NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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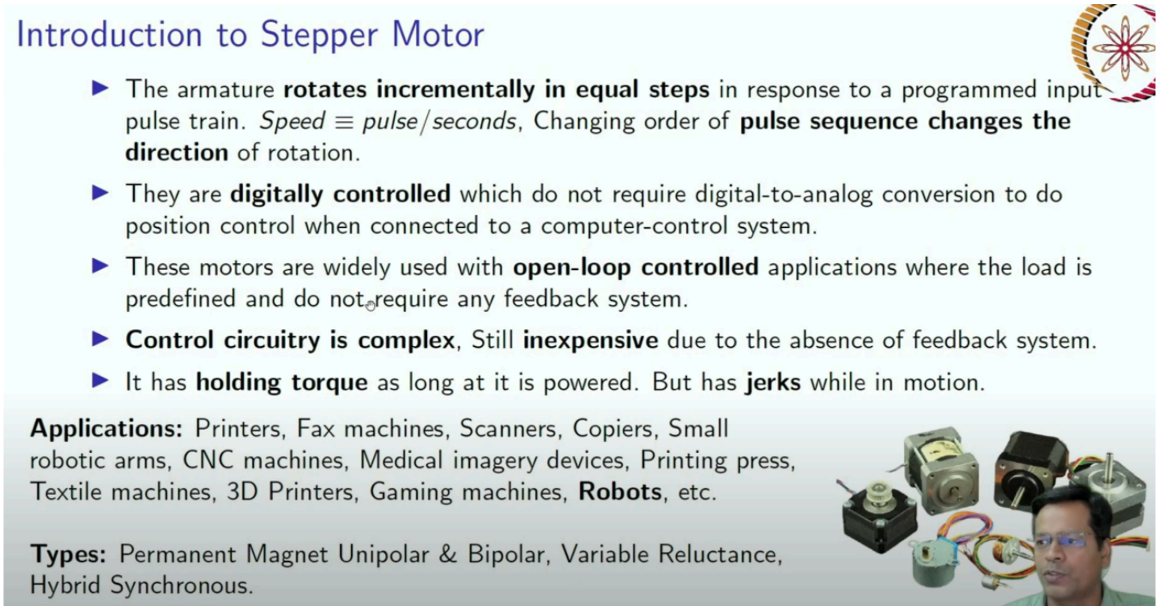
Lecture: 08

Stepper Motors

Hello, and welcome back. So, in the last class, we discussed DC motors. DC motors have different drivers that can make them run. So, in one of the demonstrations that you saw, we used an industrial controller and industrial drive through which I communicated to the drive using EtherCAT, and finally, I attached a DC motor, a standard DC motor without any encoder or anything, and I made it run. So, that is one of the approaches to running a DC motor using industrial controllers and the theories we have discussed already in our last class. So, continuing that in the same sense, today we will be discussing the stepper motor, which is one of the very broad classes of actuators which have been commonly used in robotics for a long time.

So, here is the outline for my lecture today. So, I will be introducing you to stepper motors with the working of unipolar motors and bipolar stepper motors in detail I will be discussing. I will also be discussing something on micro-stepping, hybrid motors, and variable reluctance stepper motors, and I will show you a demonstration of when I have used a standard stepper motor, industrial stepper motor and drove it using an industrial servo motor drive. So now, here we begin, starting with the stepper motor.

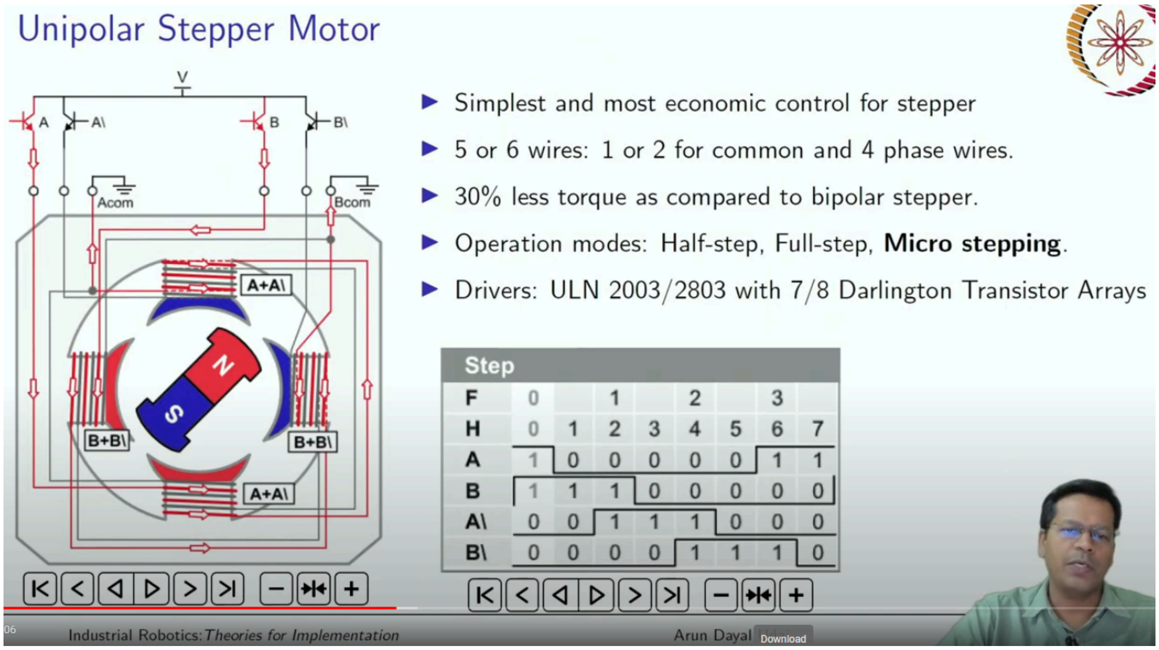


So yes, what exactly is a stepper motor? Stepper motors are small DC motors, and normally, they are small. Nowadays, it is not that small, though. So yes, you must have seen your digital watches, so what you have seen is at every second, it moves by just one tick, one second, one by sixtieth of a 360-degree angle that it can make. So, what you have seen is there is also a specialised, dedicated, low-powered stepper motor which can move just in one second, one small displacement it used to do. So yes, even stepper motors are very, very similar. They are electrical devices, electrical motors which can move incrementally in steps in response to some programmed input pulse train to its wires. It has four wires or five wires, depending on the type of stepper motor it is.

So, all the wires will carry some sort of electrical pulses and pulses, and the level of the pulses will be as high as the driving voltage of the motor itself. Different pulse orders will have different positional places in the circular dial of your stepper motor. So, changing the order of the pulse basically changes the direction of the rotation. So, the order is there, so we will see when we will actually discuss stepper motors. So, they are digitally controlled, and they do not require any digital-to-analogue conversion to do position control. Like in the case of a DC motor, if at all you want to do position control. You have to take feedback in terms of angle. Angle is to be converted, it is to be compared, and then you have a controller which compares and does some sort of control. So, that is all not there in the case of a stepper motor; even if you want to do precise position control, the hardware allows you to do it even without any feedback. So, as long as I must add to this: as long as the load is within the prescribed limits and the motor is not slipping. So, these motors are widely used in open-loop controlled applications where the load is predefined, and you do not require any feedback system, and the control circuitry, in this case, is a little complex as compared to a DC motor. Still, they are inexpensive because you are able to do position control even without feedback.

