Electrical Measurement and Electronic Instruments
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Lecture – 09
Damping and Eddy Current Damping

Hello and welcome again. So, in last few videos we have studied about a number of Electromechanical Instruments, like to recall them PMMC instruments, then electrodynamic instruments. Electrostatic also we have discussed, moving iron we have discussed, in all these instruments, there is a moving pointer and it can have a coil which is attached to the pointer or may be plates. But in general, the idea is when we apply a current or maybe a voltage across the terminals of this instruments, the pointer or the coil or the plate it moves and settles down at some position on this scale depending on the value of the applied current of the voltage higher the voltage or current is, the pointer moves further and further and further.

So, this is the basic idea and we know that there are number of different torques that act on this moving system; by moving system I mean the coil and the pointer or maybe the plates and the pointer. So, the system or the object or the part in the instrument that moves. So, a number of different forces act on this moving system, what are those forces?

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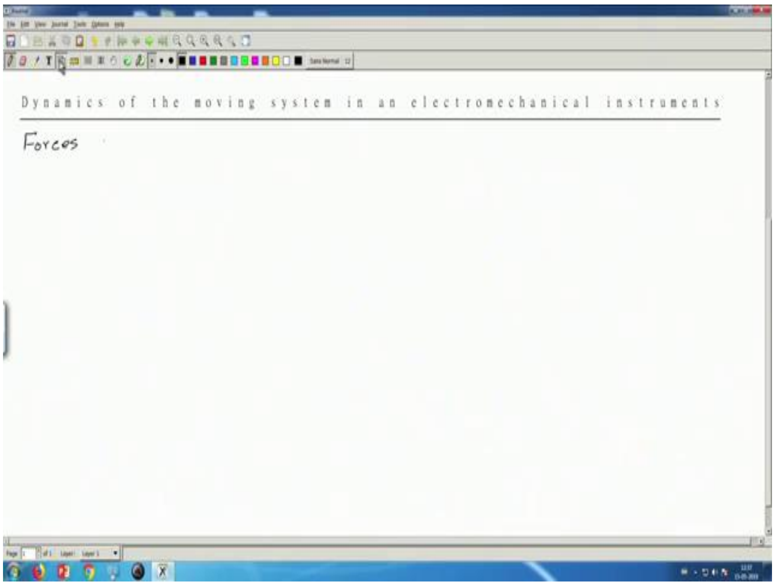

So, we have seen some of them. The forces, I should better write torque, because we are talking about angular displacement.

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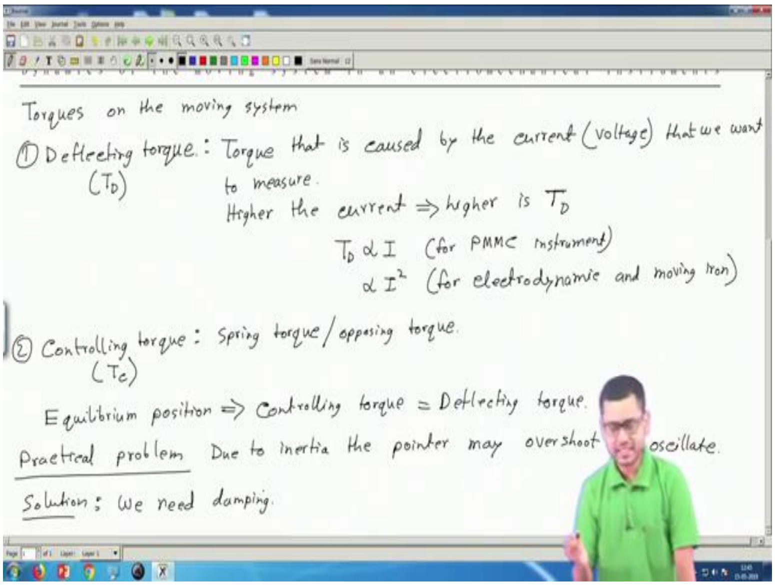

So, torques you can also say torques on the moving system. So, the first thing that we have, the most important thing is the deflecting torque. So, this is the torque that is caused by the flowing current, by the current or voltage that we want to measure. And so, little we have denoted this as T_D; D for deflecting and higher the current is; higher the current higher is T_D.

$$T_D \ \alpha \ I \ (For \ PMMC \ instruments)$$

$$T_D \ \alpha \ I^2 \ (For \ elecrodyanamic \ and \ moving \ iron)$$

So, this is the torque that tries to rotate the pointer, turn the pointer, deflect the pointer that is why we call it the deflective torque. Another important torque which we also have mentioned is the torque due to this spring, which you call the controlling torque.

