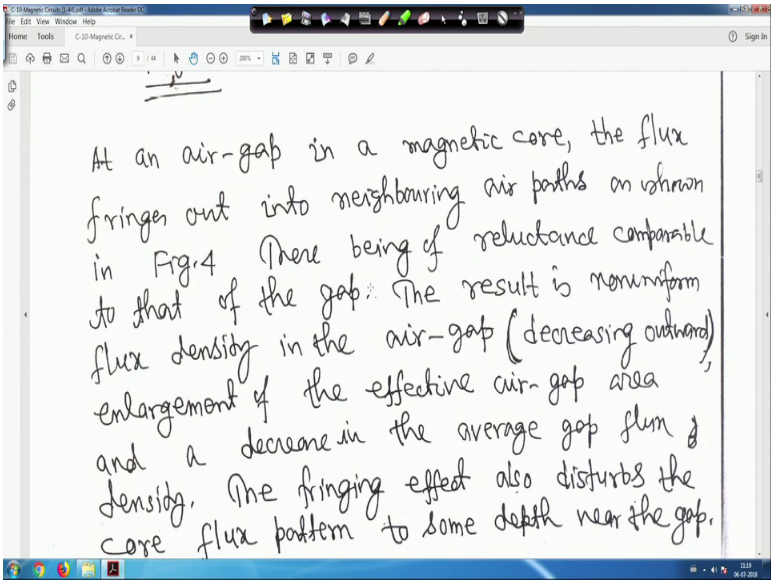

At an air-gap in a magnetic core, the flux fringes out into neighbouring air paths as shown in Fig.4 There being of reluctance comparable to that of the gap. The result is nonuniform flux density in the air-gap (decreasing outward), enlargement of the effective air-gap area and a decrease in the average gap flux density. The fringing effect also disturbs the core flux pattern to some depth near the gap.

So that means, at an air gap in a magnetic core right, the flux fringes is out into neighbouring area your sorry neighbouring air paths as shown in figure 4. So, it is like this, it is taking like this right so, this is basically your non-linear path right. So, there being of reluctance you are comparable to that of the gap right. The result is non uniform flux density in the air-gap that is decreasing outward right, so I mean decreasing your it is outwards. So, in that case, your what you call your that is your enlargement of the effective air gap area, and they decrease in the average gap your what you call average gap flux density. The fringing effect also disturbs the core flux patterns to some depth near the gap right.

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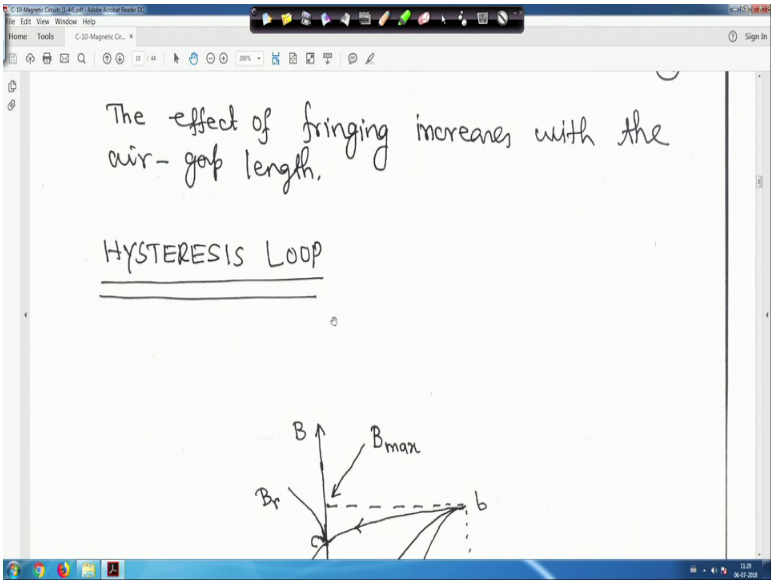

The effect of fringing increases with the air-gap length.

HYSTERESIS LOOP

And the effect of fringing increases with the air gap length I mean it is I mean it depends on the length right. So, I mean if it is the suppose if this air gap length increases, the fringing effect also will increase. So, this type of although we will not study in detail for this course, we will not study this, just to give an idea that flux density is not uniform right, an effective air because of this fringe effective your area is getting decrease right, so, this is called fringing.

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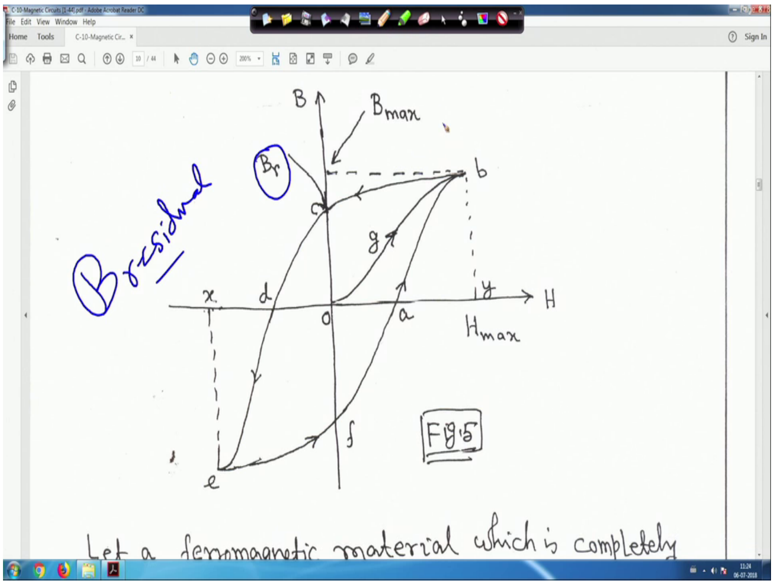

Let a ferromagnetic material which is completely

Now, next is the hysteresis loop, here we have to understand something what is hysteresis loop, because magnetic circuit you will see this one, so this hysteresis loop. So, magnetic you will see this a your what you call hysteresis loop suppose, this is in figure 5, it has been drawn.

