Electrical Measurement and Electronic Instruments
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Lecture - 02
Electrodynamic Instrument

Hello and welcome. So, this is our second Tutorial of Electrical Measurement and Instruments.

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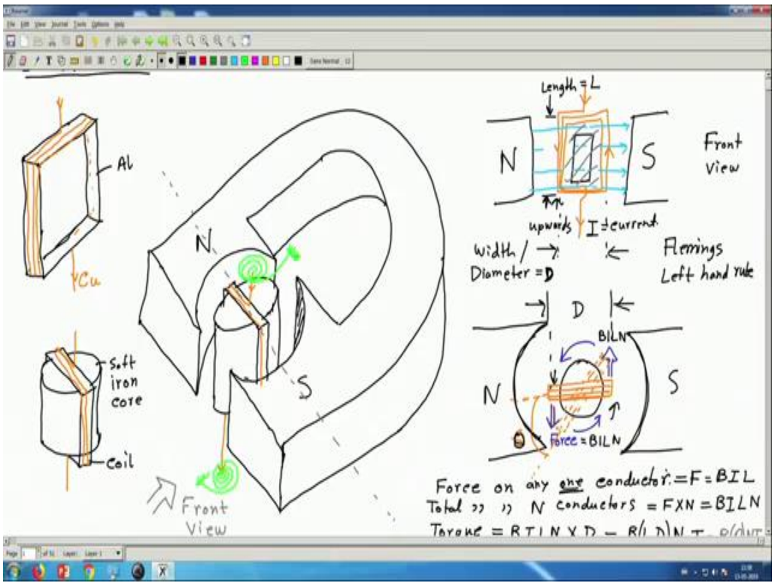

Force on any one conductor = F = BIL
Total " " N conductors = F×N = BILN

And in our last class, we have seen the working principle of an ammeter, which you call permanent magnet moving coil instrument, PMMC or D' Arsonval's Galvanometer and we have found the expression for torque and the deflection angle. So, let us recall them in a brief.

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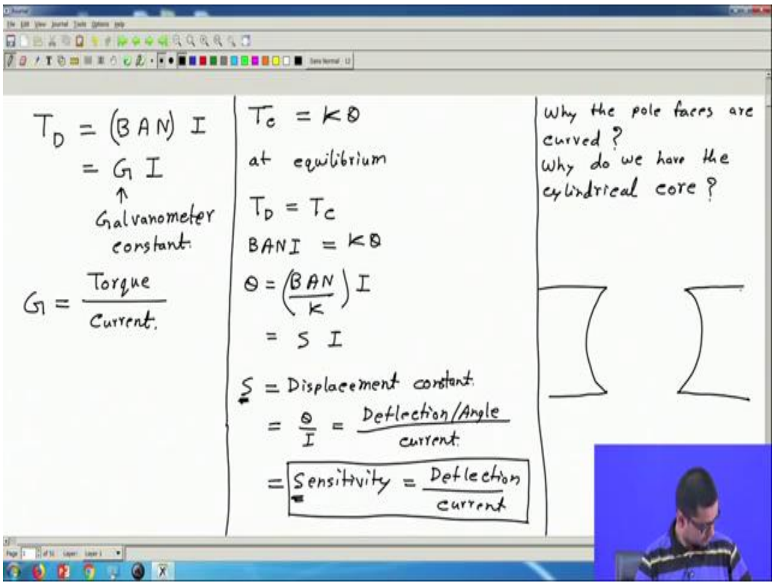

$$T_D = (B\,A\,N)\ I$$
$$= G\ I$$
$\uparrow$ Galvanometer constant.

$$G = \frac{\text{Torque}}{\text{Current.}}$$

$$T_c = K\theta$$

at equilibrium

$$T_D = T_C$$
$$BANI = K\theta$$
$$\theta = \left(\frac{BAN}{K}\right) I$$
$$= S\ I$$

$\underline{S}$ = Displacement constant.

$$= \frac{\theta}{I} = \frac{\text{Deflection/Angle}}{\text{current.}}$$

$$= \boxed{\underline{S}\text{ensitivity} = \frac{\text{Deflection}}{\text{current}}}$$

Why the pole faces are curved?