So, the feedback mechanism is totally missing, and that is what is making it still inexpensive. So, it has a holding torque. As long as it is powered, it can stand still in its place, and it has its holding torque. So, any external torque will not deviate from the position where it is locked now. But yes, while running it can offer some jerks because it moves incrementally like a clock, so every next location where it goes, there is a jerk in between. So, it goes, stops, goes, stops like that.

So yes, the application that you have seen is a small dedicated digital watch. There is another very common thing that you might not have noticed at the time, and that is your standard printer. Standard printers have a paper roll that uses this type of motor. Even the cartridge moves using this type of motor. Similar machines are fax machines, scanners, and copiers. All of them use small stepper motors, small robotic arms, and CNC machines. 3D printers you have already seen. 3D printers have three stepper motors, which are orthogonal to each other. Each of them moves your head to a different location. So, imaginary devices, printing presses, textile machines, gaming machines and robots also. So, they all use stepper motors. But they are all, I tell you, they are all small stepper motors. Industrial stepper motors can be very, very big compared to them. So, different types of stepper motors are permanent magnet, unipolar, and bipolar stepper motors, which we will be discussing today. Variable reluctance stepper motors are there, and hybrid synchronous stepper motors are there. They are commonly used in the industry. We will discuss a bit of that also.



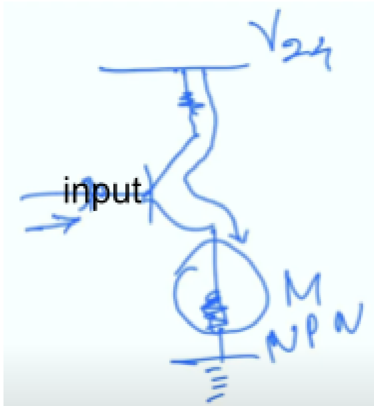
So yes, the unipolar stepper motor is one of the types of stepper motors. Let us discuss this.

So, this is one of the simplest of its kind, and it is the most economical type of stepper motor. It has 5 or 6 numbers of wires, 1 or 2, which here are Acom and Bcom, the common ones. They are the common ones. If you can see my cursor, yes, it is Acom one and Bcom one. So, all together, it is different motors that you see that started running. I should stop this one before we discuss it.

So yes, these are four different wires: A, A bar, B, B bar (A, A ǀ , B, B ǀ). Basically, if A is high, A bar is low, B is high, and B bar is low. So, four different wires will have different signals, which are like this A common and B common are the wires which are connected to the ground. So, they can be either connected within the motor itself or outside the motor they can be done. In that case, it is six wires if it is outside.

So yes, it has 30% less torque as compared to a bipolar stepper motor. We will be discussing bipolar stepper motor as well later on. Before that, let us discuss this one. And then operating modes they can run in half step, full step, and micro stepping. We will see all of these.

Before we go there, let us first see this one. So, if you remember, you can do switching using a transistor. Let us say this is your high line where you have a voltage of, let us say, 24 volts if your motor is 24 volts. This is your transistor. This is where you must have some sort of resistance everywhere, small to bias the transistor, and this is your input.

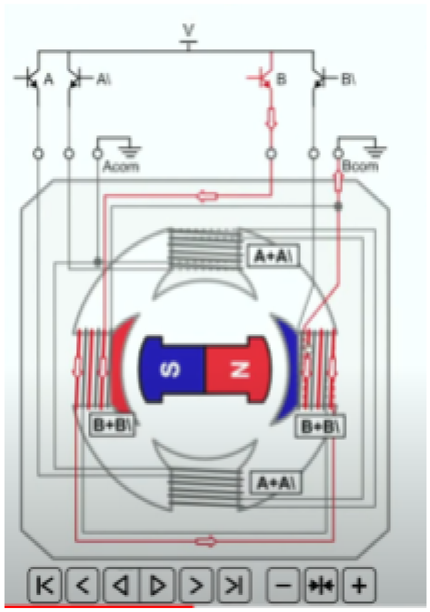


So, your motor can be fitted somewhere over here. So, when you give it a high signal from here, this current from here comes, and finally, that drives this motor. So, this is a way you can switch using a transistor if it is for an NPN transistor. It can be even for PNP a different connection can be made. So yes, this is a type of switching that you did using a standard transistor. It can also be done using MOSFET. So yes, over here in our circuit also, if you can notice, you have all these similar connections. You have all these similar connections. So, A can be switched by this wire terminal, which is here. A bar has got another terminal that goes here.

So, what is the difference between A and A bar? I'll tell you. So, if current flows from A, it comes like this, it comes like this, it is wound on one of the poles, and it goes. It is a reverse wound on the other pole so that when A is high, it makes the bottom one north and the upper one south. Finally, it goes to the earth, that is, to the ground. A bar is high in that case; the wire comes from the other side of it, and it makes the upper one north and the bottom one south if it is. So, it goes back to the ground once again. So, this is to reverse the polarity of the pole which is there. So, north becomes south, and south becomes north from one pair of the set that is A and A bar.

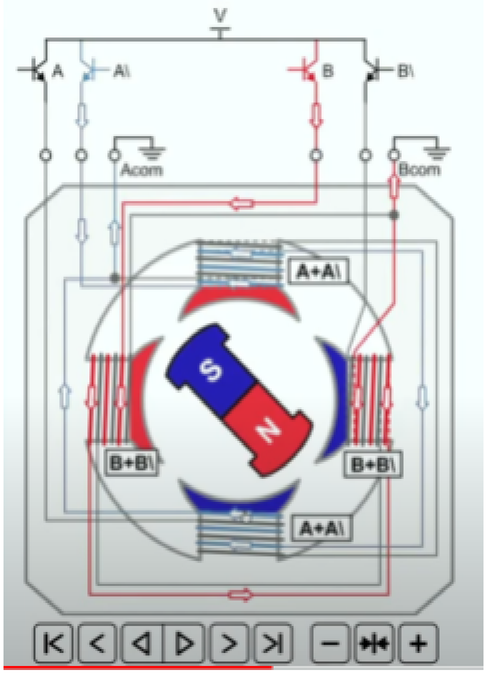
So, similar is the connection for B and B bar that is controlling the horizontal pole which is shown here. So, that will control the current over here in clockwise and counterclockwise direction finally and will make the polarity reversal in these two poles. So, you have four different poles to pair of two. So yes, now let us see how it works. Let us say your motor has started already.

It is here in this position that you see the blue one. If I say it is the north pole, the blue one is the south pole, which is attracting the north pole of the armature. The armature is at an angle now. So yes, when both the poles are high, when both the poles are high, the armature goes to this particular position. It is a magnet which gets attracted towards the pole which is high.