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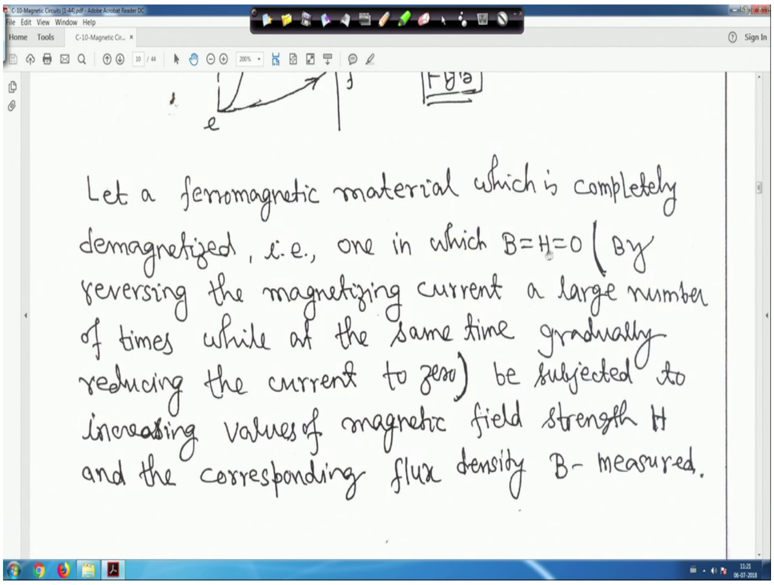

Let a ferromagnetic material which is completely demagnetized, i.e., one in which B=H=0 (By reversing the magnetizing current a large number of times while at the same time gradually reducing the current to zero) be subjected to increasing values of magnetic field strength H and the corresponding flux density B- measured.

Now, suppose let a ferromagnetic material, which is completely demagnetized that is one in which B is equal to H is equal to 0. Now, generally if you want to make that your what will if you want to completely demagnetize the ferromagnetic material, what you have to do is before going to the figure, you have to make B is equal to H is equal to 0 that means, I has to be 0. If H is equal to 0, I has to be I mean your 0 all right.

So, what you can do is so this by making this B is equal to H is equal to 0. By reversing the magnetizing current say I, a large number of times while at the same time gradually reducing the current to zero that means, several times you have to see you have to reverse the direction of the your magnetizing current, I mean large number of times, and while at the same time gradually you have to reduce in the current to zero, then only you will get B is equal to H is equal to 0. And be subjected to your what you call me subjected to increasing values of magnetic field strength H right, and the corresponding flux density B measured right.

So, in this case, what will happen that you have completely you are what we called demagnetize that ferromagnetic material, so that means, it is starting from 0. Now, what you can do is now what else I am do is that you are you are trying after making this, we are trying to increase the H right. So, H will what you call if H means you are increase the current right then this one we will follow the path o g b right.

So, in that case, what will happen that your H, now increasing values of magnetic field strength H and the corresponding flux density B measured right, so that means, you are increasing the H value now. Then we will starting from the origin that 0, because we have totally you are what you call demagnetize the ferromagnetic material, now we are increasing the H that means, we are increasing the current I say right.

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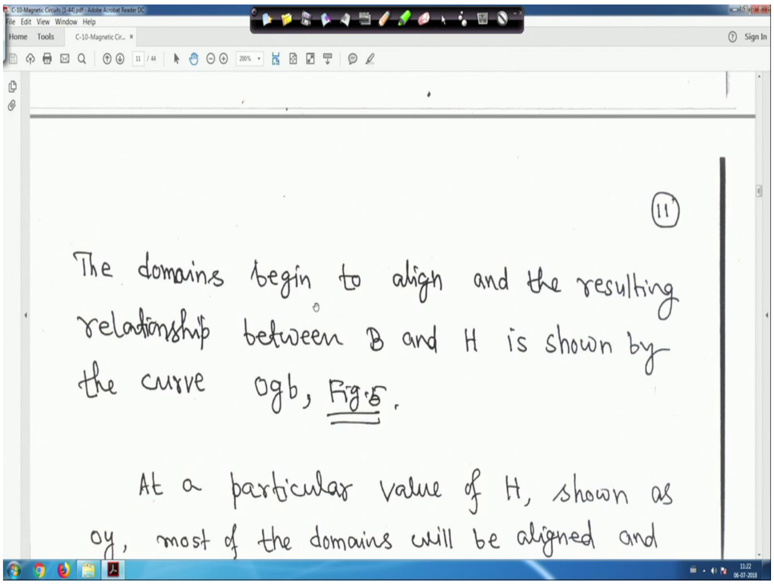

⑪

The domains begin to align and the resulting relationship between B and H is shown by the curve ogb, Fig.5.

At a particular value of H, shown as oy, most of the domains will be aligned and

So, in that case, what will happen after going on increasing the current right, the domains actually begins to align and the resulting relationship between B and H is shown by the curve o g b right. So, this is the curve o g b right, this is the middle line right, this middle your curve right o g b right, suppose it has reach up to H.

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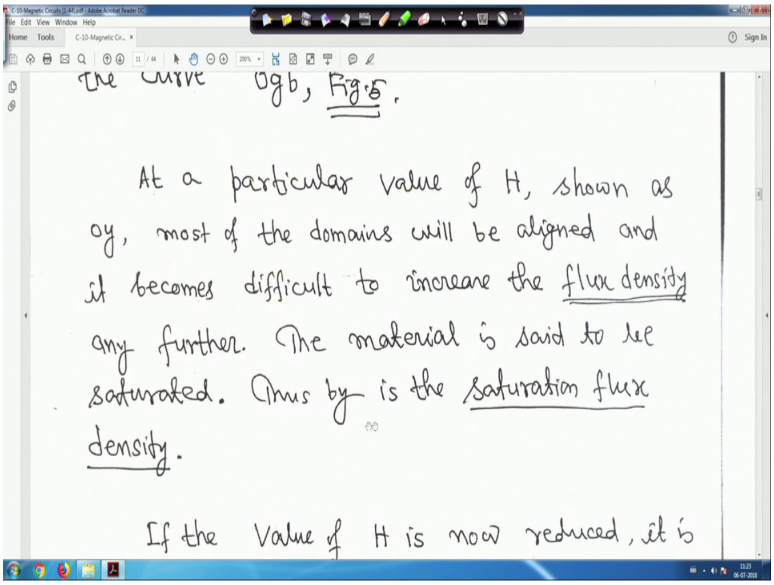

the curve ogb, Fig.5.