So, this is same as the spring torque or we say the opposing torque, this tries to hold the pointer in its normal position, it does not allow the pointer to move from it is normal pointer. So, these are the two important and this we call as T_C; C for controlling. We call it controlling because it is controlling the amount of movement or rotation of the pointer. So, this is controlling torque and then we have talked about the equilibrium condition, what is an equilibrium condition? Suppose, I have a meter across which I pass some current, some constant current I applied suddenly.

So, if I suddenly apply some current, then there will be a torque deflecting torque, which will be generated suddenly, which was not there before, and the pointer was that its 0 position before that. And now this deflecting torque will try to move the pointer from it is 0 position and this deflecting torque is constant if I assume the current is constant. So, T_D is constant, the pointer starts to move and as it starts to move as theta increases the spring is twisted. And as the spring is twisted it will apply an opposing or controlling force according to Hooke's law this is proportional to theta.

So, as the pointer is moving towards a higher value the deflecting torque will be constant, but the controlling torque will increase as the pointer is moving, the deflecting torque is constant, but the controlling torque is increasing. So, therefore, at some position both of them will be equal and that is the position of equilibrium, where there will be no more net resultant torque, because controlling and the deflecting torque, they will balance each other, they are opposite in direction equal in magnitude and then the pointer can stay at that position without moving further.

But, then there can be a problem. The problem is that due to inertia, due to the moment of inertia the pointer may overshoot that position. And if that happens then the controlling torque will increase further, because when theta increases controlling torque increases further, deflecting torque is same. So, now, the resultant torque will be in the opposite direction. So, the pointer will start to come back. And it will come back again at the equilibrium position, but due to inertia it may overshoot again and now on this side controlling torque is weaker than deflecting torque. So, the pointer has to go back.

So, the pointer in this way will oscillate and it can take a long time or may oscillate indefinitely when theoretically, before it settles down to it is equilibrium position where both the torques, controlling and deflecting are equal in magnitude and opposite in direction.

So, let us write at equilibrium; equilibrium means, equilibrium position or angle implies controlling torque will be same as deflecting torque, but as we have just mentioned there is a practical problem, due to inertia the pointer or the moving system; that means, coil everything which moves together may overshoot and oscillate. And if this happens then it will be very difficult to get the reading, because if the pointer is oscillating, it is very difficult to get any reading and it may take long time before the pointer settles down.

So, the speed of measurement will be very slow, we have to wait one for a long time before we can measure the current or the voltage. So, this is a problem. Therefore, we need some mechanism so, that the pointer stops at it is final value very quickly. And this mechanism is called damping. So, solution to this problem is we need damping, what is damping? Assume, let us take a very simple example easy to understand. Let us take a pendulum, a small blob of mass hanging from string and say this is in air or maybe in vacuum even better.

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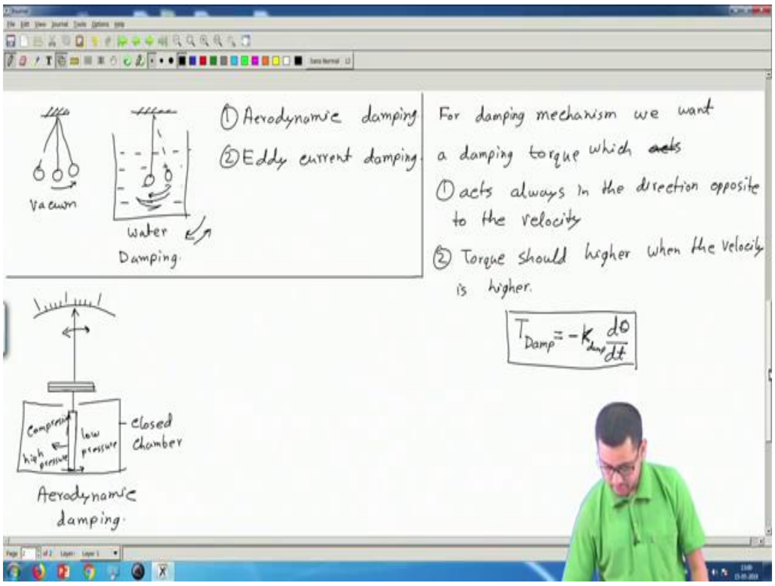

So, this is in vacuum and I move it in either direction, then this will start to oscillate. And, this will keep oscillating, maybe forever because it is in vacuum there is nothing to stop it there is no energy dissipating reason to stop it, there is no friction nothing.