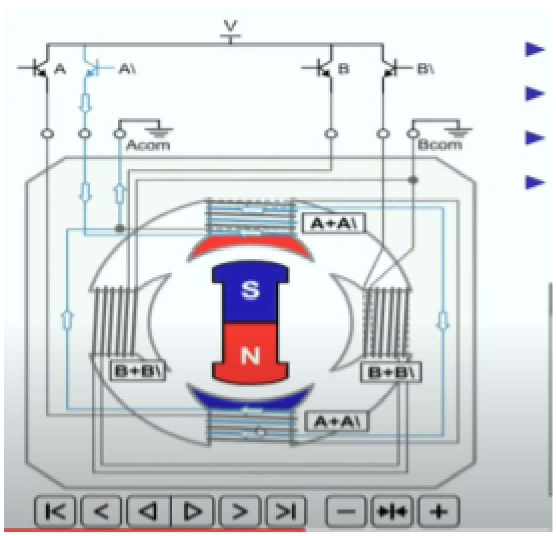


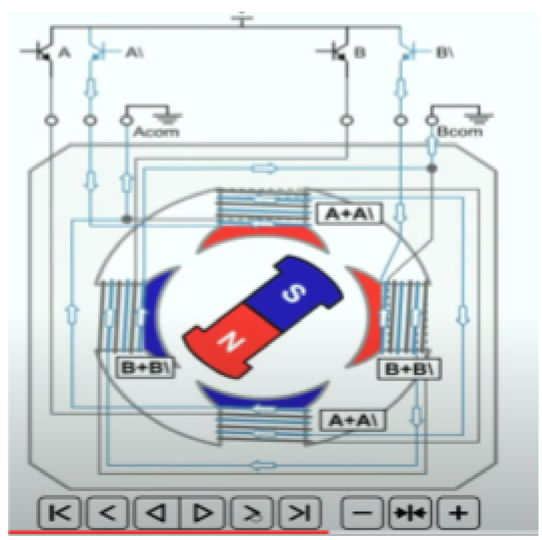
In the next position, you will see that one of the poles is only high. The other one becomes the opposite of that. So, the next pair A A bar is now off. So, both the wires which are here are zero. So, in that case, what will happen is you have just B, which is high. As over here in the truth table also, you can see, so initially, it was in this position. Initially, it was in this position. So, you see, both of them are high, A and B both are high, the armature was like this.

In the next position, when you have only B high, only B from here, this transistor is switched on, and it goes to this location. So, what happens in that case? It is the north, this is the south pole, the blue one, and this is the north pole, and the armature goes like this.

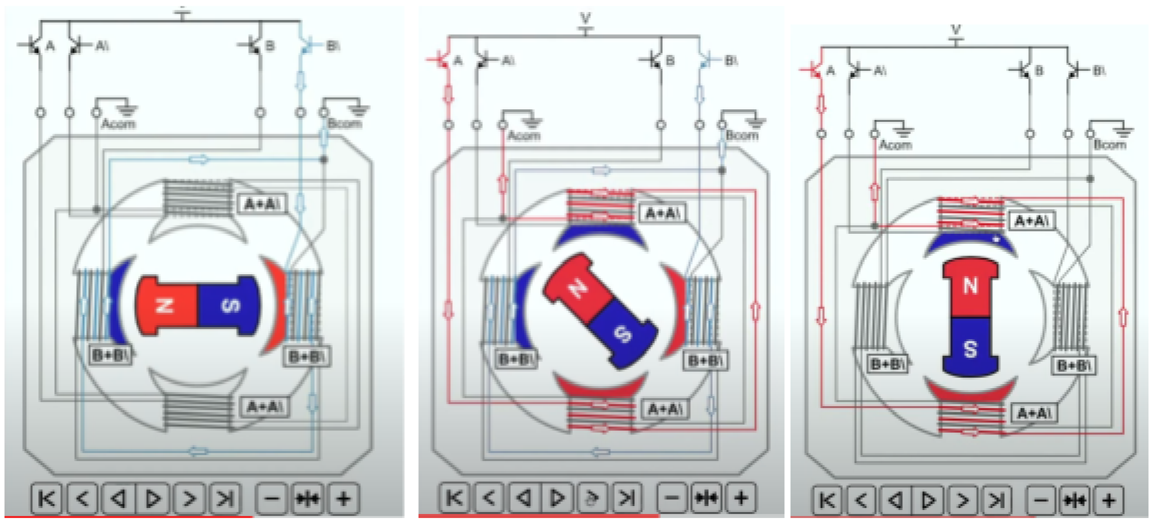


And next position when you have B and A bar high, that is the position which is here, this is B and this is A bar which is high. So, again, the bottom left one, the right corner, and the bottom right corner is now your polarity, which is south. So, ultimately, this armature comes like this, and the next consecutive pulse phase will be only A bar is 1. In that case, it goes to A.





So yes, only when this is high, A bar is high it has come here, A bar is high it has come here



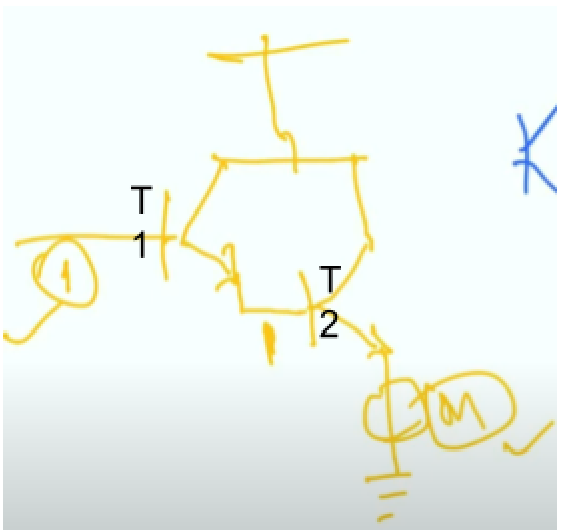
and in the next phase, so yes, now it is A bar, B bar both are high, in that case you see the armature is like this and then next is this when only B bar is high when only B bar is high again next one will be B bar, and A is high. So, it goes back to this position when it is B bar, B bar, and A is high; it comes here, and then it goes back to the original location, that is when only A is high, and when only A is high, it is the last stage. So, in total, eight steps made one full revolution.

So, you see, how it works, you see how it works by the time it keeps running, we can discuss other things. So, in this type of running, when you have the number of poles and the armature is able to go even to the midway in between, that is because of the energising of both the poles simultaneously, so that is half-step running.

