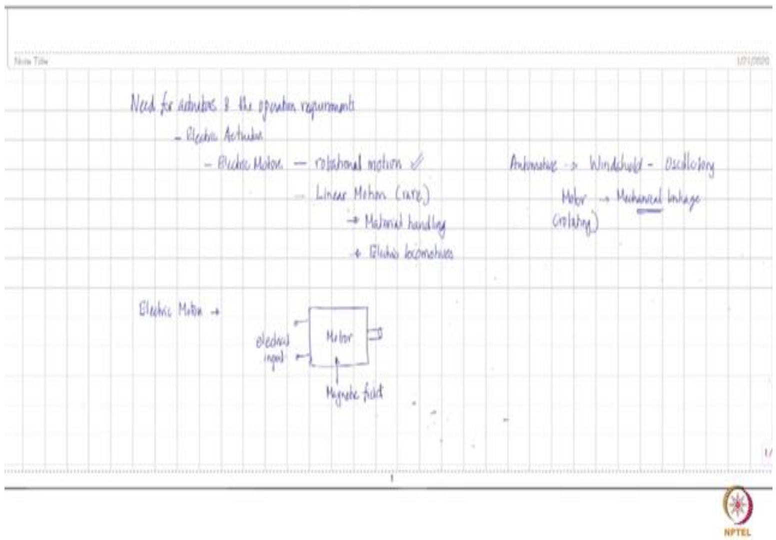
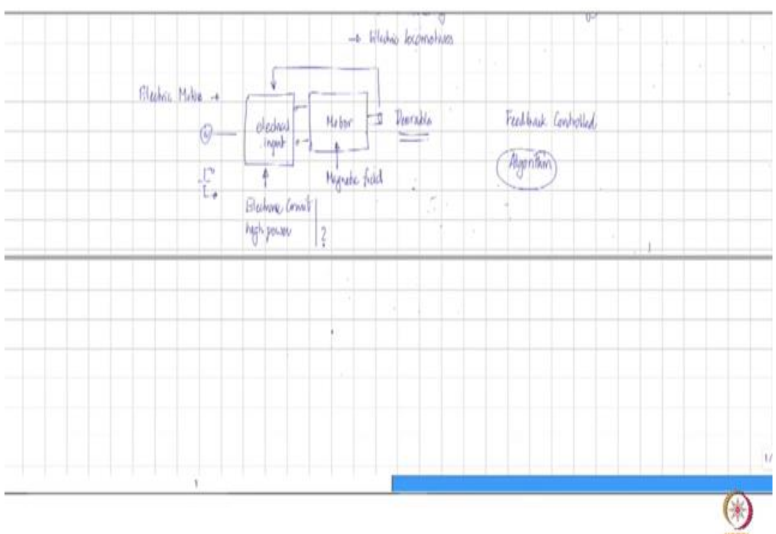
Introduction to Robotics
Professor Krishna Vasudevan
Department of Electrical Engineering
Indian Institute of Technology, Madras
Lecture 3.2
Principles of DC Motor Operation

(Refer Slide Time: 00:20)





So, in the last class we had looked at need for actuators and the operation requirements that one may expect. So, and we saw the different varieties of actuators, you may take for hydraulic and then electric. What are the advantages that one has with respect to another, and then we therefore we said that there are lot of advantages you are having electric actuators. And the electric actuators are of different varieties, for the case of robotic application we usually say that these are electric motors, and these are of different varieties.

There are you have electric machine or electric motors that generate rotational motion, and then you have electric motors that have basically linear motion. Usually when we talk about electric motors, this is what we refer to. This variety is rather rare, it is rather rare and not very much useful to industry; and therefore our discussion will be more focused on motors that produced rotational motion.

But, if the end effect that you want with not rotational motion, we want something to move along straight line. Then appropriately we use mechanical linkages or a mechanical an accessory mechanical system to ensure that a rotational motion gets converted into a motion that is a linear, so that can always be done.

For example, if you are looking at your automotive application. In the automobile you have you know the wind shield, wind shield is what between front, and you have blades that are going to remove the dust from the wind shield. That has an oscillatory operation, oscillatory in the sense that is not a reciprocating movement; it goes to one direction to another. Any idea how that is achieved?

Professor: Yes, so you have this is actually you, this is an oscillatory motion, but this is achieved by having one motor which is rotating motor, a rotational type motor. And then there is a mechanical linkage which makes this into an oscillatory operation. So, you will have to use some such mechanical linkages you will in order to get this rotational motion, converted into some other kind of operation.