So, it will oscillate forever. Now, see I have the cell arrangement, but now the pendulum is kept inside a beaker of water. Now, if I bring it to one side and leave it, you will see that it will probably not oscillate it, will probably just come from here to here and stop or it may oscillate, but for a shorter time, maybe for one or two oscillation and then it stops. Why? Because the friction, the viscous friction or the fluid friction stops this pendulum. And at any moment this friction acts in the direction opposite to the velocity of this pendulum thereby helping the energy to dissipate to the water and stop causing the pendulum to stop quicker. So, this is called damping, we need similar mechanism.

Now, the similar mechanism can be created in our instruments and meters, galvanometers whatever you call in different manners. So, we will talk about the two important damping mechanisms. One is aerodynamic damping. So, this is due to air friction and then we will talk about eddy current damping. So, these are two important or commonly used mechanisms in measuring instruments.

So, how an aerodynamic damping can be used? Suppose I have a coil which looks like this from the top view. So, these are the turns. And there is a pointer attached to it which moves along a scale, what we can do, we can connect a vein like this. So, this is like a flap, this is like a flap I mean flat plane although this is just a flat plane.

Now, if this pointer moves, then this flap will also move, and this has to move through the air. And the air will due to aerodynamic friction will try to stop it. Suppose, I have a flap flat, it is a page, it is just a page. So, it is a flat plane, now if I am trying to move it. So, if you do this experiment on your own, you see that you will realize the aerodynamic friction, which is trying to move it which is opposing to movement.

So, will feel it. Just take a pages and try to move it, you will feel the aerodynamic friction which is opposing the motion. So, this is the mechanism. And this will be even more effective if we put it inside a closed chamber or almost closed chamber and let me make it longer. So, this is an almost closed chamber. Now, if this flap, the vein is say moving towards this direction, then what will happen air will get compressed. So, here we will have compression. So; that means, high pressured and here we will have low pressure. So, then what will happen as this vein is moving towards the left this high pressure and this low pressure the pressure difference will try to bring it back. And so, it is not absolutely airtight. So, this high pressure air can leak from this side to this side, but it will take some time. So, therefore, this higher pressure will try to oppose the motion of this fan. This should not be absolutely airtight then there will be some other problems.

So, this becomes more effective and this mechanism we have seen in one of our earlier videos where we were demonstrating a real moving iron instrument. So, if you recall we had this mechanism there. So, this is an aerodynamic friction. Now, we shall talk about another mechanism, which we call the eddy current damping. But, before that let me tell what we want for damping.

So, for damping, we want a force which you call the damping force, which acts always in the direction opposite to the velocity or angular velocity in our case. And secondly, we want this force should be higher when the velocity is higher. So, we want basically something like this, the damping force or the damping torque so, I should write torque everywhere.

This means the damping torque should always act in the direction opposite to the velocity and it should be higher, when the velocity is higher.

$$T_{damp} = -K_{damp}\frac{d\theta}{dt}$$

Why do you want this? Because, this is motivated from this experiment, where this pendulum is stopped due to the fluid friction, the water fiction, viscous friction, because in case of viscous friction or this is approximately we know it is proportional to the velocity. If you try to move faster through the water the opposing force, opposing fiction is more. So, the water friction or viscous friction is proportional to the velocity and it is always in the direction opposite to the velocity. If the pendulum is trying to move from right to left, then the friction is always from left to right.

So, this is what we want, and we know that this mechanism helps the point this pendulum to settle down quickly. So, therefore, we want to mimic or copy this mechanism in our instruments. So, that the pointer or the moving system settles down quickly. So, this is what we want. And in case of aerodynamic friction, this is kind of true, in a sense that anyway this air itself is a fluid. So, it is it will offer some viscous friction. So, this is kind ok for aerodynamic friction. Now, another mechanism we are going to talk about is eddy current damping.