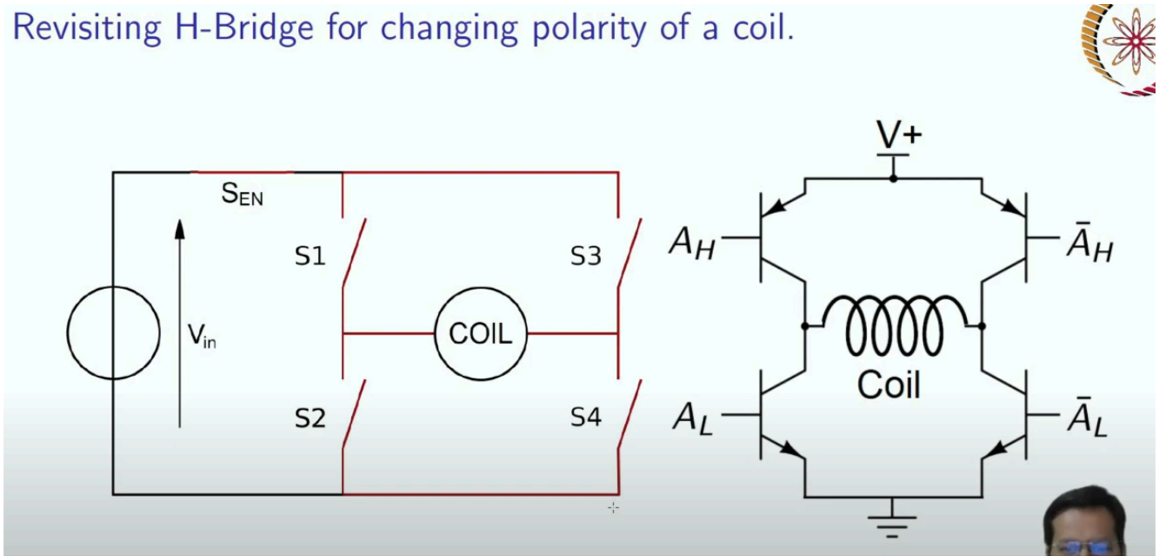
So, one full step is pole to pole. So, the half step is pole, half pole, pole, half pole, pole, half pole like that so that it will rotate like this. So, that is what half-step running is. And apart from this, your motor can also run like this. Let me just show you this way. So, just what you can do here, so you have a pole which is somewhere over here, and there is a pole which is here. So, you can gradually shift the power from this. If this is north, so this can be made north as well, but you gradually shift the power from here to here by controlling the current. In that case, your armature goes from here, this position, to finally, this position by gradually changing its position from north to south.

So, that is a way we can run using the micro-stepping technique that we will discuss very much in detail later. So, that is the way. This is how your stepper motor keeps running and running. So, with every pulse set to all four wires, you see your armature is at a particular position, and then the next pulse sequence then it is at a different position and so on and so forth. So, you see, every pole has got double winding; one is clockwise to make it north, and another one, if it is A, it is A bar, which is counterclockwise, which makes it the south pole when it faces the armature. So, north and south. One of them is always a dummy coil, so for the same motor, you have 50% of the coil which is not working all the time, at least. So, that makes it 30% less torque as compared to the bipolar stepper motor.

Now, let us see what other types of stepper motors also, so commonly used drivers are ULN2003 or 2803, which use 7 or 8 Darlington transistor arrays. So, I should again discuss this one, so let me come back to this whiteboard.

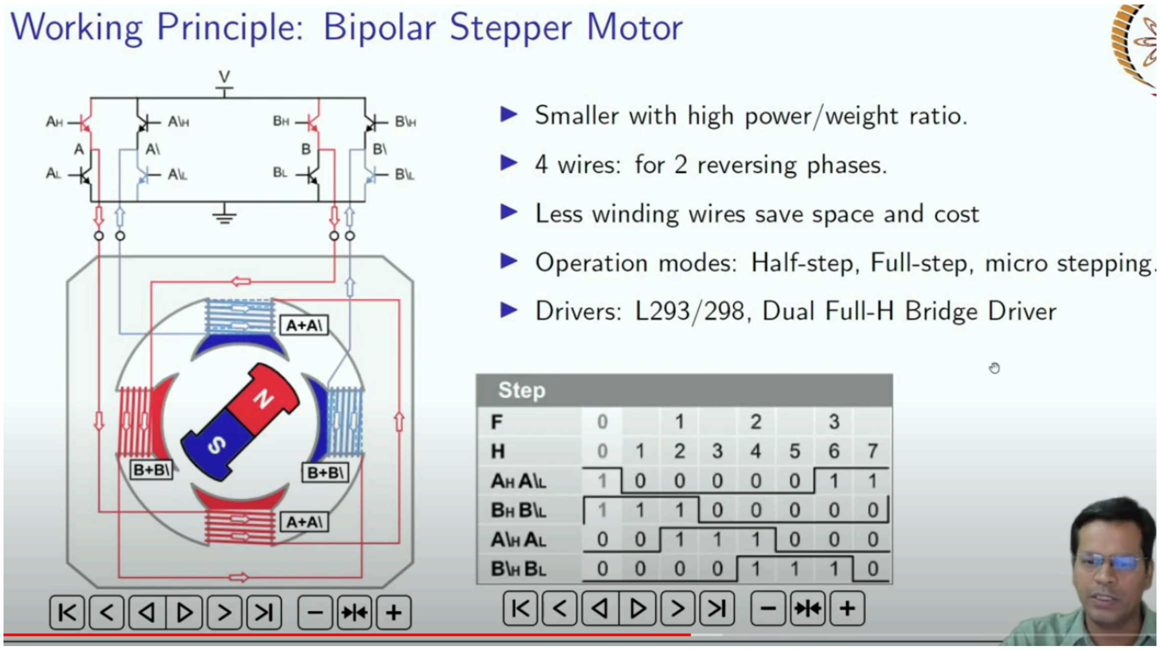


So yes, what is a Darlington array? It is, I think, nothing but something like this. So, you have a transistor which is in switching mode. It comes here, and then you have another transistor that goes to the ground. So, what happens when this is high? It makes this 0. Sorry, this also is high; this further biases the other one, and finally, you see if you connect any motor here that is switched on. So, high on can make it high over here. So, ultimately, the high current can control a high amount of current as compared to a standard small transistor set, so that is the reason this is used. So yes, this is how a simple unipolar transistor stepper motor is run.



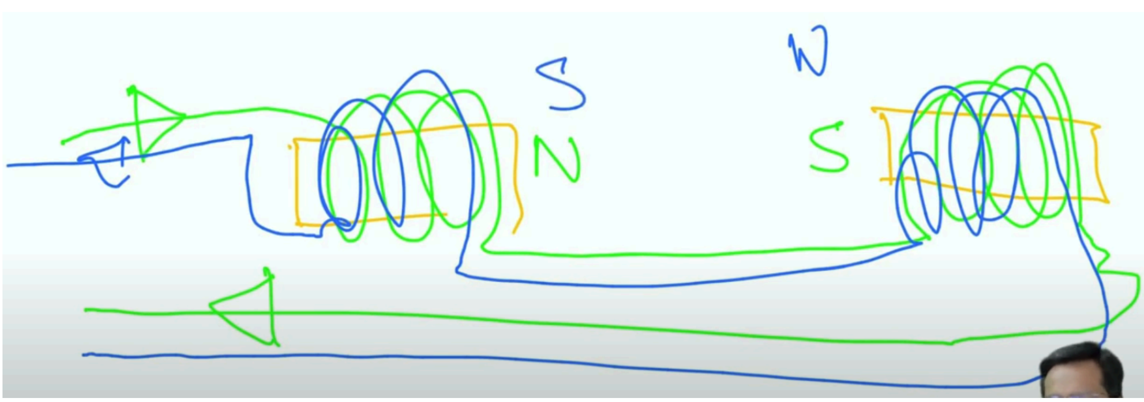
Now, let us see what a bipolar stepper motor is. Before moving on to that, let us just discuss how we control the polarity of a coil using a standard H-bridge driver. So, you had four switches, you remember: S1, S2, S3 and S4. If you switch on S1 and S4, your current enters from left to right direction in the coil, whereas if you switch on S3 and S2, the diagonally opposite one, your current flows from right to left. So, that is to change the direction of flow in the coil, you use this.