Why do we have the cylindrical core?

$$T_D = (B\ A\ N)\ I$$

So, all these constants we can write together as a common constant and I am giving it a name G.

$$T_D = G\ I$$

And, then this G is often called the galvanometer constant. Now, the name is not that important, but what is the dimension of this G?

$$G = \left(\frac{Torque}{Current}\right)$$

Then, we have seen that the controlling torque, which is nothing but this spring torque,

$$T_C = K\theta$$

$$T_D = T_C$$

$$B\ A\ N\ I = K\theta$$

$$\theta = \left(\frac{B\ A\ N}{K}\right) \mathrm{I} = \mathrm{S\ I}$$

And this constant S is can be called as displacement constant, once again the names are not that important to remember. You need not remember this or memorize these names, it is not required. You just need to understand it.

Now, what is S?

$$S = \left(\frac{\theta}{I}\right) = \left(\frac{Deflection/Angle}{Current}\right)$$

This we can also call as the sensitivity of the instrument. And, that is why I have used the letter S. Why sensitivity? Because, if we have an instrument where for smaller amount of current I, we get larger amount of deflection, we say that instrument is more sensitive, because it can detect or measure smaller current, because we can get higher deflection with smaller amount of current.

So, S is a measure of sensitivity, how sensitive that instrument is, that meter is, more the sensitivity is, we can measure smaller current easily. So, sensitivity is nothing but the deflection per unit current. So, this is the definition of sensitivity, this you should know. Now, I would like to mention some small facts about the construction of this instrument, which is a bit more detailed, but it is interesting to know. So, basically I am going to talk about why we have this pole faces curved like a cylinder. So, this is what we are going to talk about. Why the pole faces are curved and also why do we have the cylindrical core? So, let us look at these questions briefly.

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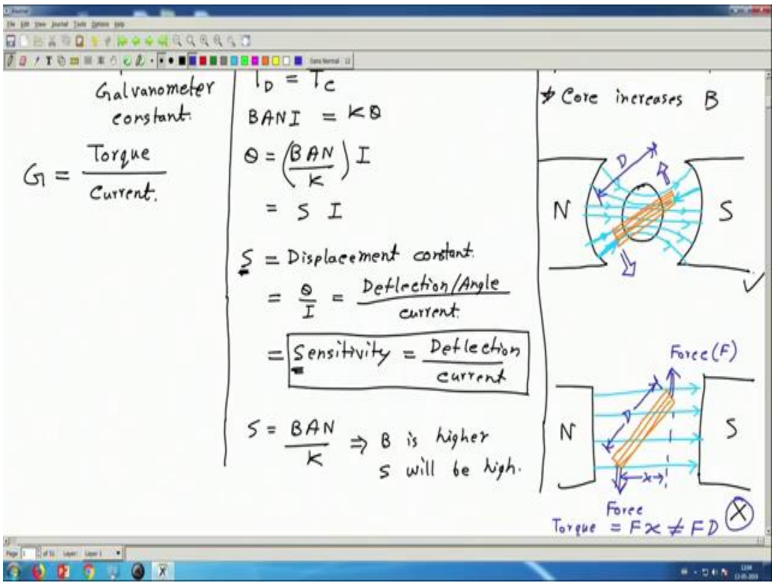

Galvanometer constant.

$G = \frac{\text{Torque}}{\text{Current.}}$

$T_D = T_C$

$BANI = K\theta$

$\theta = \left(\frac{BAN}{K}\right) I$

$= S\ I$

S = Displacement constant.

$= \frac{\theta}{I} = \frac{\text{Deflection/Angle}}{\text{current.}}$

$= \boxed{\text{Sensitivity} = \frac{\text{Deflection}}{\text{current}}}$

$S = \frac{BAN}{K} \Rightarrow$ B is higher S will be high.