But rotational electric motion, electrical machine are rather easy to use because the area of operation of the machine is really restricted. If you want to have a machine that is going to move all along the length; then you have to do the mechanical construction of the machines over such a large distance. So, you do have machines that go on linear operation, so these are sometimes used for material handling application.

And often people are attempting to higher electric locomotive as well. Not yet implemented but it is at the research level where you have electric locomotives operating on the way on the which use linear motions. So, if you then take a if you take electric motors, these electric motors have let us say you have the motor. These motors have an electrical input and generate a mechanical output; and this operation as I am not sure as I mentioned last time, this happened in the presence of a magnetic field.

And the what we essentially need to see, if this is the kind of system that we are going to have, and we want it desirable mechanical output from the system. That means we want to make a shaft of the machine rotate in a particular manner that you want. If you want to make it operate in a particular manner that you want the only thing that you can adjust is the electrical input.

There is nothing else in the system that you can adjust, and therefore we are essentially looking at what is it that one can do. In order that the input that is effect to the machine is of an adjustable nature, and how one can go above adjusting it in order to get the kind of operation that one has looking at.

And as we see that the electrical input could be in some cases an AC input; if the robot is not going to really move away from place to place. Then it makes sense to operate it with AC input, but on the other hand if it is going to be moving then it may not be very easy to have an AC input like this. In such situations you may prefer a DC input simply because energy storage can then be put on the robot itself and storage is available only in the form of the DC.

So, you can use it in that manner as well, and therefore in this in the few actuators regarding electric actuators; what we will be looking at mainly is how the electric motors operated. And the nature of this circuit that is going to sit here, which will enable you to take whatever supply is available. And give it in a adjustable manner to the electric motor to get what you want. This is what we are going to look at and this block which will going to sit here, is essentially a block that it is having an electronic circuit.

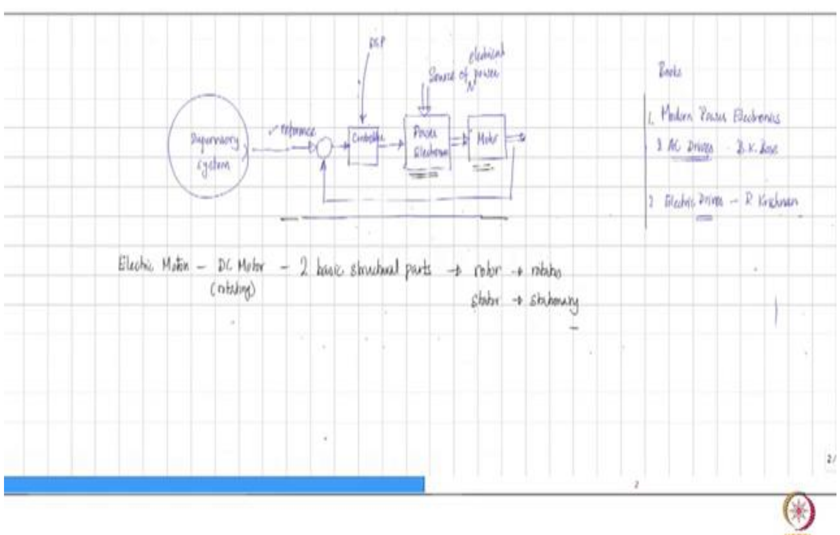
And this has to hand the full to electrical input that is going to be given to the machine so, this is a high power circuit. It is high power as oppose to the lower the sort of low power electronic circuit which is all your analog electronics, your op-amps and resistors and the different varieties of electronic circuits there. As against that this handles higher output power that is why it is called high power.

So, we will therefore have to have some understanding of what the circuit is; the nature of operation of the standard circuit and how it will impact the electric motor. And also we said that you need to get some desirable operation out of that which means that the circuit operating it must first of all know what is happening, in order that it can impose what is desire. If you do not what is happening there how do you know how much adjustment you need to give to the supply.

Therefore, in order to have that there need to be some information flow going from this end to the circuit. Which, will then enable it do decide what is it that you must do now to the input given to the motor to get a desirable performance. And therefore all these kinds of systems are basically feedback controlled system.

So, you have information that is now flowing back from the output side, and then there needs to be some algorithm based on which you are able to look at what is happening at the output. And then you also know what you want depending upon the difference, you must be able to do something so there, there is then an algorithm.