So, similar is the case when you can use four transistoride switches or MOSFET switches to convert the direction that is flowing to the coil to reverse the direction of the current which is flowing through the coil. This will make it a north or south pole, reverse polarity one. So, this is something which is going to be used in this case. So, now, a single coil is not energised. The same coil is made north or south depending on the direction of the current.



So, now you come here. Now you will see each one if you can follow me. So, this is a H-bridge. So, this is one H-bridge, which is called A1. This is B. So, A set has got AH and AL. So, if AH and AL are AL bar high, current flows from here. This makes it the North Pole; the red one is the North Pole, and the same wire goes here wound in reverse, and finally, it goes back to the H-bridge. So, this makes this one south pole. So, flowing current from here and finally like this will make it north and south, whereas if you switch on A bar over here, diagonally opposite switches are switched on. In that case, what will happen, so you have a current that flows in a reverse manner and makes the poles reverse.

The same happens to the B and B bar poles. So, they are also a pole to pair of poles which are north and south with the same winding flowing through them, same winding that flows through them. So how is it? Let me just draw a little more detail over here.



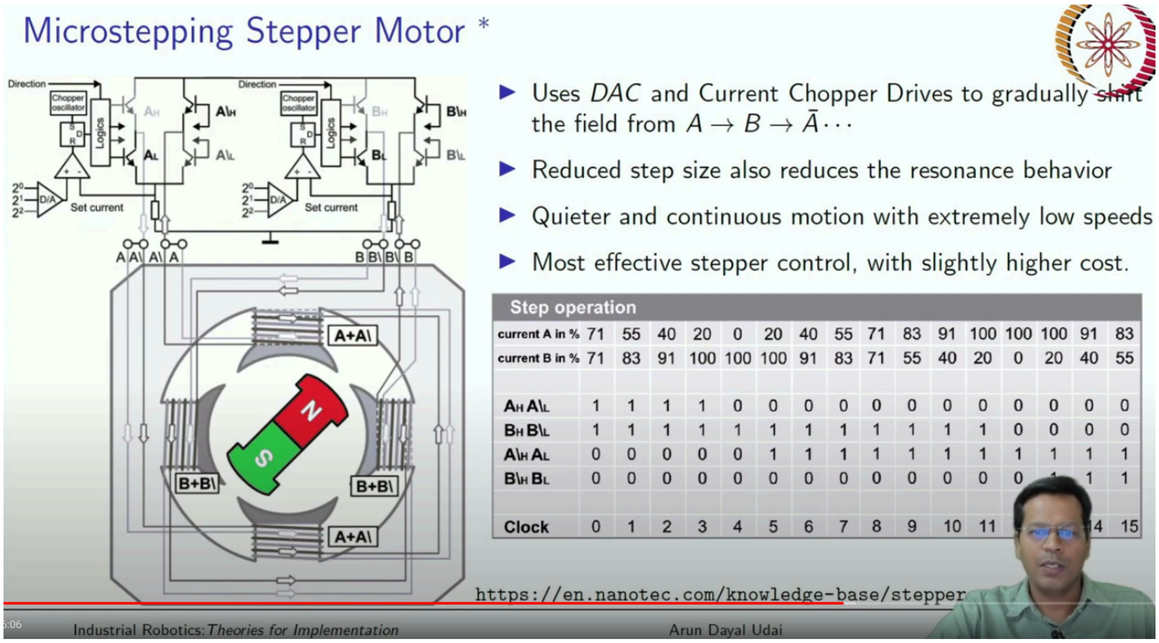
So, if you have a magnet, which is here, you have another magnet, which is here. So, you have a single coil which goes like this (blue line). It comes here. It is wound in a reverse manner, and it is coming back. So, the current flows from here. It goes like this: if this makes this north, this is south. So, what will happen if you make your current go like this (green line), go like this, it comes like this. There is no double winding. So, the same wire carries the opposite current. So, in this case, this will become north, and this will become south. So, this is how it is wound. Now you see what a miracle you can do with the same pole without any duplicate wires, without any duplicate winding.

Now, you can see, you can make it run like this. So, you see now the top right corner is both of them are south, bottom left one is both of them red, they are north. So, you see what happens, one by one you can switch off also. So, this time, I have switched this one off: A bank is totally off, B is on, so armature came here, so B is on, then comes here when you have B bar, and A is on. This is another state of this motor and then only A bar is on, again next B bar A bar, then B bar A and back to A. So, this is how you can convert. You can make it go like this. So, you can keep moving like this. You can watch one full cycle carefully. This is how it works. So, this is again a very small size as compared to a similar power-to-weight ratio of unipolar motors. So, it has a very high power-to-weight ratio as compared to similar-sized unipolar motors. So, this is the truth table for this.

Let me pause this one. Show you the truth table. Yes, it goes like this: the first one when AH BH is on, then you have BH, then you have BH AL, next AL BL, AL-only and then AL BL, BL, BL AH and then only AH. So, this is how it also can keep moving. So, this is how it can keep continuing if you reverse the direction. So, how to do a reversal? You just do something very reverse. So, it rotates in a counterclockwise manner. So, doing this can make it go this way. So, doing this will make it go in the opposite manner. So, same here, so if it is moving like this, you just have to reverse the sequence of the pulse that goes to the coil. That way, you can reverse the direction, so you can precisely control the position, you can precisely control the direction and easily control the direction, and you can control the velocity. So, if you go very fast like this, this motor can go very fast. So, the higher the pulse per second, the pulse sequence changes per second, and the higher the speed, that speed can be controlled, position is automatically controlled, and direction is controlled by changing the pulse sequence also, so this is how it works.