* Core increases B

So, these are 2 pole faces and we have a cylindrical core. Now, the core will definitely increase the amount of flux density, because this core has a higher permeability, lower reluctance than air. So, more flux will pass through this north to South Pole. So, more flux can now pass like this, that, if it did not have this core, then the flux density would have been lower. So, the core increases flux density B. So, if we have higher value of B,

$$S = \left(\frac{B\ A\ N}{K}\right)$$

So, if B is higher, then sensitivity will be high. So, you will have a higher sensitive instrument. Secondly, this core and these curved faces of the poles make the flux lines radial. Radial means, the flux lines are like this. So, they go like radially or that means these lines are almost perpendicular to this circular or cylindrical surface of the core. If, we did not have this core or if we had this pole faces flat like this, then the flux lines would have been almost parallel like this. This is generally not used, this is generally used. I mean, this is how it is constructed, generally this is not used.

Now, if we have this situation, where the poles are flat and we if we do not have any core, then you will have some small problem. Suppose this is my coil, which is now at this angle. Now, when it carries any current, it will have some force acting on the 2 sides and the direction of the force will always be perpendicular to the direction of the flux lines and the current.

$$Torque = Fx \neq FD$$

Now, therefore, depending on the position or the angle of the coil, we will have different value or different expression for torque here. So, in this case the torque expression will be different from this case. Similarly, the angle of deflection will also be different in this case from this, but here you see that if I have the coil here at any angle the flux lines are always like this. So, if this is this flux lines are radial which means, it is always along the coil.

And, therefore, the force will be in this direction. And, then the perpendicular distance between the 2 forces is still the diameter D, and this is always D irrespective of the angle of this coil, here it is not. So, this is generally not used, this is the situation which we have in our ammeters.

Now, let us move to another topic, another type of instruments, which is very similar to PMMC instrument and this new instrument is called Electrodynamic Instrument.

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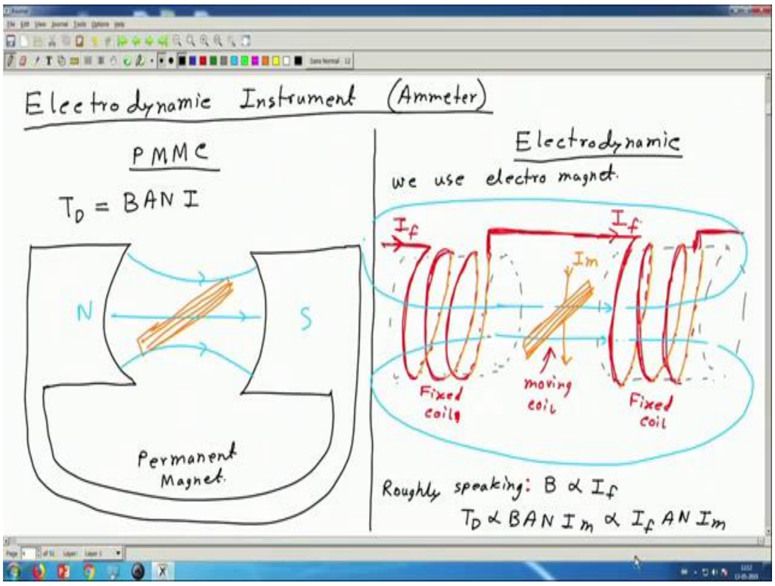

Electrodynamic Instrument (Ammeter)

PMMC

$T_D = BANI$

Electrodynamic

we use electro magnet.

Roughly speaking: $B \propto I_f$

$T_D \propto BANI_m \propto I_f A N I_m$

So, this is again an ammeter. Now, let us draw the two instruments, two type of instrument side by side. So, on this side let me draw the instruments that we have just studied, PMMC and here we will draw electrodynamic. So, in PMMC instruments what do you have? We have a pair of magnetic poles; it is not normally flat, generally it is like this. And, you know that this two sides are connected. And, we have the coil here. We also have the core and the coil turns in this magnetic field. In electrodynamic instruments, the only difference is that, instead of having this permanent magnet, so this is a permanent magnet here we will use electromagnets. So, here we use electromagnet. Electromagnets are nothing but coils or solenoids. So, we will have a pair of coils. So, I will have one coil like this. So, these are the turns, these are the not different turns of a coil and this is one end of this coil and this is another end of this coil.

