Introduction to Robotics
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Lecture No. 27
Stepper Motors

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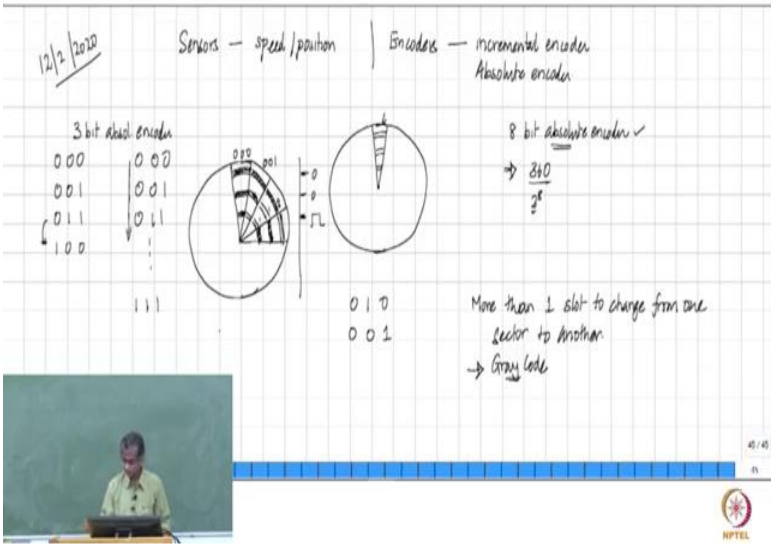

Professor: In the last class then, we were looking at sensor for speed and position. Mostly encoders are the ones that are nowadays used and these as we have seen, there are two varieties one is incremental encoder, that is what we saw in the last class, how the incremental encoder would work. And then the other variety that we have is called the absolute encoder. The absolute encoder and so if you have a disc and you have, you are looking at a certain angle, then you have slots that are located at certain distances, which then serve as a means of encoding the angle information.

So, if you have for example, an 8 bit encoder, 8 bit absolute encoder, then you have 360 divided by 2 power 8 angles which can be there which you can independently locate. And in each of those angular intervals, you then have a specific way of arranging the slots. So, that as soon as you switch it on, depending on which of the slots are open, which positions are not open, you can immediately determine where you are. So, that is the idea behind this.

So, if you need absolute angle information without having recourse to locating the index pulse and then adjusting all that, one can use this for an absolute input. So I mean, instead of taking 8 bits, I mean for example, let us say you have a 3 bit absolute encoder then these can be 000, 001, 011 and so on can go all the way to 111. So, it means that if you have a disc and you have certain angle. So, let us say that you are going to put an LED detector in this, that is along the disc you put one detector here, one detector here and one detector here. It means that in the region here you either have a slot or you do not have a slot.

Similarly, in the region here you either have a slot or you do not have a slot and similarly here. Therefore, in the sector adjacent one maybe if you have a slot, if this angle is going to is going to represent 000, then it means that you will not have a slot here, there is no slot here and there is no slot here. On the other hand, when you go to the next one, if it should be equal to 001 then there is no slot here, no slot here, but you have a slot here. So, the output from output from the detector there will give 1 in the next angle, it would give no output.

Then in the next one you may have 0 for no slot, 11, so you have slot you have slot. So, if the disc is now going to rotate to be there at this angular disc position, then you would have an output as 011. So accordingly, as the disc is going to move, you will get different varieties of outputs. And depending on what you detect, you can immediately know at which angle you are. And therefore, this can be used as a measure of absolute time.

But then the difficulty is you cannot really afford to go in this order you cannot go in this arrangement because if you look at this, you have the let us read 000, 001, 011 and then you get to 100. Going from here to here is a difficulty because now you need to have 1 0 and 0. Now since you have to make this disc and you have to have a slot here and these two slots must exactly end at this location hand you must have no slot here.