(Refer Slide Time: 11:37)



So, you may represent it in this manner that you have the motor and then you have the power electronics and this gets in source of power one may call it tools of electrical power. This is what energizes an electric motor and then you have a shaft which may be coupled to whatever application we want. This now needs to be given an input so you need to have something here, which say how this electronic circuit should act in order that the output performance is achieved.

So, there is here therefore some controller and this controller needs to know what is required, so there is a reference.

No, I clear it in this way and that requires an input of what is happening on the other side. So, this is the sort of system, this controller itself could be fairly sophisticated; maybe you need a digital signal processing. You need to implement it some kind of digital algorithm whatever needs; and this reference is what is going to tell, what you are supposed to be doing.

So, if you are going to be moving a robotic arm to pick up this object from there, and you placed it somewhere else; then this action of asking the electric motor to rotate starting from this position. Rotate the hand is lifting up and then you rotate it further; so something to happen and then come down and place it. All this has to be given as the reference; where will this reference come from?

This reference has to come from what the robot has to do. Somebody has to decide apriory, how the entire robotic system has to do these sort of program. So, this comes from a supervisory system that say how the overall system must behave. So, if you are going to have something that is going to move around in this room for example. And it then needs to locate whether there is an obstacle or not; then go somewhere and go around and then display and then return back.

So, somebody now has to write an algorithm to find out if there is an obstacle or not; there has to be a sensor that detects the obstacle. And then if there is an obstacle, what is that you need to do? Which direction you should move? When you should move forward? All that will come in the supervisory system. Finally, after do looking at all these environments, you take a decision; yes, move forward.

At that decision is implemented by this loop that we have shown. So, the actuator in the entire robotic system, the actuator is the final actuating element; it is not something that is going to involve itself in the decision of what were the robot must do. But, rather implement the decision of what needs to be done. So, we are then going to look at this end action how that can be implemented.

So, this is broadly we are then going to look at and as somebody ask me last class, what about the books for understanding this in a maybe different way. So, I would suggest the book called Modern Power Electronics and AC Drives by an author called B.K. Bose. So, this is a book that gives lot of details about how such systems operate, and how you can design this kind of systems and so on. For our purpose however we are not going to go into the level of details that this book gives. We are looking at a very-very introductory can superficial level; so, if you want to get into some more understanding, this is probably the book.

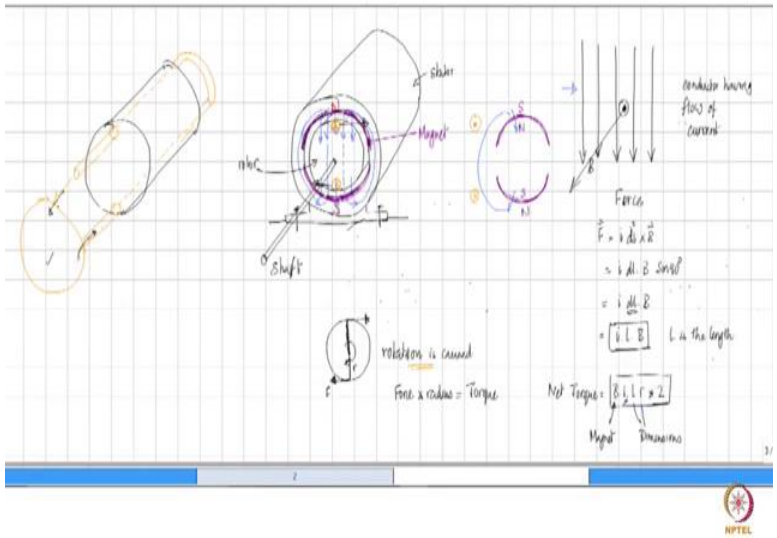
But, I am not really aware of a book that will discuss it at a level that we are going to handle in the course. This is what we are going to do is that a very-very superficial level; and you will not really find a book that deals with that level. But, however further information is available here; there is another book called Electric Drives by R. Krishnan is another book that you can refer.

So, this is especially speaks about AC drives and this book has material on DC drives as well as AC drives. So, in order to understand I mean if you are going to be a sort of system integrator or you are going to be looking at designing an entire system having the robot. Then it is only necessary for understanding the role of the electric machine, and the role of the circuit that you are going to put here.

How do these things operate and the basic operational behavior of these things, so that is what we will be looking at in these things. So, you go ahead, so let us start by looking at a simple electric motor. Electric motors of different varieties the simplest to understand the operation is what is called as a DC motor; and sure you might have a heard about it at some time or the other.