Now, here again I will have another coil which again is like this. So, these are the sides of this coil and this is one end, and this is another end. Now, if you have any current I through this and also some current I through this. Let me draw the coil completely for a better visualization. So now, if there is some current, it will generate some magnetic flux like this, this can be continuous.

So, you will have many lines of forces and then we of course have this other coil which is this one, here. This is the coil that moves that turns, this is the same coil as this. The only difference is that here we have electromagnet instead of a permanent magnet. So, this is the only difference.

$$T_D = B\ A\ N\ I$$

So, roughly speaking so, we can say that the flux density B here will be proportional to this current, which flows through this pair of coils. So, I can actually join these coils, these two coils together in series. So, that same amount of current flows and let me call this current as I_f or you can call it I_{fixed}. Because, these 2 coils are fixed coils, they do not move, they do not turn, they are stationary, they do not move, but this central coil moves. Like here, this permanent magnet does not move, but this central coil moves similarly here, these two electromagnets do not move, but this central coil moves.

So, therefore, we call this as the fixed coil. So, these are called fixed coils, this is fixed coils, and this is called the moving coil, this is also the moving coil.

$$B\ \alpha\ I_f$$

$$T_D \alpha\ B\ A\ N\ I_f\ \alpha\ I_f\ A\ N\ I_m$$

$$T_D\ \alpha\ I_m I_m$$

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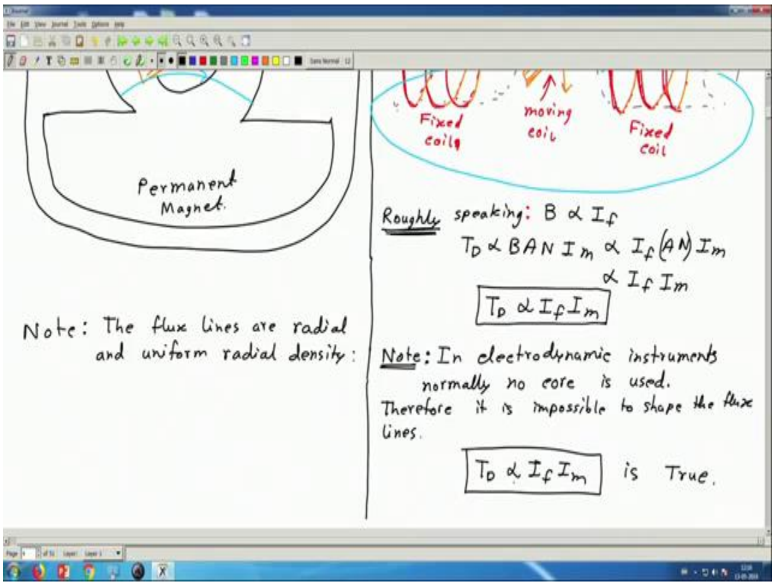

Note: The flux lines are radial and uniform radial density:

Roughly speaking: $B \propto I_f$

$T_D \propto B A N I_m \propto I_f (A N) I_m$

$\propto I_f I_m$

$\boxed{T_D \propto I_f I_m}$

Note: In electrodynamic instruments normally no core is used.

Therefore it is impossible to shape the flux lines.

$\boxed{T_D \propto I_f I_m}$ is True.

So, where I_f is the current through this coil and I_m is the current through the moving coil fixed and moving coil. So, why I am saying this is a rough idea. This is because just note that, in this case we also have the core, the flux lines are radial and uniform radial density, but in electrodynamic instruments, generally no core is used. In electrodynamic instruments, normally no core is used. There is no core here, also these coils these fixed coils, they also do not have any core, that is why I have not drawn any core here. I have just drawn a dash line for ease of drawing, but there is no core.