Which means that if there is an error, if you are going to have an error, then you may have a situation, for example, you go from 011. And if these two slots do not end exactly at the same location, then you could have a situation where you have this is going to go from 0 to 1, it may not have gone from 0 to 1, there is a small interval where the slot is slightly, this slot may be a little shorter, in which case you still have 0 existing for some time.

So, you go from 011 to 001, that is assuming that this slot has not happened exactly at this end, but it is a little further away, that means the 0 here will last for a little longer time. So, you still have the 0, what did you have, 011. So, it starts with let us say 011 and this is going to stay as equal to 0, because for some reason this slot has become a little shorter. Then from 011 it goes to 0 here again and this has now become from 1 to 0.

So, it means that the next one goes to 0 and it may go to therefore 001 or if the next slot also has an error it may go to something else. So, because of this you do not want more than one slot to change from one sector to another. So, this occurs because you are intending to change this from 0 to 1 and at the same time you want to change from 1 to 0, which may not be easy to achieve when you actually make the disc.

So, instead of having such an arrangement, you allow only one of them to change, which means that you will have to switch over to what is called as gray code, which is an arrangement of this in a way that only a single bit is undergoing a shift from 0 the 1 or from 1 to 0. So, if you arrange it that way, then you will then be able to determine the actual angle as soon as you switch on the system. So, this is then an absolute encoder and one can use this.

Professor: 0 1 1.

Professor: It should be 010, but even that is a difficulty because 1 is going to go to 0 and 0 is going to go to, you are right, it be 010. So this is therefore, one way of sensing the absolute angle.

Another device, which is used for this angle detection is known as the resolver. So, here for example, the difficulty is that if you are going to have an optical way to measure it, then this entire thing must be enclosed in such a way that dust cannot enter because if you are going to have small slots, and then LED which is going to emit and you have another electronic which is going to, going to detect and then if this is not completely well enclosed, if there is some amount of ambient disturbance, some sort of dust and if it is enters into this then your encoder will stop functioning.

So, optical encoders have this difficulty that the environment has to be very good, or the encoder has to be very good, impervious to even small amounts of data.

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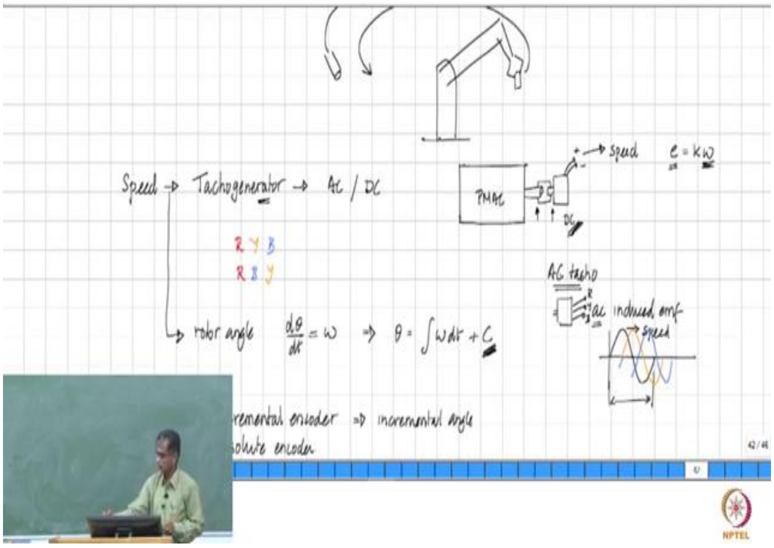

But on the other hand, if you are going to use electromagnetic equipment, which is like what we saw here, especially if it is in AC Taco. Here, you do not have a difficulty because you are only looking at induced EMF and dust is not an issue at all.