At a particular value of H, shown as oy, most of the domains will be aligned and it becomes difficult to increase the flux density any further. The material is said to be saturated. Thus by is the saturation flux density.

If the value of H is now reduced, it is

Now, if you come to this, now at a particular value of H as shown in o y, most of the domains will be you are aligned, and it becomes difficult to increase the flux density any further. The material is said to be saturated, thus by the saturations flux density that means, this you are increasing. Now, current is increasing, you will reach a value that value that is o y, this is o, and this is your y, o y right.

So, after that even if you increase your you try to increase H max that is I, you will find that flux density is not increasing, so this is the maximum value after saturation right. And this is your maximum flux density, and you can say this has been you are what you call it is saturated. So, that is why it is written here that you are what you call that after that flux density will not increase, the material is said to be saturated; now it is saturated. Thus is by is the saturation flux density B r.

So, this is my H max, and this is my B ma[x] this is your what you call this is your what you call the B max, it is saturated right. Now, and one thing is there, this B r do not read at it as saturated right, it is actually later we will see, it is actually B residual right, so anyway we will come to that. So, this one, so just 1 minute, let me this thing right.

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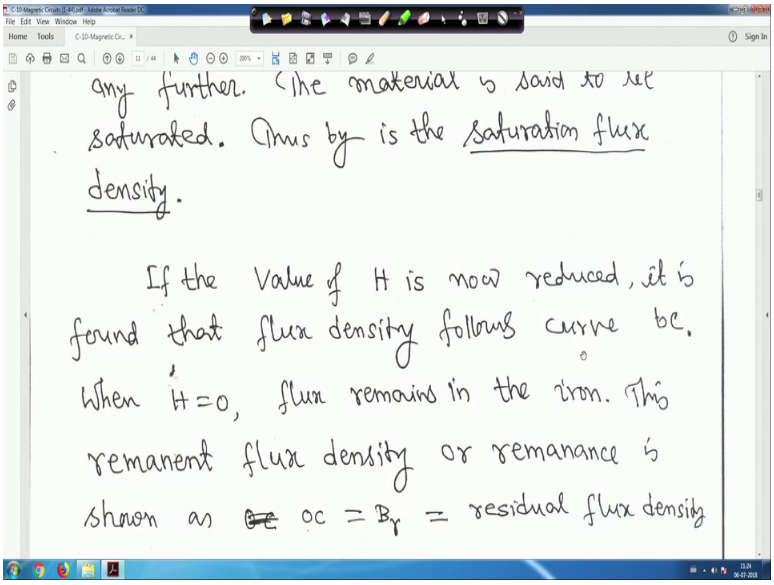

any further. The material is said to be saturated. Thus by is the saturation flux density.

If the value of H is now reduced, it is found that flux density follows curve bc. When $H=0$, flux remains in the iron. This remanent flux density or remanance is shown as oc $= B_r =$ residual flux density

So, after that what you will do that your now if the values of H is now reduce it right you try to reduce, it is found that flux density follows the curve b c right.

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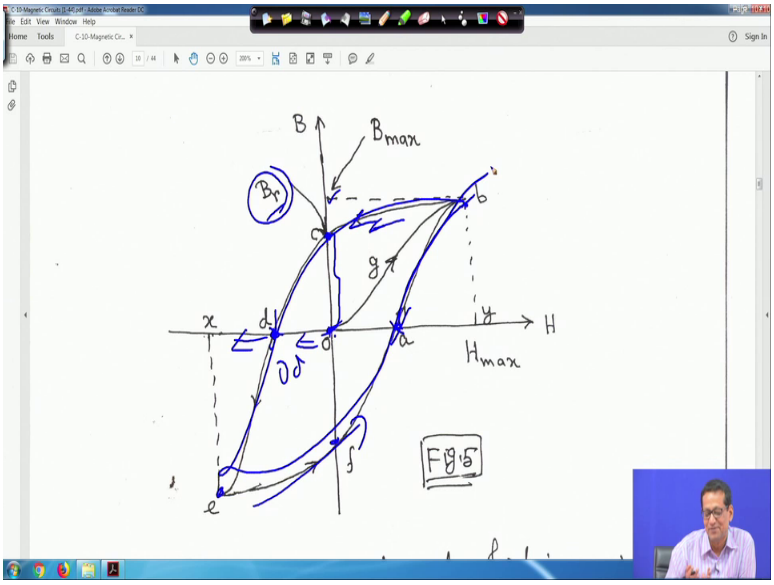

Now, when you try to when you try to reduce b c or what you call try to reduce the current now, suppose why I am moving in this the curve reducing the current, so it is moving in this direction. So, you will find when H is equal to 0, some flux will be there in the material, this is actually call residual flux right. So, this o c actually o to c that is your B r, it is actually residual flux right. So, although H is equal to 0, but some residual magnetism will be there, this is called your what you call that residual flux right, and this is residual flux density.

Now, further if you reverse the direction of the current right, now this side you are moving, you will come to some point o d right that this point o d. So, some value of will be there in the reverse direction that H value or you are reversing the direction of the current, at that time you will find that this value right your what you call this flux density right, this value you are slowly and slowly coming to 0. At that time, you will find B is equal to 0 at this point right.

So, what is happening, first it is we are from here, we have increasing the it will reach to the saturation, we call saturation flux density. Then this your B max, then you are reversing the direction of the current. When you are reversing the that means, current is decreasing now current is we are decreasing, not reversing, we are decreasing the current. So, here at this point, it will come some residual flux will be there. Further we are reversing the direction of the current, so it will come to this portion, where you will get H value will be negative, and you will find your flux density B at this point is 0 right.