I will tell you later why we do not use any core, but right now you just know that there is no core in electrodynamic instruments. Therefore, it is not possible, it is impossible to shape the flux lines. So, flux lines are not radial as in this case, flux may not be uniform. Just normally, it may be non-uniform, it may be non-radial.

$$T_D = I_m I_f \frac{dM}{d\theta}$$

Now, we will give you more precise expression for this deflecting torque, expression for deflecting torque in an electro dynamic instrument.

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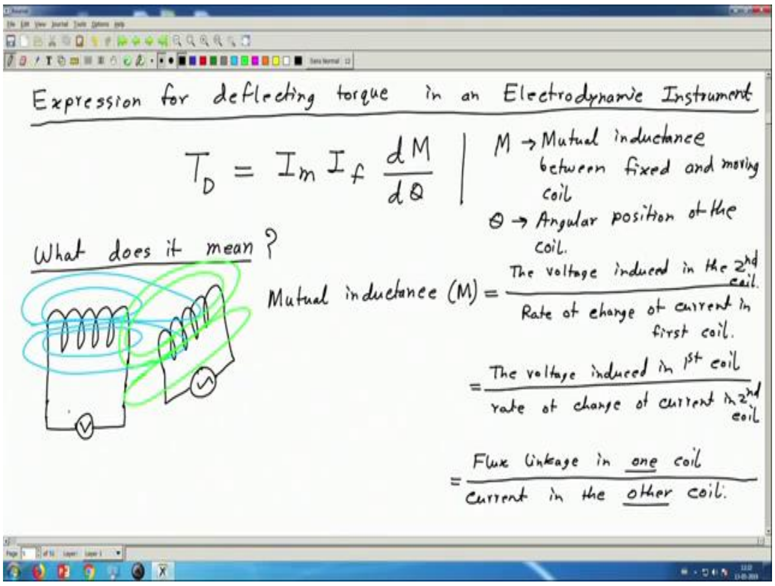

Expression for deflecting torque in an Electrodynamic Instrument

$$T_D = I_m I_f \frac{dM}{d\theta}$$

M → Mutual inductance between fixed and moving coil

θ → Angular position of the coil.

What does it mean?

$$\text{Mutual inductance } (M) = \frac{\text{The voltage induced in the 2nd coil.}}{\text{Rate of change of current in first coil.}}$$

$$= \frac{\text{The voltage induced in 1st coil}}{\text{rate of change of current in 2nd coil}}$$

$$= \frac{\text{Flux linkage in \underline{one} coil}}{\text{Current in the \underline{other} coil.}}$$

What does it mean? So, here M stands for the mutual inductance between fixed and moving coil and θ is the angular position of the coil. So, theta can be the angular position of this coil measured with respect to some position, some reference position may be this is my difference position, then this is θ. So, this is basically the angle θ. Now, what is this mutual inductance, we know that if we have two coils nearby. So, this is one coil and say there is another coil which is placed near to this coil and then if we pass some current in this coil I. So, it will generate some flux lines and some of these flux lines will also intersect or link with the turns of the other coil.

Therefore, if this say this current, I is changing, if I have say AC current, then this I is changing. And therefore, this flux will also be changing, and this flux is linked with the second coil and so, if I connect a voltmeter here. So, this is the symbol of a voltmeter I will get some reading.

$$M = \frac{\text{Voltage induced in the } 1^{st} \text{ coil}}{\text{Rate of change of current in } 2^{nd} \text{ coil}}$$

This is also same as, say a current or a voltage source connected here and if we measure the voltage across the first coil. So, we have a source here and we measure the voltage here. So, this will also generate some flux lines which will link to the first coil and therefore, we can get some reading here.

$$M = \frac{\text{Flux linkage in one coil}}{\text{Current in the other coil}}$$

So, if there is a current in the first coil, what will be the flux linkage in the second coil, or if there is a current in the second coil, what will be the flux linkage in the first coil. So, this is also another way of defining mutual inductance. So, we expect that you are already familiar with this definition. So, this is not a tutorial on mutual inductance, but rather this is a quick recapitulation, but the essential thing that I want to bring out is that in mutual inductance depends on the positioning of the two coils.