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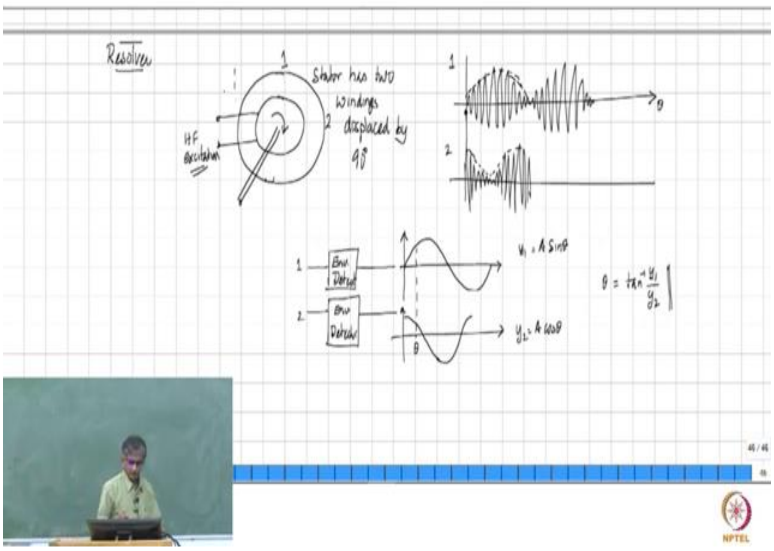

So, one can go a little bit more into this and have another entity known as resolver. In this case, this is again an electromagnetic equipment you have a stator and you have a rotor, coils are there on the rotor, I will just show it as two leads and you give a high frequency excitation to this. Stator has two windings displaced by 120 degrees, displaced by 90 degrees and the rotor is then linked to your system, electric motors for which you want to determine the rotor angle.

Then, because you are giving high frequency excitation, both the two entities here, they are going to have induced EMF and so they will also have high frequency induced EMF because this is a high frequency excitation. But on top of that, since this is also going to rotate, the induced EMF that is going to be there will also depend on how the rotor is oriented with respect to those two. And because of that, if you look at the high frequency induced EMF in the first winding let us say 1 and 2 here.

If you look at the induced EMF at 1 with respect to the rotor angle, you will have an induced EMF that has a sinusoidal envelope like this. This envelope occurs because of the variation of the rotor angle. So, if this high frequency excitation is going to lie along the same axis of 1 then the induced EMF will be highest, as it is going to rotate further then the linkage due to this high frequency excitation at this that 1 will decrease and because of that there will be an envelope for the high frequency excited, high frequency induced EMF.

And similarly, for the next one, since it has been displaced by an angle equal to 90 degrees. So, if you are having low value of induced EMF here, the next one would have a high value of induced EMF and therefore, that would go like. So, this has a sinusoidal envelope that also has a sinusoidal envelope and you can then have these two signals that are going to come from 1 and 2 and you send it through an envelope envelope detector, this also through an interval of detector, that is an electronic circuit. This will then give as an output a sinusoidal waveform, this will give a core sinusoidal waveform.

Student: Hows the stator winding arranged.

Professor: Stator winding is like a normal AC machine, it will be a distributed arrangement. So, here therefore, if you know the amplitudes of the envelopes then at any given angle of of the of the rotor this would have an amplitude equal to A sine theta, this will have an amplitude A cos theta and therefore, you can see. So, this is let us say y1 and y2 and then the angle can be determined as inverse tan of y 1 by y2 at any given instant. You have to contend with the situation that the denominator may go very close to 0 that you can address it in some manner.

So, in this way one can determine the absolute angles of the rotor using this particular measuring occurs. So, this equipment incidentally is fully electromagnetic and therefore, it does not have the difficulties of optical mechanisms as we saw earlier and therefore where you have an environment which a lot of dust this may perhaps be a very good approach.

Professor: See, you need to have an oscillator outside, it will involve bulbs, that you cannot avoid. So, this is then an approach to detect the angle as well.