Same philosophy will happen, if you further go on your what you call that your increase the current in the negative direction I mean this thing, the way it has reached here same way it will the right, and it will get as get a point there like your saturated point you will get there. And again further you are moving again in this direction, that again you are you are what you call go with your this negative current this side, you are slowly and slowly you are decreasing and coming to this point, so some residual magnetism again will be here.

And finally, again after this point same as before, see it will come like this, and finally it will come like this. So, this way your B H loop will be completed right. So, this is actually your what you call that your B H curve of a with a ferromagnetic material right.

So, this is what we have this thing right, what you have understood. This did not much we will just as is a magnetic circuit, so you have to explain, then you have to your what you call little bit understand on that, so that means, everything is given here, that from here it will start, but finally, it will move like this right. So, just step by step you go through whatever I have written here and whatever I will said right, and that is the philosophy behind this right.

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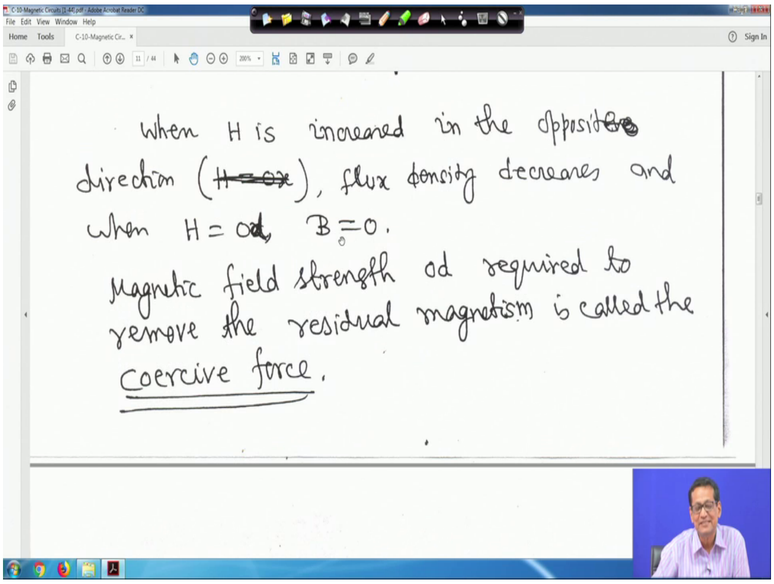

When H is increased in the opposite direction (~~H = ox~~), flux density decreases and when $H = od$, $B = 0$.

Magnetic field strength od required to remove the residual magnetism is called the coercive force.

So, here also everything is whatever I said everything is written here right. And one thing is there magnetic field strength that is o d required to remove the residual magnetism is called coercive force right. So, this time in this value, this is this value actually this is the value, this is o d, this is that your this is your o d this, portion this portion right.

This is your whatever free step is required right to make the flux density is 0, this o d is required that is your H is equal to o d, this will be negative value, this is actually called coercive force right let me clear it. So, this is this is actually this one that magnetic field strength o d required to remove the residual magnetism is called the coercive force right.

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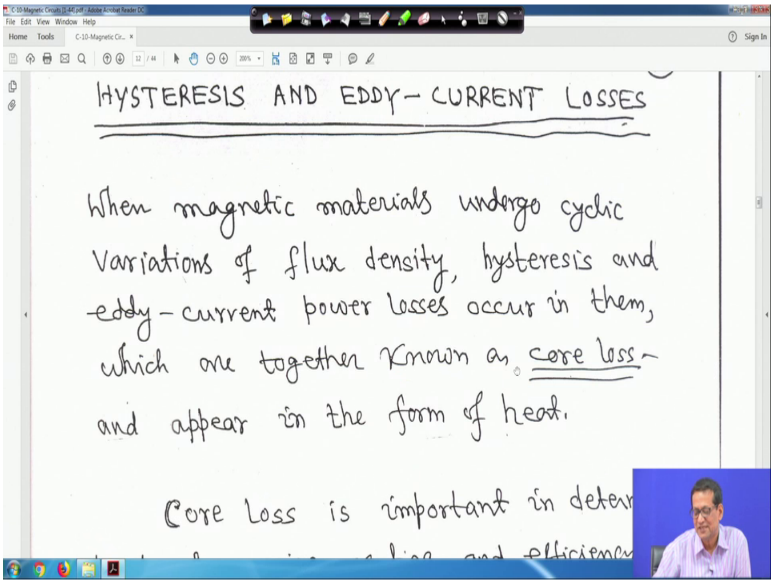

HYSTERESIS AND EDDY-CURRENT LOSSES

When magnetic materials undergo cyclic Variations of flux density, hysteresis and eddy-current power losses occur in them, which are together known as core loss and appear in the form of heat.

Core Loss is important in deter

So, hysteresis and eddy-current losses, when magnetic materials undergoes cyclic variation of flux density right, hysteresis and eddy-current power losses occur in them, which are together known as core loss. Core loss means hysteresis loss plus eddy-current loss right, we will see later in the single phase transformer after this topic. So, and appear in the form of heat right.

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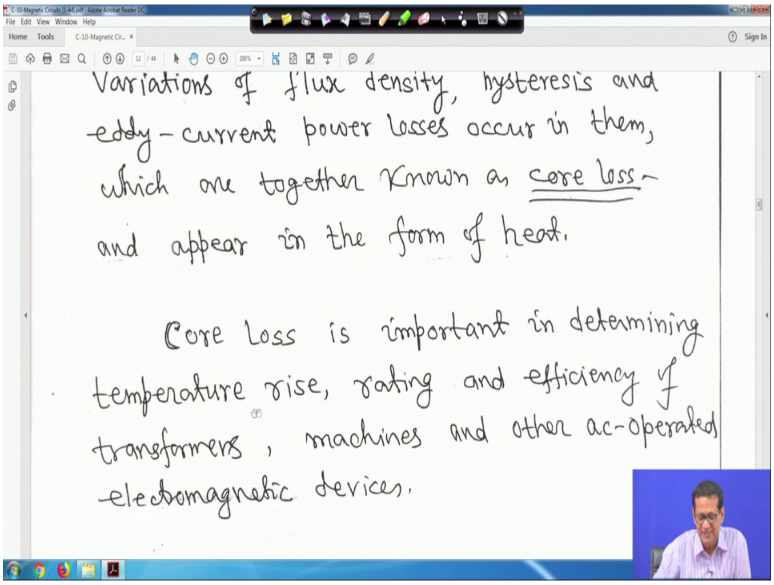

Variations of flux density, hysteresis and eddy-current power losses occur in them, which are together known as core loss and appear in the form of heat.