And so this then has two basic structural parts, we are ofcourse looking at rotating machine and therefore you have one entity called as a rotor. Another called as stator, the rotor is the entity that rotates and stator as the name implies is stationary. So, you have the stator so the stator is a cylinder, where you have a cylinder with a hole all through; and the rotor is another cylinder that is inserted into this.

(Refer Slide Time: 20:55)



So, this member the outer member which is called as I said stator is fixed in some way to a base you may put a bolt and fix it. And therefore the stator is stopped from rotating and this member which is inside, this is then called as the rotor, the rotor is free to rotate. And your application whatever you are going to connect is then connected to a shaft which extends from the rotor. It may not be as long as I have drawn, but there is a shaft which extends from the rotor.

So, the basic idea of operation of the machine is very simple and same from the simple laws of physics which I am sure you are all aware of. The simple law of physics is that if there is a magnetic field that is going to be there. Let us say you have magnetic field that is oriented along the directions of the arrows that I have drawn. And then you have an electrical conductor that is located in the magnetic field that means I am saying that the magnetic field exists in this space which is going from up to down.

And in that you have a conductor that is located like this field is going like this way. You have a conductor oriented like this and then this conductor, if you have let us say that you have a flow of electricity. This is flowing in this direction so you have the field flowing from up to down. You have a conductor and you have a flow of electricity that is coming out of the conductor in this manner.

If this is the arrangement that is there, then we know from basic electrical that is basic physics that I can say this is a electrical conductor having flow of current. Then this conductor experiences a force, it experiences a force that somebody remember the equation linking force to the magnetic field to the conductor. I vi, vii, so the force is actually given by I into dl cross B is the equation.

So, if you have a situation where as I have drawn, the field is going from up to down, you have this electrical conductor located here. How the angle how much is the angle between the magnetic field and this conductor, equal to 90 degree and therefore this means I into dl multiplied by B into sin of the angle between them which is sin 90 degree. And therefore this reduces to I into dl into B.

This is the force experienced by a small length of the electrical conductor dl, but if you are going to have a situation, where all along the region of the magnetic field. The conductor is in the same direction then the net force that is experienced is simply I into l into B where l is the length of the conductor. So, this is your familiar equation B into i into l, so this is fairly simple and this is the basis of all electrical machine operations. So, the laws of physics based on which motors are built is very-very simple.

Now, therefore if you can somehow make a field exist inside the machine that let us say goes like this; comes out this way, goes through this one and then comes out this way. Similarly, you make another field or you make a field that exist and goes this way. So, this field line goes around like this and closes, this goes around like this and closes. So, effectively then as far as the rotating member is concerned, it is going to see field lines coming down from this stator in this direction.

And field lines going out in this direction and therefore if you sit on the rotor, and look at the space around you; you see lines of magnetic field that are entering from somewhere. And leaving from somewhere and therefore you would imagine that you have a source of field which is there outside for which North Pole is setting and South Pole is setting here. You see that North Pole is the region for which the field exists, and therefore that is a place where it exiting and it is entering somewhere here… There is a North Pole here and South Pole here and I am seating right in the middle.

Now, therefore since you have established a magnetic field that is going to do like this, and it is going to do like this. It is the situation very similar to what we have drawn there; there is a region now having magnetic field. And now in this space if you now locate an electrical conductor, let me draw a conductor here.

I place the conductor here that is going to run all along the length of the rotor. I also place another conductor here which is going to run all along the length of the rotor, along the axial length of the rotor. And then let us say I make a flow of current happened such that it is dot here and cross here. If I draw a circle and represent here by a dot; it means that the flow of the current is out of this.

And if I put a circle and represent it this way; it means the current is flowing in to that. If this is the case how one the force be experienced by this conductor, which direction will be the force? You have field line going from top to bottom; you have a conductor setting there with flow of current outside. So, dl is a vector that is going along the direction of I that is outside; B is down, so I dl cross B is I dl cross B is going to exert a force in this direction.

How will the situation Be in the other conductor? You have the same direction of field, but the flow of I has now been reversed. And therefore you experienced a force in the opposite direction, which means in this direction. So, you now have a cylinder where a force is exerted in this direction and one hand and exactly opposite if I locate the other conductor. You have a force of acting in this direction and therefore how will this cylinder respond; it will begin to rotate.