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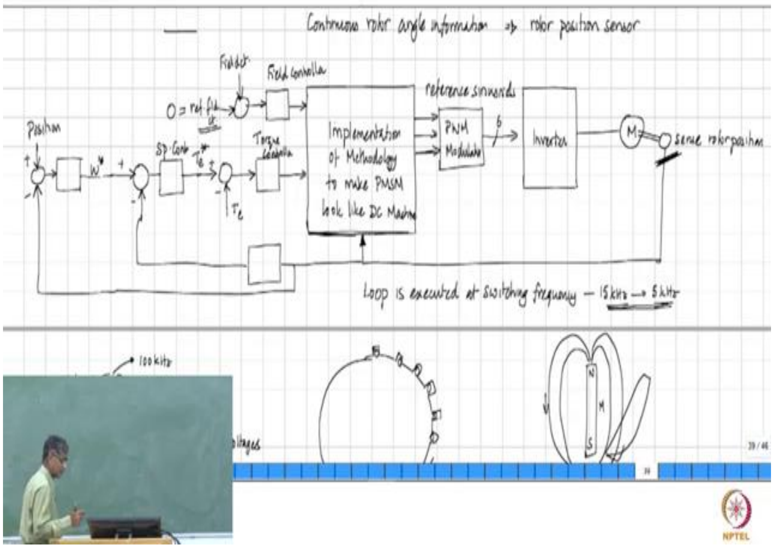

So in all these, so the angle all the instruments or the devices, which we said can be used for angle measurement are to be used here. In order to sense the angle of the rotor, which is required in order to make this AC motor look like a DC motor for the purposes of control. We have drawn a block here, which I said you do something inside the block, which ensures that whatever happens this looks like a DC machine on this side. And for that purpose you need the rotor angle, that rotor angle can be obtained in this manner.

Note that in the case of a sinusoidal EMF AC machine, you do not need all switches like the case of the other one, you do not need hall switches here, you need the angle instant to instant because you need to define the sinusoid by which you have to excite and for that therefore you need instantaneous angle. And that is being implemented by having these kind of mechanisms, encoders to sense they are.

Professor: See the Hall Effect, this is you see that the resolver is able to give you an output like this which is a sinusoidal output after you do the envelope detection.

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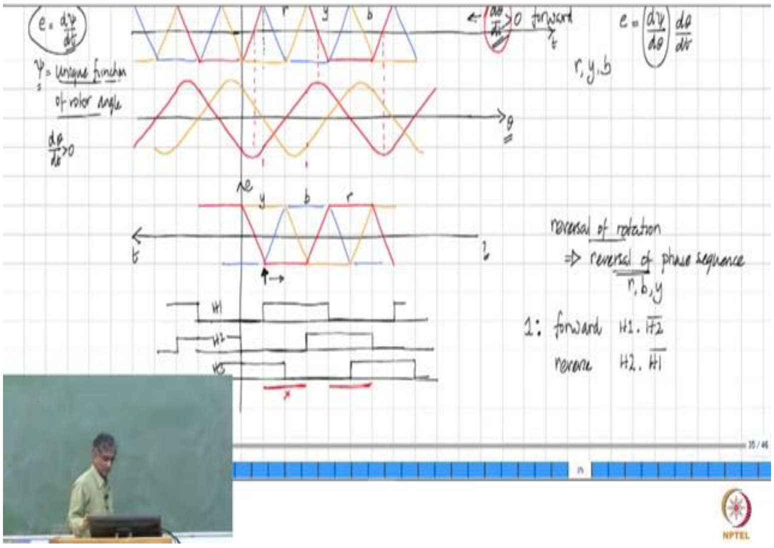

But a Hall Effect sensor like the one that we had used for the BLDC machine. So, this Hall Effect, Hall switch it only says whether the field is high or low that is all. You cannot infer what the angle is based on the outputs, it is simply high. So, this is not a mechanism that you can use to detect the angle of the rotor, the only information that we are getting from this is that when it goes from low to high you know something about the rotor position.