Core loss is important in determining temperature rise, rating and efficiency of transformers, machines and other ac-operated electromagnetic devices.

So, core loss is important in determining temperature rise, rating and efficiency of transformer, we will see that right, machines and other your AC-operated electro your what you call AC-operated in electromagnetic devices.

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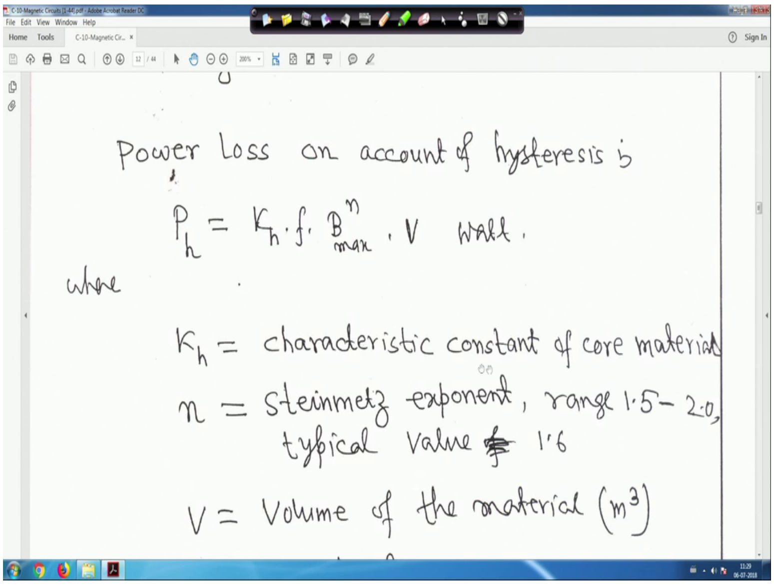

Power loss on account of hysteresis is

$$P_h = K_h \cdot f \cdot B_{max}^n \cdot V \text{ watt.}$$

where

K_h = characteristic constant of core material

n = Steinmetz exponent, range 1.5 – 2.0, typical value 1.6

V = Volume of the material (m^3)

So, now power loss on the account of hysteresis is actually it is an empirical formula right key or K h into f into B max to the power n into your what you call V watts right. So, your V is not the voltage, V is the value of the material right. So, K h is characteristic constant of your core material, n is equal to Steinmetz exponent, range 1.5-2.0, typical value is 1.6, so it is called Steinmetz constant right. And V is equal to volume of the material in meter cube. This V is actually meter cube volume right. And f is equal to supply frequency is hertz, this f in hertz right. This is the formula for the your what you call for the your hysteresis loss right.

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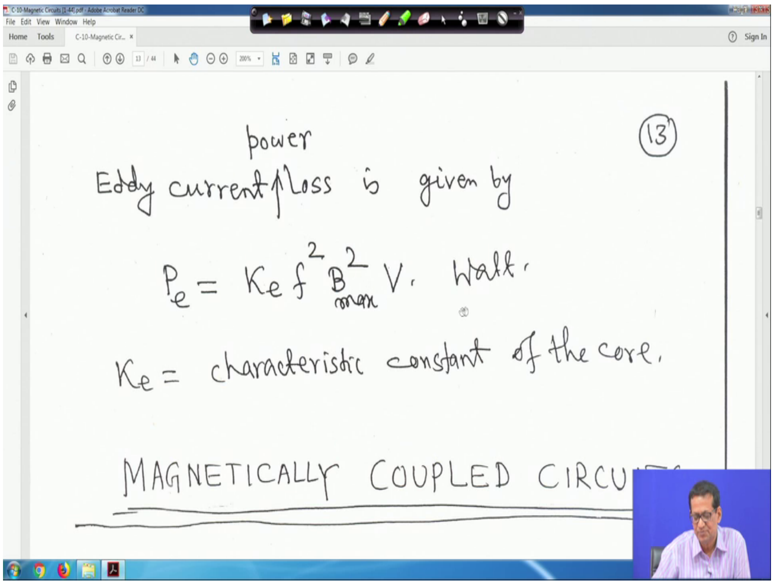

⑬

Eddy current power loss is given by

$$P_e = K_e f^2 B_{max}^2 V. \text{ Watt.}$$

K_e = characteristic constant of the core.

MAGNETICALLY COUPLED CIRCU

Similarly, for eddy current power loss is given by it is K e f square B max square into V watt. For some material, it can be derived, but here this is your what to call we are not giving that derivation and other thing, just you keep it in your mind that K e is the f square B max square into V watt. So, K e is the characteristic constant of the core right. So, up to this, your what you call that you are regarding little bit on magnetic circuit.