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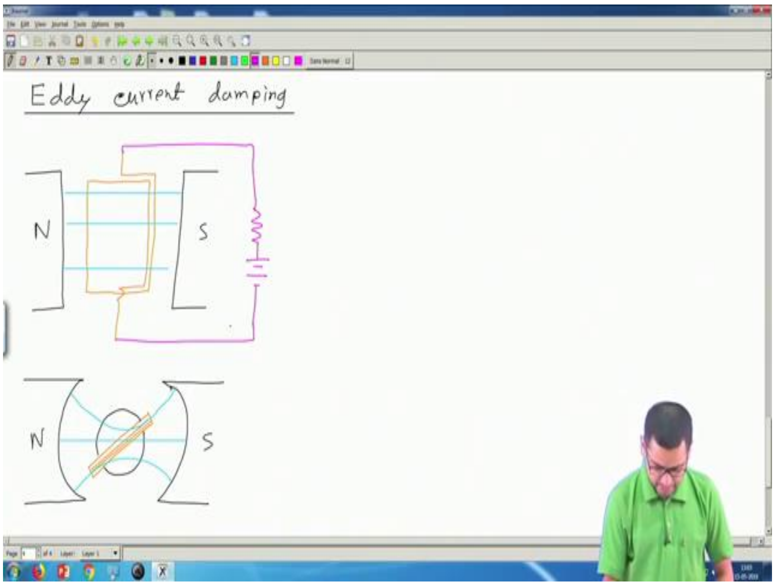

For this, we have to recall our PMMC instrument, for ease of understanding. So, let us draw the PMMC instrument and let us draw say only a cross section, frontal cross section, and maybe also the top view.

This is north, this is south, this is north, this is south so, this is the front view this is the top view and in the front view the coil looks like this and in the top view the coil just looks like this. And let me draw the flux lines also and here we will have a core. So, the due to the core, from the top the flux lines will be radial. So, they will be all like this. Now, what happens if say this coil is moving with some velocity?

Now, this must have a closed circuit through the external network, maybe through let me just draw for simplicity some resistance and some battery, this is the circuit which is driving the current which you want to measure. So, there is a closed part. This may not be as simple as this, may be a complicated circuit in which you want to measure the current, but this is a closed path, through this coil and this external circuit. Now, I do not even need this battery, see this is a passive network even.

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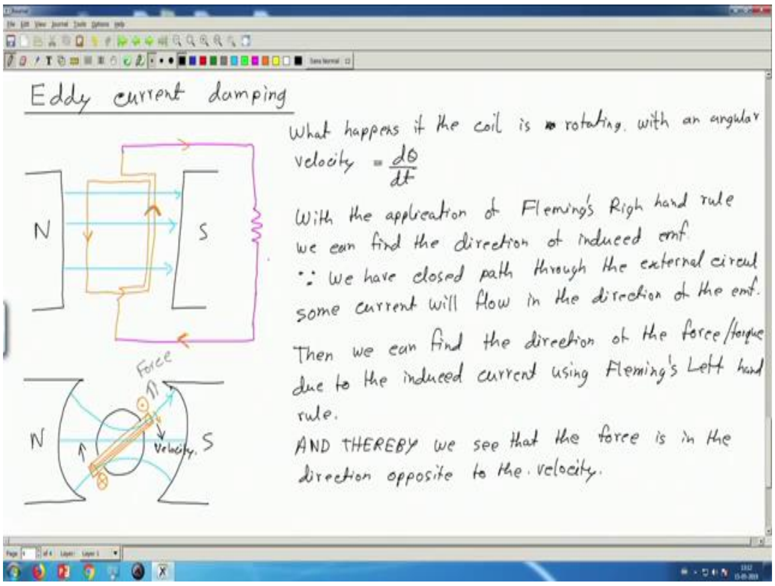

So, then normally there is no current. So, normally there is no current, so, the coil will not move normally, but if the coil starts to rotate due to any reason, if the coils say if the coil is moving, then what happens. So, the question that we are going to ask is what happens if the coil is moving or rotating. Say the coil is rotating in this direction; I am just choosing a direction arbitrarily.

$$Angular\ Velocity = \frac{d\theta}{dt}$$

So, if it is moving with this angular velocity, then what will happen then these two sides are actually intersecting or cutting through these flux lines. So, so, this side and this side they are then cutting through this flux lines. And according to Faraday’s law, then some EMF will be induced in these conductors. Now, what will be the direction of this EMF? So, we have chosen this as the direction of velocity. So, what will be the direction of the EMF? Find the direction of the EMF, we need to apply Fleming’s right hand rule. So, we need the overhead camera for this.