So, it is only at that instant you know where the rotor is, after that you have no idea. Whereas, if you take the other one you have a amplitude output that is going to vary and therefore, you know where the rotor is. So, that is what happens here. But there are some applications which are low performance still. And you may not want to use encoders. Encoders are also sometimes depending on how robust you want the encoder to be. If you really go for high quality industrial grade encoders they may be as expensive as the motor itself.

So, it is an expensive expensive thing to have. And encoder also means that you need additional space on the motors because you have to have a motor shaft. So, if you need to use an encoder this is important.

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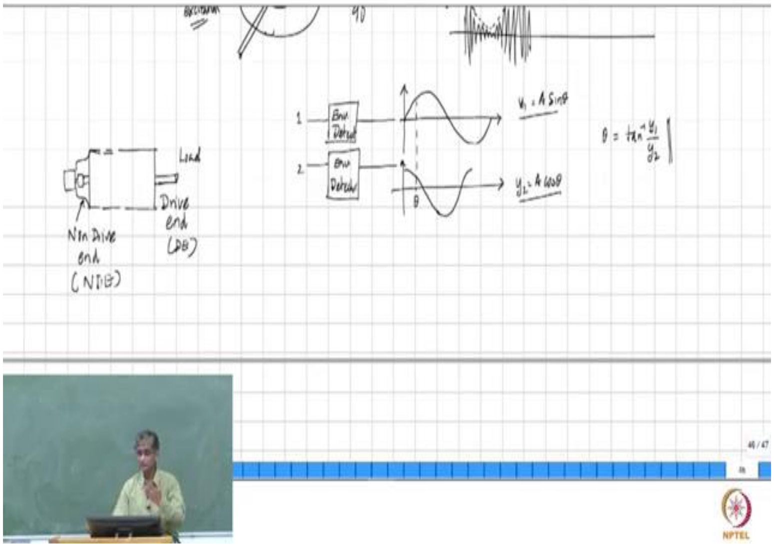

You need to have you need to have the electric motor and the motor has shaft, this shaft is going to connect to the load. So, this is known as the drive end, of the motor because that is the end of the shaft that is going to be driving the load. You cannot put the encoder here, I mean obviously, we said that the encoder must be linked mechanically to the shaft, so that the encoder rotates at the same speed encoder or this one. So, this must rotate at the same speed as that on the shaft, which means that they will be mechanically linked together.

And since you are going to connect this side to the load, you cannot afford to put the encoder here there is no space. So, if you want to have an intruder on the machine, then it is necessary that you need to have an extension of the shaft on the other side. So, this side is called as the non drive end. So, this is usually called as NDE and this is DE. So, at the non-drive end you need to have a shaft extension or a way by which the encoder can make a physical mechanical connection of the shaft.

And then you need to have an arrangement, the encoder obviously has to sit here that will have its own shaft and you make a mechanical connection. But you cannot leave the encoder hanging like that at the end, there must be an arrangement to fix it appropriately. And therefore, you need to have some arrangement that fixes the encoder on to the motor itself.

And then there is another difficulty that if you are going to have an encoder which is made by somebody as you are going to get an encoder as another small piece that you need to fix to the motor, this encoder must be aligned such that it is shaft is exactly in line with the shaft of the electric motor and not shifted this way or that way. So, fixing the encoder is not at all an easy job.

So, the first thing is the encoder itself may be expensive depending on how you want the encoder to be. If you want a low cost encoder which is not so immune to all the disturbances, you can get very low cost encoders and you can put them onto the electric motor it will work. The only thing is ambient conditions etc you need to take care it may not be very accurate. If those inaccuracies and difficulties are acceptable for you, there are low cost encoders that are available, you can get something for very low cost.

But still the aspect of fixing is important, however low cost it is, you have to fix it in such a way that the shafts are aligned and locating that in such a manner is not at all an easy job and therefore, the demand is difficult. So, in applications where you do not want the sophistication of an encoder and indeed where you do not even want to, if you can avoid the encoder altogether that is then good. But you cannot use any of these kind of machines because they need the rotor end.