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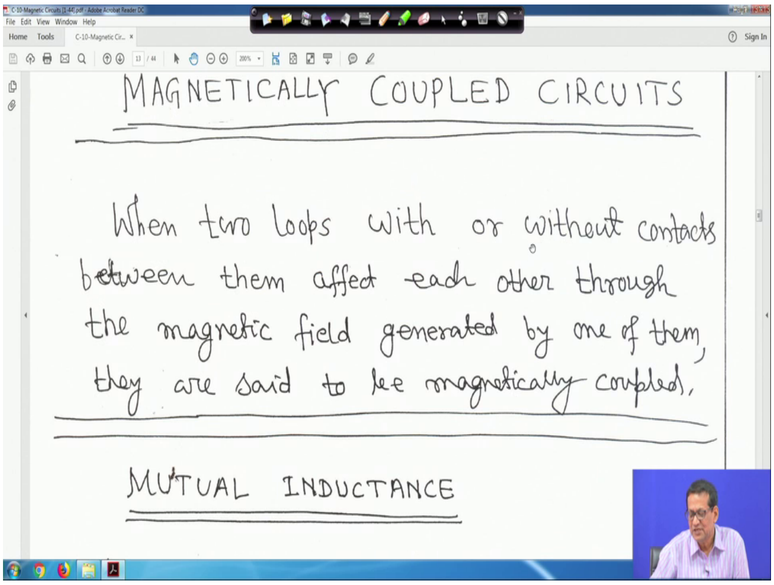

MAGNETICALLY COUPLED CIRCUITS

When two loops with or without contacts between them affect each other through the magnetic field generated by one of them, they are said to be magnetically coupled.

MUTUAL INDUCTANCE

Now, next is magnetically coupled circuit. So, when two loops with or without contact between them affect each other through the magnetic field generated by one of them, they are said to be magnetically coupled right. Suppose, you have two loops with or without contact between them, but affect each other through the magnetic field generated by one of them, they are said to be magnetically coupled. Then two loops are there, if one loop is carrying that your what you call that time varying current, and another loop that some flux will be it will links some flux to the other coil right, and they are said to be actually magnetically coupled.

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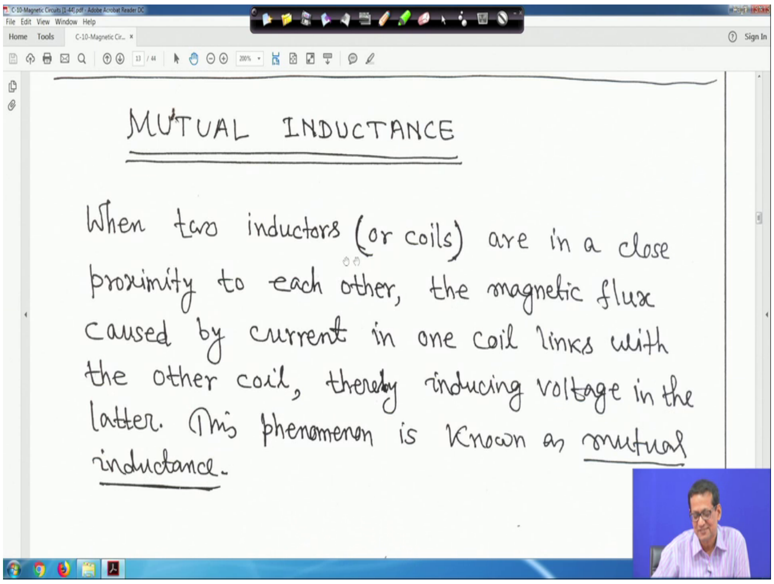

MUTUAL INDUCTANCE

When two inductors (or coils) are in a close proximity to each other, the magnetic flux caused by current in one coil links with the other coil, thereby inducing voltage in the latter. This phenomenon is known as mutual inductance.

Now, mutual inductance, now, when two inductors or coils right are in a close proximity to each other, the magnetic flux will see later in the circuit diagram, the magnetic flux caused by current in one coil links with other coil right, thereby inducing voltage in the latter right. And this phenomenon is known as mutual inductance, that means, when two inductors or two coils are there in a close proximity to each other, the magnetic flux caused by current in one coil links with the other coil, thereby inducing voltage in the latter; this phenomenon is known as mutual inductance right.

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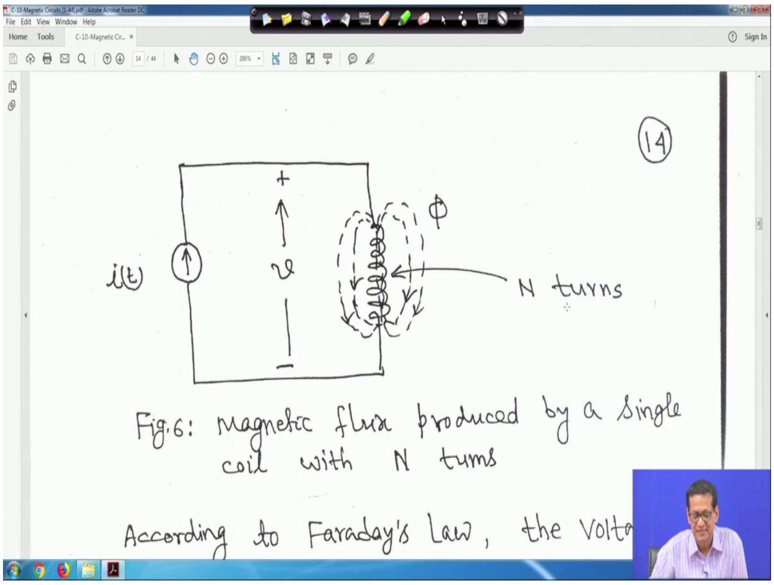

Fig.6: magnetic flux produced by a single coil with N turns

According to Faraday's Law, the volt

So, for example, suppose this is simple circuit, this current is current sources shown say it is i t for easy understanding, and voltage across v’s beyond this. This is the phi right that flux your what you call this is a time varying your what to call time varying current, and this is the flux phi right, and it has number of your N turns.

So, in your what you call the magnetic flux produced by a single coil with N turns. So, in this case also, if you your what you call that this is the your what you call this is the direction of the your what you call direction of the flux right, and this is your N turn.