So, let us apply Fleming’s right hand rule. Let us consider this side of the coil, this side or; that means, this side now, this side is coming in this direction. So, it is coming in this direction, flux lines are like this. So, to apply right hand rule flux lines are like this, the direction of the motion is like this, which is along my thumb. This is my right hand and then my middle finger is pointing upwards, as you can see my middle finger is pointing upwards.

So, the EMF on this side will act in this direction. So, the EMF will try to drive our current in this direction here. So, we can denote it with a dot notation. Similarly, on this side let us go back to the overhead camera again. So, on this side, we have the flux again in this direction. So, this is the direction of flux and then the motion which is according along my thumb is like this and the middle finger is pointing inwards.

So, the EMF here will be like this or like this. So, this is the direction in which the induced EMF will try to drive the current. Now, if so, if there is a; there is a closed path then this will drive the current like this. So, this is due to the induced EMF. Now, this induced EMF, or this induced current is flowing in a magnetic field. So, we will have the motoring action coming in the picture.

So, now there is a current in a magnetic field. So, there will be some force acting on these sites and we can find out the direction of that force using now the Fleming's left hand rule. So, now, let us apply Fleming's left hand rule. So, the direction of the current is upwards for this branch. So, my middle finger is upwards, flux lines are left to right. So, this is these are flux lines and the thumb is the direction of the force.

So, the thumb is pointing inwards here. Similarly, which will mean here the force will be in this direction. So, let me draw the force in a different color. So, this will be the force, and this is the velocity. So, you see velocity is and the force they are in opposite direction.

Let us do this exercise once again. So, here in this diagram in the lower diagram, the current is according to this dot symbol is upwards. So, in this diagram I put my middle finger upwards, this first finger is along the flux lines like this and then see this is the direction of force, which is in the direction opposite to the velocity. So, what have we seen?

So, let us write with the application of Fleming's right hand rule, we can find the direction of induced EMF. Since, we have a closed path through the external circuit, some current will flow in the direction of the EMF. Then we can find the direction of the force or torque due to the induced current using Fleming's left hand rule and thereby we see that the force is in the direction opposite to the velocity.

So, this is therefore acting like a viscous friction, because this force is in the direction opposite to the velocity as we wanted. Now, the last thing that we will see we will find the magnitude or the value of this force. And how this value of this force or this torque is related to this velocity. So, let us do that. So, now, we will find the magnitude of this force.

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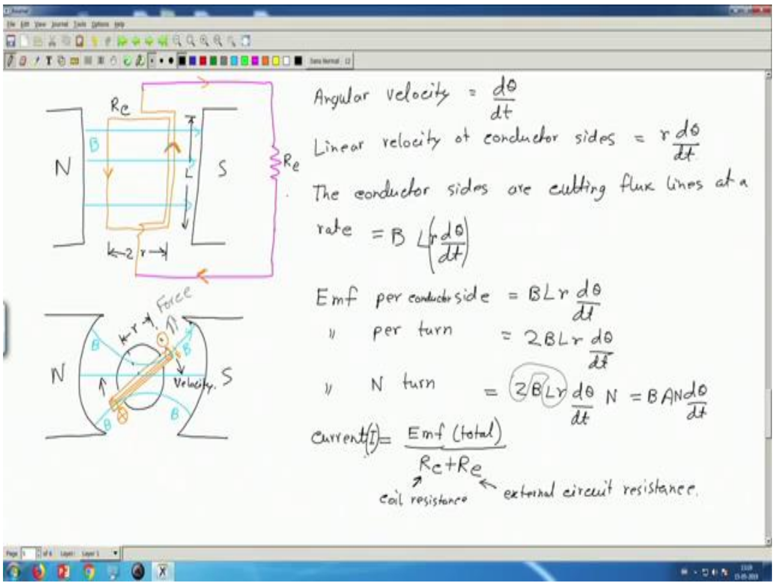

$$Angular\ Velocity = \frac{d\theta}{dt}$$

$$Linear\ Velocity = r\frac{d\theta}{dt}$$

Now, we have to find out the induced EMF due to this, then we can find the current due to that and then we can find the force. So, to find the induced EMF we need to compute the rate of intersection of this conductor side with the flux lines. So, the conductor sides cutting flux. How much flux? So, if this length is L and if the flux density is B so, it is B everywhere, due to the radial pattern. So, this side of the conductor is moving through a flux density of B with this velocity. So, the conductor sides are cutting flux lines at a rate how much? So, this will be same as the flux density, this is proportional to flux density, multiplied by the area swept by this coil side. How much area it sweeps per unit time?