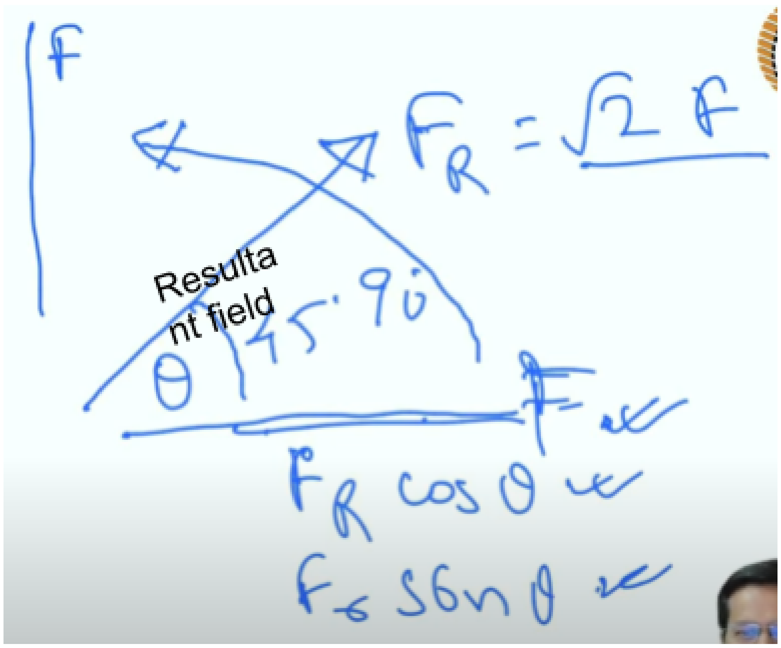
This motor has just four wires, two reversal phases, and less winding, so it saves space and cost. It can also run in half-step, full-step or micro-stepping so that you can go. You can just leave the single pole steps. This one, you escape, you directly make it high, so this one escapes, this one is there, so in 4 steps, four pole pairs are covered that means it is a full step and micro-stepping if you can gradually shift the power of the electromagnets that are the poles from one to the other if you can gradually shift, your armature can move in a very gradual manner.

So yes, the possible drivers for this are L293 and L298, which are dual full H-bridge drivers which you know that through your embedded knowledge may be or hobby electronics, people do it. There are industrial drivers also for this.



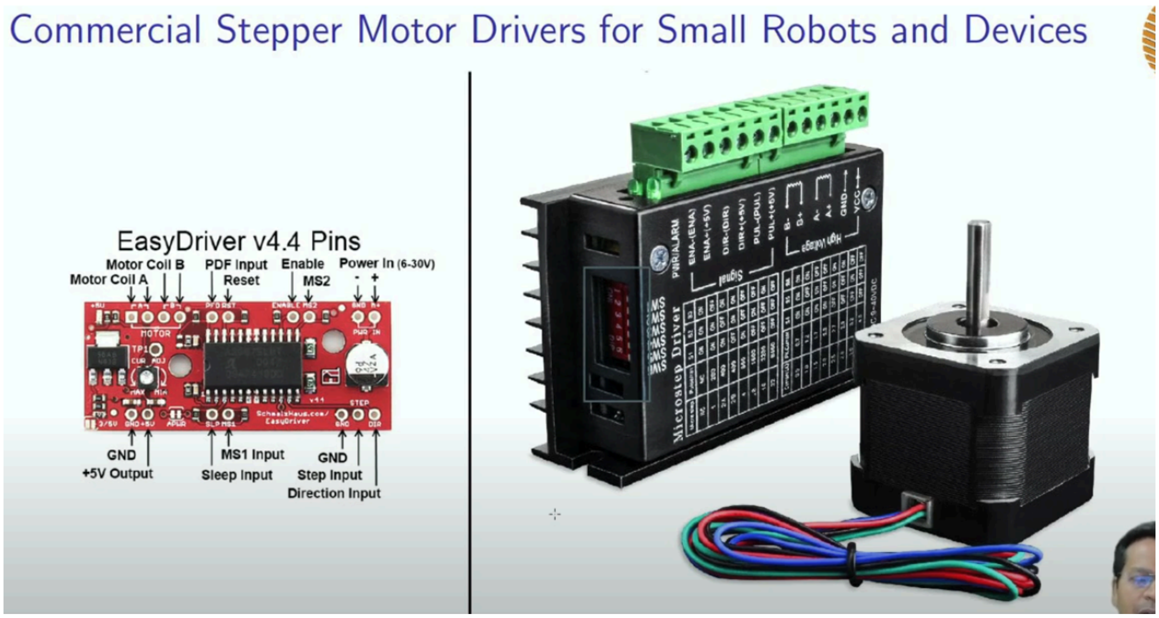
So, now let us move to the modern stepper motors and drivers. We will also see a demonstration of this. So now, I have been talking about micro stepping even for unipolar, for bipolar, how it is actually done, so just see this carefully. This is the same. This is your bipolar stepper motor. Now, what we do here is we gradually shift the load. So how do we do it? So, you have to gradually switch the low power from one of the poles to the other pole. That means this time, and you do not have to make a coil high or low, okay? High shifts from one of the poles to the other one, it gradually shifts, and now you have to control the current. So, you know the strength of a pole depends on the current that flows through it, so it requires a special type of drive which is known as current chopper drives, which will gradually shift the field. So, how can it shift the field because one of the poles is high, this one gradually dies off, another one which is there, so this one gradually picks up, okay? So, you have two poles, so your effective energy is transferred from one of the poles to the other one, okay? So, it uses a DAC, digital to-analog converter that is there. So, the higher the resolution of digital to digital-to-analogue converter, so higher the current control you can obtain from 0 to maximum. If it is a 3-bit, so maximum could be 0 to 2 to the power, 1 to 2 to the power three, that is eight intermediate steps of current control you can. So yes, it reduces the step size and also reduces the resonant behaviour of your motor. So, they are less noisy in that case. They are quieter, and continuous motion can be achieved with extremely low speed if possible okay. They are creating less noise also. The most effective stepper motor with a slightly higher cost because it includes a bit more electronics here.

So, this is the step operation. Now you see, when A is high, it is high for quite a long time, okay? Quite a long time you see, so it is high. You are making it high but not allowing full current to flow using the chopper drive, which is actually powering the H bridge in total. So yes, what will happen? Gradually, you see it goes from here to here. So, you can see complete details in this link if you can follow, which is here, okay? So, I will share this link in detail in the resources section, so do not worry you can directly go there and you can read further. There are a pretty good amount of stepper motor videos on YouTube. I will share a few of them with you all.