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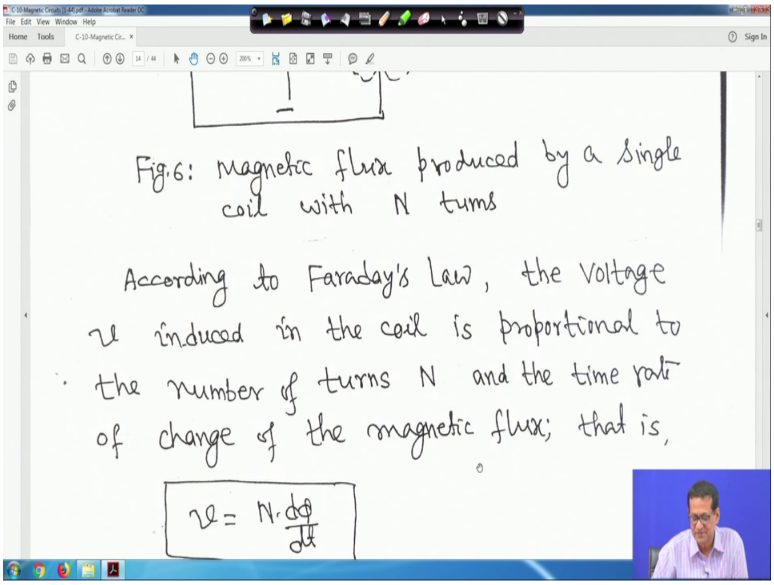

Fig.6: magnetic flux produced by a single coil with N turns

According to Faraday's law, the voltage v induced in the coil is proportional to the number of turns N and the time rate of change of the magnetic flux; that is,

$$\boxed{v = N\cdot\frac{d\phi}{dt}}$$

So, in that case what according to Faraday's law right, according to your Faraday's law, so your the voltage v induced in the coil is proportional to the number of turns N and the time rate of change of the magnetic of the flux that is we know, the v is equal to N into d phi by d t right. So that means, v is equal to N into d phi by d t right but, question is that this phi the flux phi it depends on the current I. If I decreases, phi will decrease; if I increases, phi will increase right. So, this phi actually that phi actually is a for your what you call it say is a function of I.

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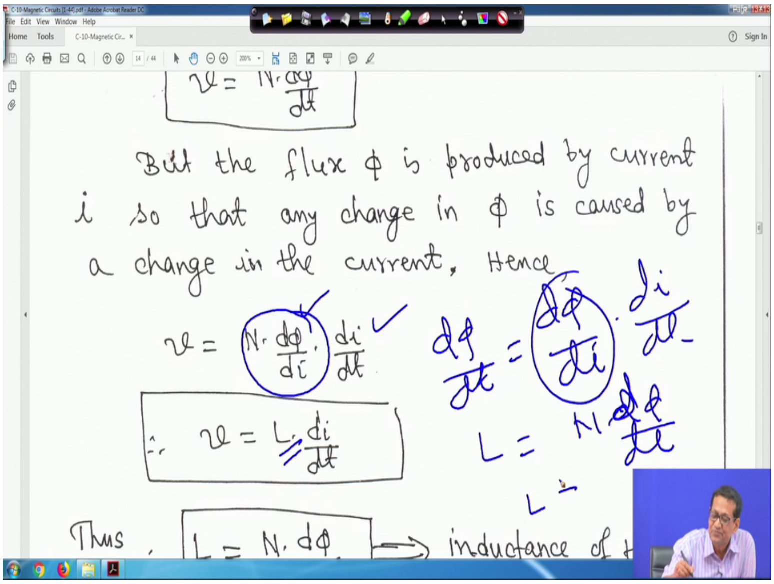

$$\boxed{v = N\cdot\frac{d\phi}{dt}}$$

But the flux ϕ is produced by current i so that any change in ϕ is caused by a change in the current, Hence

$$v = \boxed{N\cdot\frac{d\phi}{di}}\cdot\frac{di}{dt} \checkmark$$

$$\frac{d\phi}{dt} = \boxed{\frac{d\phi}{di}}\cdot\frac{di}{dt}$$

$$L = N\cdot\frac{d\phi}{dt}$$

$$L =$$

$$\boxed{\therefore\ v = L\cdot\frac{di}{dt}}$$

Thus, $\boxed{L = N\cdot d\phi}$ ⟶ inductance of

So, in that case what will happen that your that means, this equation this N into d phi by d t, we can write as a chain rule right. So, d phi by d t, we can write d phi by d i into d i by d t right. So, it is d phi by d i and d i by d t. So, this term N d phi by d i, this is actually L, the inductance that means, v is equal to L into d i by d t, which you have seen earlier also right, so L into d i by d t. And your L is equal to N into L is equal to N into d phi by d i right; or in general, sometimes we can write L let me clear it.

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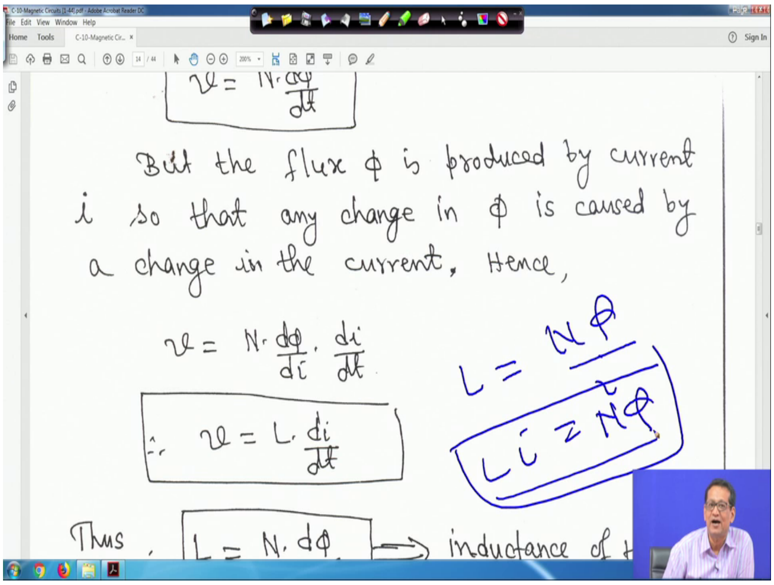

$$\boxed{v = N.\frac{d\phi}{dt}}$$

But the flux ϕ is produced by current i so that any change in ϕ is caused by a change in the current, Hence,

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

$$\boxed{\therefore\ v = L.\frac{di}{dt}}$$

$$L = \frac{N\phi}{i}$$

$$\boxed{Li = N\phi}$$

Thus, $\boxed{L = N.d\phi}$ ⟹ inductance of

That means, sometimes you write that your L is equal to right N phi by your i that means, L i is equal to N phi right. This is also we require for numericals that L i is equal to N phi.