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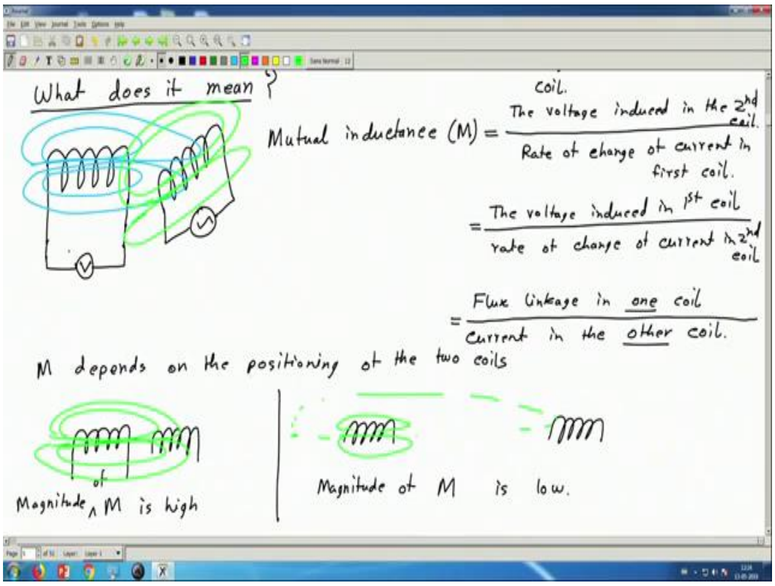

What does it mean ?

Mutual inductance (M) = $\dfrac{\text{The voltage induced in the 2nd coil.}}{\text{Rate of change of current in first coil.}}$

$= \dfrac{\text{The voltage induced in 1st coil}}{\text{rate of change of current in 2nd coil}}$

$= \dfrac{\text{Flux linkage in \underline{one} coil}}{\text{Current in the \underline{other} coil.}}$

M depends on the positioning of the two coils

Magnitude of M is high

Magnitude of M is low.

For example, if I have two coils very close to each other, then M is high, but if I have the two coils quite far from each other, then the magnitude of M is low in this case. Because here more flux can link them together. But here I think very little amount of flux possibly can link them. So, M depends on the positioning. It also depends on the angle between the two coils.

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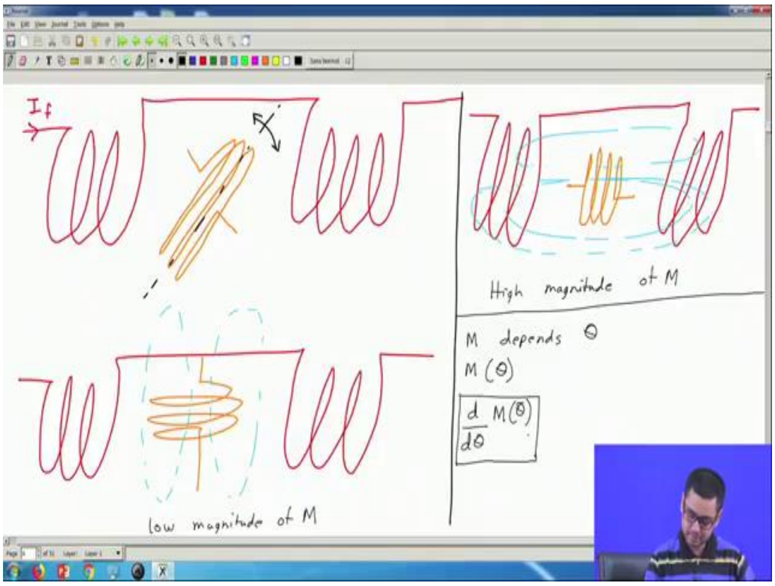

High magnitude of M

low magnitude of M

M depends θ

$M(\theta)$

$\boxed{\dfrac{d}{d\theta} M(\theta)}$

So, let us consider our electrodynamic instruments where we have two pairs of coils. This is say fixed coil, this is one of the fixed coils, this is another fixed coil and they are carrying some current I_f and we have a moving coil between this two.