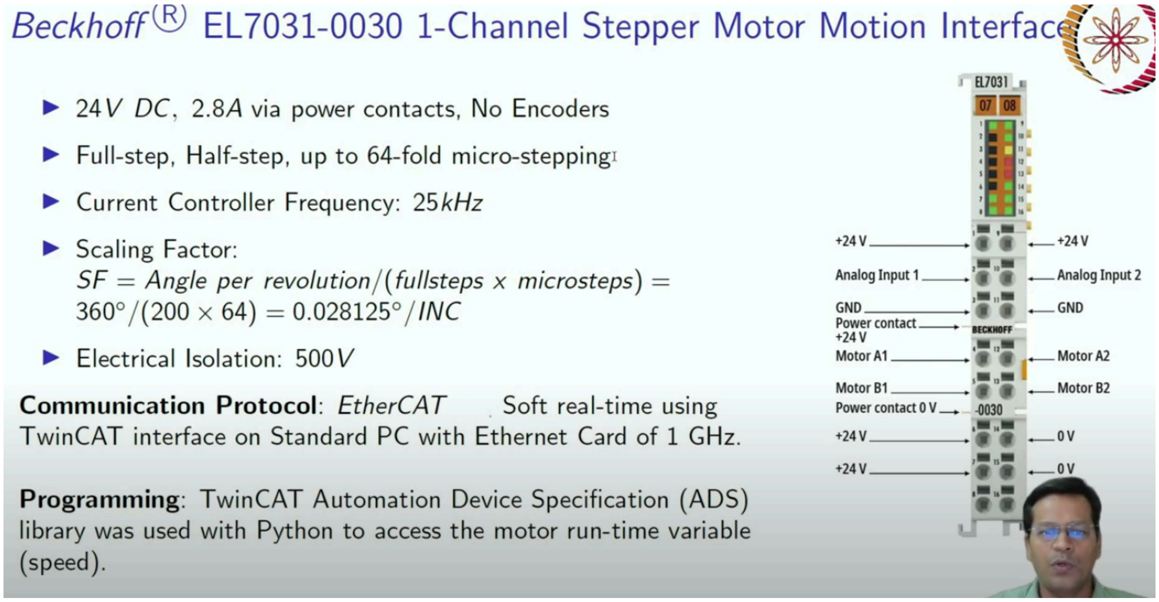


So, what is it doing, basically, if at all you want to switch? Now, let me go to my whiteboard once again. So yes, now what is happening here? So, let us say you have two poles. You want to shift your field from here to here. So effectively, let us say the resultant field is somewhere over here. So, this is what you want to rotate, so this is the resultant field, so that is root two times of these fields. So, if it is at 45 degrees. Let us say if it is just theta, so what is there? So, it is F_R cos theta(F_RCosθ) and Fr sin theta (Frsinθ), right? So, what effectively should go here is F_R is the full resultant that you can get. That is root two times of F. So, F varies. So, what happens?

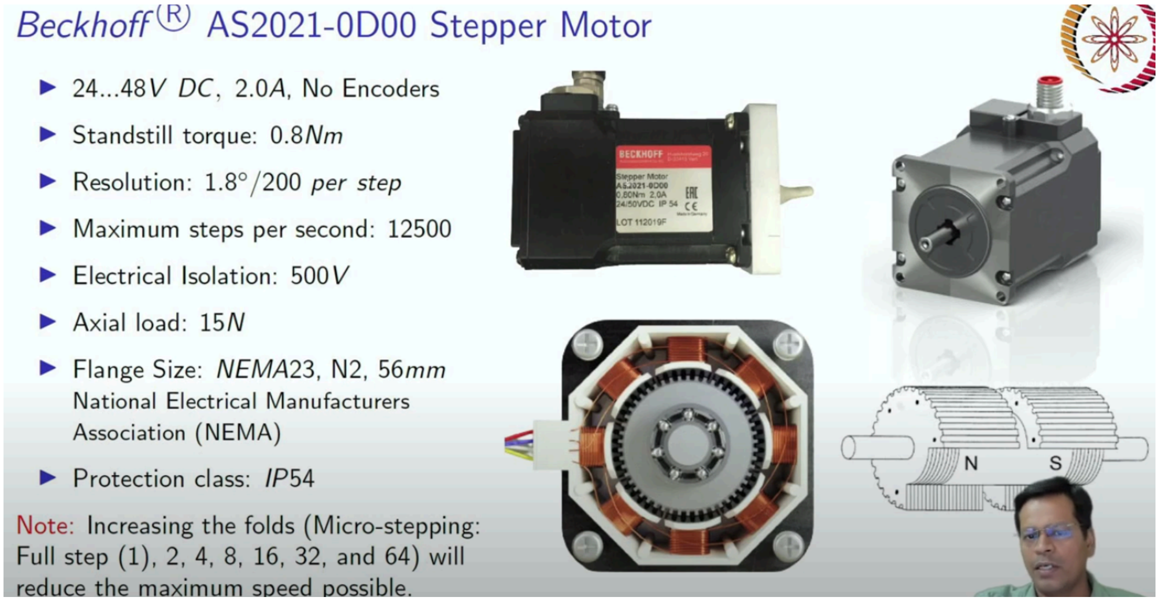
One of them is if you keep on increasing theta, theta, theta like this. So, if the pole will gradually, Fr cos theta over here when it is 0 degrees, this will be the maximum one, this will be the maximum one. If it is minimum, that is at 90 degrees. At 90 degrees, what will happen is this will completely die, and this will become the maximum one. So, this is the way it gradually goes from here. So, at 45 degrees the position which is shown here in this figure. So, if you can see this, at 45 degrees, it is f cos theta, cos theta, sin theta both are equal; that is 45 degrees, that is 0.707. So, percentage-wise, if you see, it should be 0.71 per cent approximately. So, 0.71 per cent of pole strength will effectively create the pole strength at the 45-degree location. So, this is the position here. So, that is one of the demonstrations. So yes, it varies in one of them. It varies as cosine, the other one varies as sin a, yes, and that is how it works. So yes, you have a chopper drive that can do micro stepping also.



So, these are some of the commercially available stepper motor drivers for small robots and devices. This is a commercially available one which you can club through different embedded systems micro controllers because it has 5-volt signals, which are required to signal to change the direction to move every pulse of it. So, this is a dedicated chip which has all the driver circuitry which is required to run a bipolar stepper motor whereas the right one is an industrially safe one to some extent. Yes, it has the capability to do a micro stepping driver also. So, it has some configuration switches, which are here. It has some configuration switches, which you can see here, and then you have an enabling switch enabling that enables a motor. So, it has A, A bar, B, B bar, those wires which can be connected here. It is sometimes, these type of drivers has mod bus connections already to address the stepper motor velocity and address the stepper motor pulse signal. You can do everything from here, or you can directly control it using the direction width. So, you do not have to take care of 4 wires. You just have to address the pulse bit, which will be one high pulse for one tick, one position shift, one another high pulse, and another shift. One high pulse, another shift so that the pulse rate will determine the velocity, and every pulse will be removed by another incremental displacement. So, this is a type of driver which is there. So, we will be using an even higher-up in the industrial sense.