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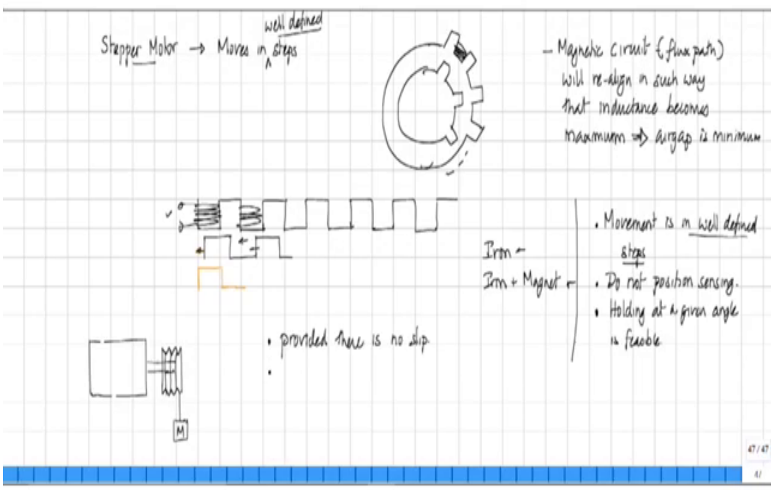

So, one other electric motor that is used in such cases is is known as the stepper motor. The main advantage of this is that it moves in steps and that is an advantage as well as it is a disadvantage. It moves in steps, but it moves in well defined steps. So, that is the major advantage of this machine. So, essentially if you are going to have a machine that has a stator and the rotor, so the stator then has slots like that and so on and the rotor has extensions like this.

So, this means that if you are going to have some coil placed around here and you energize this, then the rotor will move in such a way that some tooth which is most adjacent to it will snap on and align itself with that. So, it works based on alignment, it works based on the idea that magnetic magnetic circuit, that means, the flux path will realign in such a way that inductance becomes maximum which then means that the air gap is minimum.

So, one can represent this in a manner which is spread out so if you have the stator like this and then you have the rotor which is let us say like this and if I am going to have a coil there and energize this, this means that the rotor will immediately snap into this angle. So, this will move by a small amount and snap into that angle and you must have designed it in such a way that when this moves and snaps into this angle, the next one obviously, the whole thing is going to move and there is an asymmetry there now.

So, after you excite this, then when you excite the next one, this should cause a similar amount of displacement here and therefore, if you go on exciting it in steps, first this coil, then this coil then this coil it will move in steps as you excite it. So, that is why this is then called as a motor that moves in steps.

Professor: Uneven yes, that means the gap here and here cannot be the same. If this width this width is the same this gap, this gap is the same it will just lock and after that you cannot do anything. So, you must have different number of slots here as compared to the rotor, so that there is an asymmetry that is there and because of that asymmetry when one of them is aligned, the next one is not aligned. And therefore, when you energize this this draws into alignment and the next one now becomes unaligned.

Then you energize this that draws into alignment, so it moves in steps and steps have well defined angle because the spacing that you provide here and the spacing that you provide here are fixed by design and therefore, the rotor will move in predefined steps.

Student: does the rotor have any coils.

Professor: The rotor does not have any coils, nothing is there.

Professor: It depends on the speed with which you want to rotate, it depends on the speed with which you want to rotate and the number of such faces that are disposed around the machine. So, it varies definitely yes.

Student: what is the rotor material.

Professor: Rotor is usually made of iron. So, there are different varieties here. So, you may have the rotor made of just iron, it may be iron plus magnet, this will obviously increase the amount of force with which it is going to align whereas, in the first case it is not so high a force. Now an advantage of this kind of machine is also that once it aligns it is rather difficult to make it unaligned because you are providing an excitation here and it has aligned, so it will tend to hold.