$$\text{emf per conductor side} = \mathrm{B\ L}\left(\mathrm{r}\frac{\mathrm{d}\theta}{\mathrm{dt}}\right)$$

$$Emf\ per\ turn = 2\,\mathrm{B}\,\mathrm{L}\left(\mathrm{r}\frac{\mathrm{d\theta}}{\mathrm{dt}}\right)$$

$$Emf\ for\ N\ turns = 2\,\mathrm{B}\,\mathrm{L}\left(\mathrm{r}\frac{\mathrm{d\theta}}{\mathrm{dt}}\right)\ N = B\ A\ N\ \frac{\mathrm{d\theta}}{\mathrm{dt}}$$

$$Current\ (I) = \frac{Emf\ (total)}{R_c + R_e}$$

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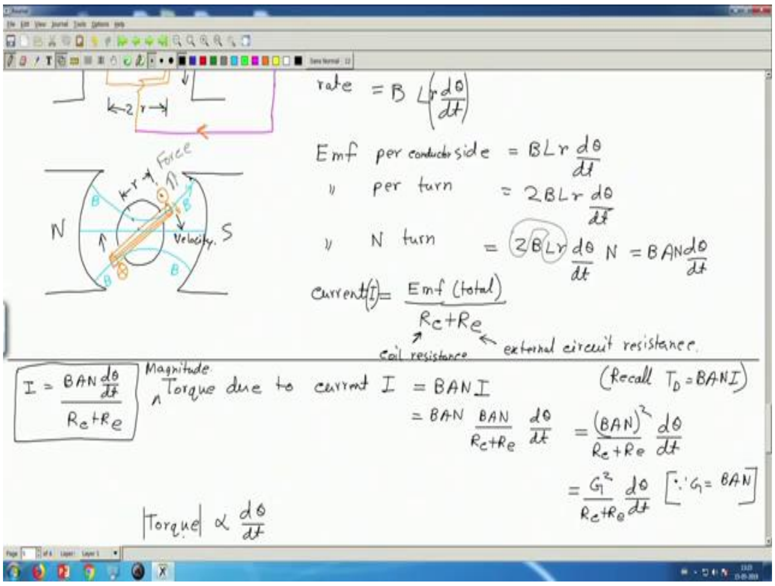

$$Current\ (I) = \frac{B\ A\ N\ \frac{\mathrm{d\theta}}{\mathrm{dt}}}{R_c + R_e}$$

$$T_D = B\ A\ N\ I = B\ A\ N\frac{B\ A\ N\ \frac{\mathrm{d\theta}}{\mathrm{dt}}}{R_c + R_e}$$

$$T_D = \frac{(B\ A\ N)^2}{R_c + R_e}\frac{\mathrm{d\theta}}{\mathrm{dt}} = \frac{(G)^2}{R_c + R_e}\frac{\mathrm{d\theta}}{\mathrm{dt}}$$

Where, $G = B\ A\ N$

So, what we see? We see that the magnitude of the torque due to this current, we call this eddy current. This current which is generated due to the induced EMF, we call this eddy current and the torque is due to that current is given by this expression. So, we see that the magnitude of the torque is proportional to d theta d t this is the velocity of the coil.

$$|Torque| \ \alpha \ \frac{\mathrm{d}\theta}{\mathrm{dt}}$$

Therefore, this torque which is due to the eddy current, is always in the direction opposite to the angular velocity and is proportional to this magnitude of the velocity. Therefore, it acts like a viscous friction and then this can help in causing the pointer to stop earlier, like the viscous friction, like the water fiction. So, we have; so, we have got what we wanted two conditions that the damping that the force is proportional to the velocity and in the direction opposite to the velocity like this, it is like the water fiction. So, we will continue from this in our next video. We will talk about the eddy current damping and slightly more and some more interesting topics.

Thank you!