Why it will not move either this side or that side? Net force acting on it is zero; therefore there is no horizontal movement of this mass. It will only cause a rotation about the axis and therefore this rotor will begin to move; it will begin to rotate, rotation is caused. So, B into I into l if you now look at the way I am going so we somehow need to have a methodology of allowing a flow of current here and bringing it out into this.

So, I have an electrical conductor here going all along the length; if I simply make a interconnection with this conductor and that conductor at the back. Then any current that goes in and come out through the other side. So, that is a very simple arrangement which means effectively that if you have a cylinder here and that is going to go along the length.

Then I have a conductor here that goes all along the length of the cylinder, emerges out at this point. I have another conductor that goes all along the length of this cylinder, it emerges at this point. I simply short this two and therefore if I have this two as outputs what I can do is send the flow of current into this. This current travels all along the length and then comes back and goes back into the circuit, if I am going to connect here which will be the source of electric current.

So, if I do this then I we have already seen that it results in rotation. So this is the basis of motor operation. Now, this is a force that is existing at this location. In order to cause rotation, you need a this force multiplied by this radius is called force into radius is mechanical torque. And you have this force which is going to generate one torque, and similarly that is going to generate another torque.

Both of them bending to torque rotation in the same direction, and therefore the net amount of torque is B into i into l into r multiplied by 2. This is the torque that is going to be generated by having these two conductors located in this manner. So, then the issue is how do you generate the magnetic field first; so that is now fairly simple. What you do is in the region here, so the region here you fill it up with that is fill it up with by having a magnet.

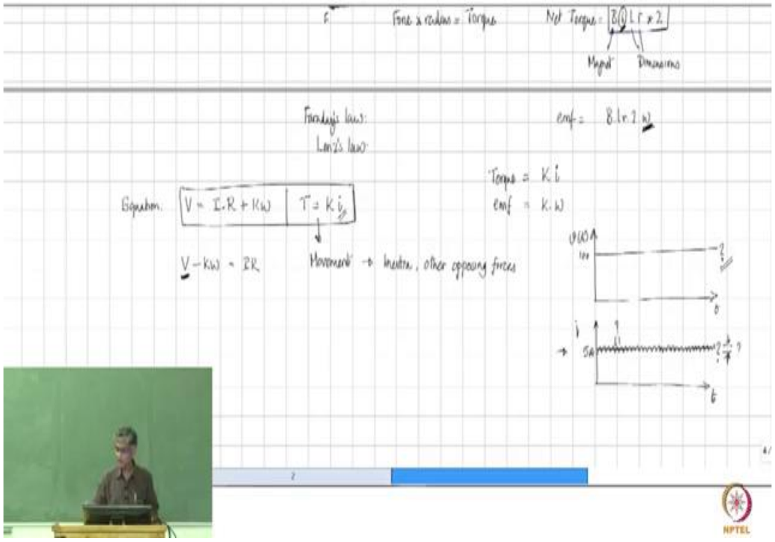
If you put a magnet that magnet is going to generate a magnetic field so that is your source of magnetic field. So, you will then have to put another magnet to have symmetry in operation. So, the magnet above will be arrange in such a way that this face is going to be North; and that is South and the magnet below will be arrange in such a way that this face is S and that is N.

Which then means that you will have magnetic field generated which will come out of this and go into this and this will complete the circle in the iron of the stator. So, this is very simple that is going to be there. So, now in this equation therefore you have B into I, l into r; B is going to be generated, this is going to be generated by having a magnet; l and r are dimensions of the system. So, you really cannot adjust either B or l or r in operation.

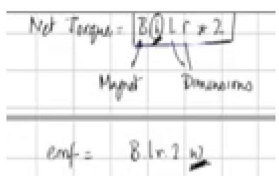
So, you cannot meddle any of them, but however you can meddle with i because this i is caused by an external circuit that we have connected here. And this is what is going to result in a flow of current here and then coming out of at this point; and therefore you can do something only with this flow of current i. And the goal therefore is if you are going to have an electric motor and you want to control it as per your need, of your of the robotic system.

Then what you need to control is how much flow of current is there; so, the question is how to do that. Now, apart from this there is an another phenomena, now that if rotation is going to happen.

(Refer Slide Time: 38:06)



Then there is another law of physics enters into the picture which is called as Faraday's law. It says that if you are going to have a magnetic field and some conductor is going to move then there will be an induced EMF there.