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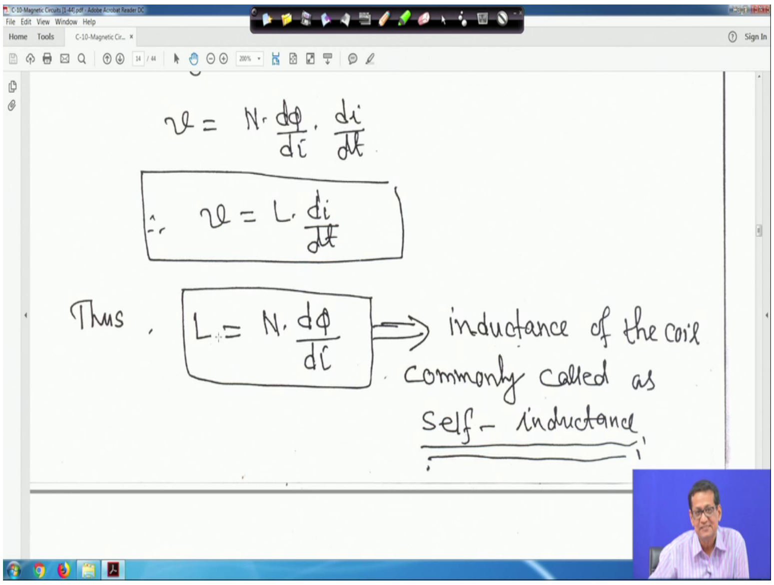

$$v = N \cdot \frac{d\phi}{di} \cdot \frac{di}{dt}$$

$$\boxed{\therefore\ v = L \cdot \frac{di}{dt}}$$

Thus, $\boxed{L = N \cdot \frac{d\phi}{di}} \Longrightarrow$ inductance of the coil commonly called as self-inductance.

So, that means, v is equal to L and L is equal to N into d phi, so inductance of the coil commonly called as self-inductance. So, this is actually self-inductance for this kind of coil. And in the here there is no other coil in the your what you call in the vicinity of this right, no other coil.

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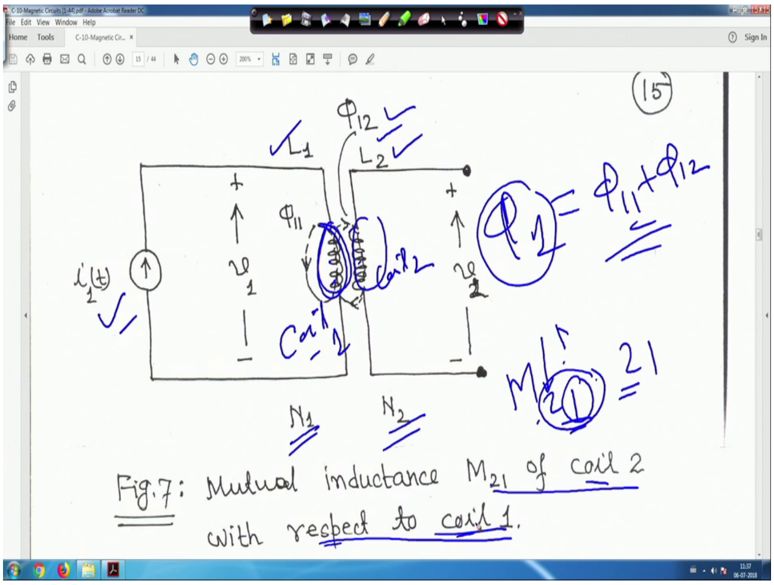

$$\phi_1 = \phi_{11} + \phi_{12}$$

M_{21}

Fig.7: Mutual inductance M_{21} of coil 2 with respect to coil 1.

So, next is your suppose this is the your what you call this is your two coils in the your what you call mutual inductance M 2 1 of coil 2 with respect to coil 1. Now, here a current source is i 1 t is there, this side it is not there, so it is volt[age] earlier voltage here is measured v 2. And two coils are there so, if my total flux linkage, if total flux linkages say my phi say this phi 1 for this coil 1, this is coil 1, this is my coil 1, and this is my coil 2, this inductance is L 1, inductance is L 2.

So, total flux is phi 1 so, phi 1 1 is the flux linkages your what you call your this coil 1 right. In addition to that, phi 1 to another path right, it will all it will phi 1 to also link phi coil 1 as well as your coil 2, this is actually mutual flux. So, this phi 1 is equal to your phi 1 1 plus phi 1 2 what actually you are doing, phi 1 is the total flux right that links this your what you call links the coil 1, but phi 1 2 actually links the coil 2.

This is your this is the other part linking the coil. So, phi 1 1 plus phi 12 it links the coil 1, and phi 1 2 only links the coil 2. So, phi 1 is equal to phi 1 1 plus phi 1 2 right and whenever you say mutual and number of turns of the coil 1 is N 1, and number of the turns in coil is N 2 right.

And mutual inductance M 2 1 means 2 1 means coil 2 with respect to coil 1. When you say M 2 1 right that means, coil 1 is excited by some current i 1 right, and that is the thing. And we are trying to find out the mutual inductance M 2 1 that is that is this one M 2 1. So mutual inductance M 2 1 of coil 2 with respect to coil 1 whenever, we write M 2 1 means, it is actually what you call mutual inductance of the coil 2 with respect to coil 1, this way you will read rights. This meaning of the suffix 2 1 is like that, the mutual inductance M 2 1 whatever writing here with respect to your what you call of coil 2 with respect to coil 1 right.

So, thank you very much, we will be back again.