Therefore, even if you have a load that is going to make the rotor attempt to make the rotor to rotate, this fellow will hold it and you have a holding effect, which if you want to reproduce in the other kind of machine is not so easy, you have to have a control system which attempts to do that. Whereas, in this case, there is no big closed loop system that is necessary because the movement is well defined.

Professor: Rotor does not have anything, it is just iron. On the stator, you have an electronics that will drive this coil, you have to give a signal saying energize this coil and then you de energize this coil and energize this coil and de energize, energize, so you must have a circuitry outside and some arrangement to switch to all that has to be done.

Student: So the backlash is minimum.

Professor: Backlash backlash is minimum, yes, one can say that. See the difficulty here is so I will just come to the difficulties before that, the advantage. So, one important thing therefore is the movement is in well defined steps. This is one major advantage. And therefore, where this motor can be used, then you do not need position sensing. Why you you do not need to sense the position.

Because if you somehow have an independent way of determining where you are starting, then depending on number of sub signals that you have given to energize, first energization given, now you know that the rotor is moved by delta theta next energization you give a further amount of that angle, third energization another angle. So, number of such steps that you have given to indicate what is the angle by which the rotor has moved. So, you do not need to have any special mechanism to detect the rotor angle, so you do not need this.

Then holding at a given angle is feasible. So, these are all some of the good aspects about these machines. So, where you want to have a simple arrangement, you do not want to have a sophisticated control system for the motor, this is probably what you want to do. So, let us say that you have a system like this, you have a motor you have a shaft which is then connected to your drum and you have a rope that goes around this and you have a mass.

So, if you now want to stop this mass from moving up or down how will you do it? The rotor has to be held. How will you hold it? If you are going to use any one of the other varieties of motors, you need to have a control system that detects what is the angle and then energizes the motor such that that angle does not change. Which means you need a pressure sensor and then error detection mechanism and then that mechanism has to energize the control circuit and whichever circuit you are going to have of across that, all that has to be done.

Whereas here, if you are going to energize 1, 2, 3 and you want to stop, you just energize 3 and stop. You do not need to do anything else further, the motor will simply hold. So, all this of course has to be within the ability of the machine, you cannot put something that is beyond the capability of the machine and say hold and expect it to hold, it will just go on. So, the disadvantages then are movement we said is in well defined steps, provided there is no slip.

If for example, let us say you want the rotor to rotate so you are giving one by one and you want a high acceleration, then it means you have to move through very fast. And it may so happen that it may miss some alignment. If your rate of if your acceleration is too high as compared to what the motor can really do, so if you really want to accelerate first then there may be a slip and if there is a slip, you have lost information about the angle, you do not know how much it has slipped, because there is no other feedback mechanism and this is gone.

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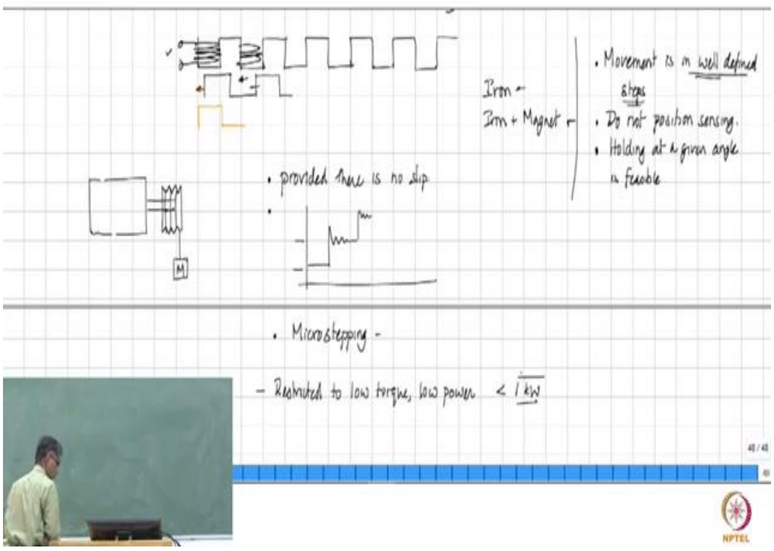

Then if you want the rotor to move by a step, what you are actually saying is that you are going to energize something on the stator and the rotor will then snap into the next location. And when the rotor is going to snap into that location, no mechanical system is an ideal mechanical system. Imagine if you want something will snap into location it means that that must have a high acceleration and the velocity must then go to 0 exactly at that position, which is impossible.