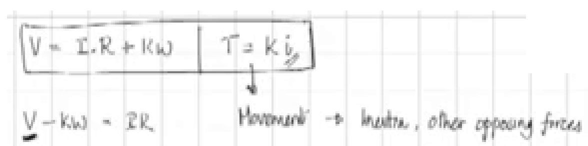
Emf=Bil*r

And you can show that, that induced EMF is again equal to B into l into r multiplied by 2 multiplied by omega, which is the speed of rotation, speed of rotational motion. So, you see that there is an induced EMF, the induced EMF has an expression which look very similar that of the mechanical torque which is generated except that in this place you have i and here you have omega and therefore you can write an expression for the developed amount of torque as some numbers k multiplied by i.

You can write an expression for the induced EMF as the same number k multiplied by speed. And this law also has an accompaniment which is called Lenz's law which says that the direction of induced EMF is to so as to, oppose the reason why it is there. And the reason why it is induced EMF is there is that these conductors are attempting to move. And why these conductors are attempting to move is because there is a flow of ampere i; and therefore the induced EMF will attempt to oppose the flow of i.

So, looking at all this one can therefore develop a simple equation describing the electrical aspect of the DC motor. You are going to apply an input voltage v and this input voltage v result in a flow of current I which is going to flow in these two electrical conductor. So, if there is a flow of current in an electrical conductor, this conductor obviously has some resistance to it. And therefore this v has to be equal to the flow of current i multiplied by the resistance.

But that is not all there is an induced EMF now existing which is opposing this flow of current therefore, V equal to I into R plus K into omega. So, this is a very simple equation describing the electrical part of the machine. The machine has a mechanical part as well which says that the developed mechanical torque; it is actually electromechanical torque is equal to K multiplied i.



So, these two equations then together describe everything about this machine. In response to this torque you have a rotating mass which is going to move. Rotating mass means the moment of inertia et-cetera all those things which are there.

Professor: Why?

Professor: Right, so you are applying an input voltage V and this induced EMF is opposing that V and therefore the difference will result in a flow of current I, which is I into R. I just wrote it on the other side, so now this is going to result in movement which has inertia, other opposing forces and so on. So, it has to overcome all that and then start rotate. Now, therefore what we need to understand is how one can do some control on this.

Usually when you talk of a DC motor, I am sure you might have seen small DC motors which you excited a low power DC sources that you supply a nice DC voltage to it, the motor starts rotating. Now, the question is looking at this expression, you may say that you want to supply a DC voltage to the motor. What you normally mean by DC motor? What generally it implies is that if you draw a waveform of this voltage V as the function of time.

You talk about this voltage then you draw with respect to time. if one says It is a pure DC voltage what you would expect is a graph which look like this. It is a pure DC voltage, so we say for example a 100 volt DC then I would say that this is equal to 100. And for all time it remains exactly at 100 volts that is pure DC. Now, one can supply this kind of a DC voltage to the motor, in which case you would expect that we say draw a graph of i with respect to time.

Then you would expect like this graph is also flats, if you draw some amount of flow of current maybe 5 ampere, 6 ampere or whatever it is, some current will flow. But, out of the two having an applied voltage that is flat and having a flow of I that is flat. Which one is more important? Which is more important? Is it necessary to have a flat voltage profile like this? Is it necessary to have a flat flow of current like this? Why would you say that you need a flat current?

Torque will otherwise fluctuate and that electromagnetic torque term is the one that is going to result in motion. And you want the motion to be nice and small; you do not want an oscillatory motion. So, you would like that input current to be a flat profile. It is not essential that the voltage also needs to be flat. So, one needs to therefore look at maintaining the flow of current I to be as flat as you can allow. This is where what we discussed in the last class entered the picture that it may not be feasible to keep it like that; it may be feasible only to keep it like this.

Why, we will discuss as we go along, but that is what may be feasible. And if that is what is going to happen then this i multiplied by K is going to give you electromagnetic torque which is also be like that. To the question is what is this amplitude that is allowable for you, for the particular application at hand and what is the frequency that is allowed for the particular application in hand.

Given any application like you can always you should always be able to determine the high enough value of the frequency such that the mechanical system is immune to that. If you have a mass and you go on hitting it at small amplitude at high frequency after some time it will just not respond. So, what means to therefore determine what is this and what is this, and how do you get? Why should you go for this kind of an operation? Why it is that we are not able to get this? A smooth DC wave form. So, all this we will see in the next class, we will stop here.