So, whose turns are let me draw it like this. So, the turns of the moving coils are like this. Now, this coil can rotate. And, therefore, we can have different situations, like this is one situation, we can have another situation, where the middle coil or the moving coil is like this or we can have another situation, say where the moving coil is like this. So, you see that in this case the two sets of coils are aligned, their directions are aligned.

So, the flux linkage between this will be very high. So, the flux lines will link them very well, whereas in this case flux lines cannot link them that well because the two coils are perpendicular to each other. So, here we will have high magnitude of M, here we will have a low magnitude of M. So essentially, we see that M depends on the angle between the two coils θ or the angular position of the moving coil. And this is what we have in this expression for the deflecting torque.

$$T_D = I_m I_f \frac{dM}{d\theta}$$

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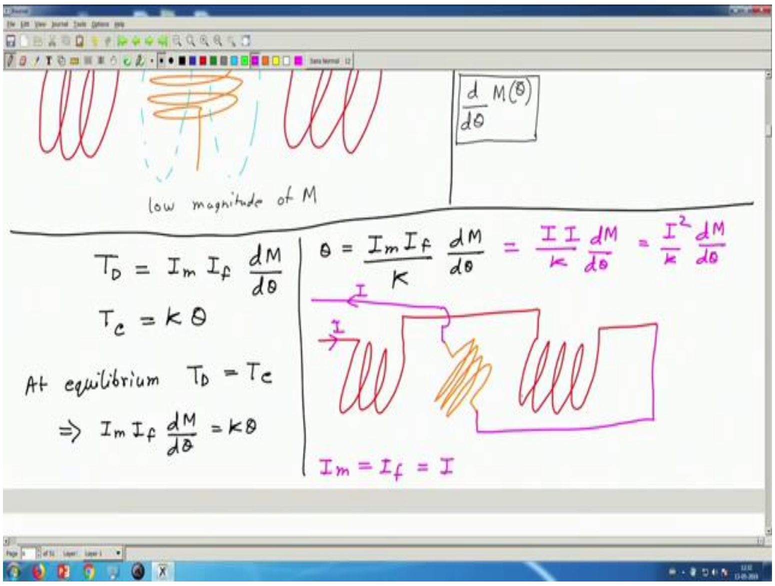

$$\frac{d}{d\theta} M(\theta)$$

$$T_D = I_m I_f \frac{dM}{d\theta}$$

$$T_c = k\theta$$

At equilibrium $T_D = T_c$

$$\Rightarrow I_m I_f \frac{dM}{d\theta} = k\theta$$

$$\theta = \frac{I_m I_f}{K} \frac{dM}{d\theta} = \frac{I\,I}{k} \frac{dM}{d\theta} = \frac{I^2}{k} \frac{dM}{d\theta}$$

$$I_m = I_f = I$$

$$T_c = K\theta$$

At equilibrium, $T_D = T_c$

$$I_m I_f \frac{dM}{d\theta} = K\theta$$

Now, last thing I will discuss in this video is that in this arrangement we have one current through the moving coil, another current through the fixed coil. So now, what we can do we can pass a constant amount of current a known amount of current and an unknown current I_m. And, therefore, we can find the unknown current by observing the angle of this coil, but this is not nice way to do that because we need another extra current source or voltage source to excite or magnetize this fixed coil.

So, a simpler way of using this device, this instrument is to connect the two sets of coils both in series. So, let this be my fixed coil and let this be the moving coil, I will connect both in series like this. And, I will pass the same current I through both of them.

$$I_m = I_f = I$$

$$\theta = \frac{I^2}{K}\frac{dM}{d\theta}$$

Thank you let us meet in the next video.