So, you will have a certain overshoot and when it overshoots, because you have energized this it will tend to snap back into alignment and therefore, it will tend to rotate back and when it rotates back there will be an undershoot. So, when you attempt to energize this and move it into a particular location, the actual movement of the rotor angle, suppose it was here and you want to move it to the next angle you will have something like this. Now, that must be acceptable for your application.

And because it is now going to resonate like this, if your acceleration is too fast, let us say by the time it finishes all this oscillation you give the next step, then you will lose control of the system completely, it will just only begin to oscillate and make noise and nothing will happen the way you require it to be. So, these oscillations also have to be considered, therefore you cannot have too fast and increase in speed and that therefore has to be considered.

So, though it is going to move in well-defined steps, one has to consider these aspects as well. However, there are some other advantages to overcome this, I mean other ways to overcome this. This is happening because you are discreetly energizing one phase, waiting for some time, and then discreetly energizing the phase face, switching the first one off. But however, if you do not switch off one phase and switch on another, you maintain some excitation here and as you gradually decrease one excitation, increase the other one, then if you do that, you can do much better.

I mean for example, if this is the angle by which it is going to move, when you go from one phase energisation to the next phase, you can also manage to hold the rotor anywhere in between, if you give a mix of excitation to both of them. You give an appropriate smaller excitation to one and a larger flow of current in the other, then the rotor will be held somewhere in between. So, that is then known as doing my Microstepping.

So, you can do that and attempt to hold the rotor anywhere else. And if you are doing that, then these oscillations are not likely to occur because you are moving in a gradual manner.

But one has to be slow enough, you cannot do it very fast, because again, it might slip. So, the use of these kinds of machines is therefore restricted to low torque, low power applications muscle usually less than about 1 kilowatt or so.

And if you go more than that, you do not even get these kinds of machines. So, where your application requirement is small, you do not require much, you know mechanical torque to move your load and it is okay if you move in small steps, then these are probably the best machines use for robotic applications where the discreteness of movement if it is not much of concern to you. You want very smooth movement then this is ruled out.

Student: is it restricted by what the motor can do?

Professor: Yes. So, it is restricted by what the motor can do that is what I said. How the motor, what the motor is designed to operate? Well, it is not just one place like this. If you really look at the motor design, if you say one phase you are energizing, this will not mean just just one single tooth. This face will also go around somewhere else and alignment will be such that one tooth pair, one tooth pair, another tooth somewhere else is going to be aligned.

So, the rotor is really held in different locations around it, so that it is not so bad, but nevertheless, everything has its own limits, that is what I mean. So, with that, then we will close the discussion on electric actuators for robotics. And the goal was to give you an overview of what are the various varieties of motors, what sort of control systems are involved and the various descriptions that you may be hearing when you looked at these kinds of actuators and the importance of various things, that was the overall goal.

And we also have given some idea about how we are going to select a particular actuator, which are the considerations you will have to look at when you want to say that I will choose, I have this particular application in mind, how do you then decide whether you will choose a DC motor or an induction motor or a synchronous motor, BLDC, stepper motor, what will you select. So, which are the considerations, so that also we have looked at.

And some information on the high frequency operation, what is the impact of high frequency manner of switching. Which is necessary because today, if you want to look at a high efficiency operation you have to go for switched mode control, you cannot afford to say that I will give an analog voltage or whatever you want to the motor, it just does not work, you cannot do it. So, what is the impact of that and how you can configure a control system, all this we have seen and I hope this will be useful to you when you really have some application at hand. So, we will close at this.