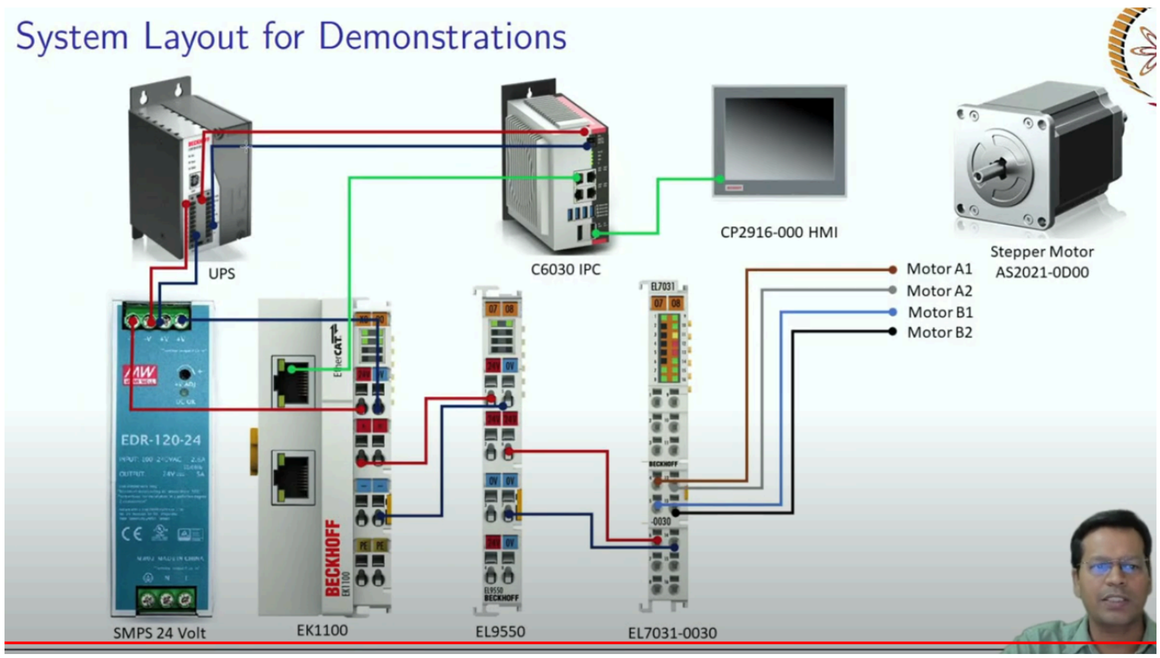


So, this time, I will be using a Beckhoff EL7031 series, which has a channel stepper motor motion interface. It can handle almost around 24-volt stepper motor and 2.8A of power contacts without any encoder. It cannot even see the stepper motor, although it can run in an open loop. Sometimes, they are also fitted with a to ensure that, yes, it has reached there. It has not handled any over torque at any point of its motion. So, you may have feedback to be doubly sure. So, even steppers are served sometimes. So, this has the capability to run it in step mode. So, run it in step mode is full step, half step or 64 fold micro-stepping. So, what does it mean to be 64? That means one pole to another one it can shift in 64-bit, 64 fold. So, how many bits, actually it is? You can imagine 64 intermediate positions. So, that means 2 to the power six intermediate steps. At least it can go in between. So, that is a micro-stepping it can attain. The current control frequency is very high that is 25 kilohertz. So, 25 kilohertz means it has a very high change in current, which you can see. So, in that case, it does not create any noise as such. The scaling factor is each 360 degrees, so 360 is divided full step angle. A full step is when 200 poles are there, poles are there. Ok, each of them is further divided into 64 small micro folds, so the total number of micro folds which are there is 200 into 64 times. So, pole to pole is 200 different poles for 360 degrees. So yes, it can move almost at 0.028125 degrees per increment. So, electrical isolation is there. It is I.P. Certified. So, this has the capability to handle EtherCAT communication using short real-time using TwinCAT 3 interface on a standard PC and EtherCAT Ethernet card of a standard PC should have an Ethernet card with one gigahertz frequency, that is, a prerequisite to use any TwinCAT interface. Programming will again follow similar stuff. We will use the TwinCAT automation device specification TwinCAT ADS library, and we will call import it in the python interface and access the motor run time variables, which are defined in the TwinCAT configuration tool, which is there, that is the driver for it. Finally, that is for configuration and declaring all the objects and their parameters. So, we will see by example now.

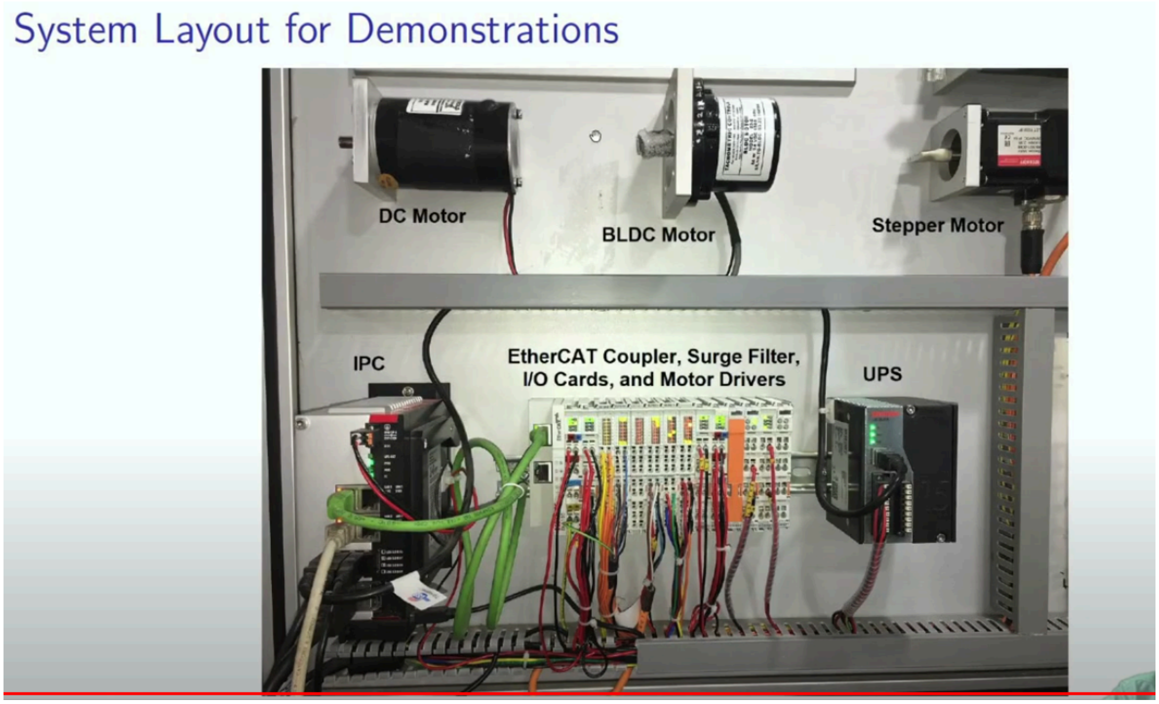


So yes, this is the motor that I will be controlling. You see, it has a resolution of 1.8 degrees, pole to pole-to-pole gap is 1.8 degrees; mind it, this is not precisely a bipolar stepper motor. It is a kind of because it has a dual property of variable reluctance motor as well as bipolar stepper motor, which is a permanent magnet motor. So, in this case, your winding is not straightforward. It varies like this: you have a north pole, which is at the fore side of your armature, rotating armature and aft side, you have the south pole, and there is more number of poles which are generated. So, this is the soft iron core, which is a cap from the top, from the front and the end, and finally, it is a soft iron core and a permanent magnet. So, it has dual. These are advanced architecture motors. When you see you have less number of armature poles as compared to the number of poles which are from all around ok, that is the stator poles. So yes, it can move at a very small angle. So, that is the reason it is able to move at 1.8 degrees, but it does not matter, even though this motor follows the principle of a bipolar stepper motor. It has four wires, and in the same way, you have to shift your poles right. So, nothing to worry about. The same drivers are suitable for this as well. So yes, the maximum number of steps per second is, this is a very important parameter because of the rotor moment of inertia. It is static in nature, so once you start, you cannot go to the next position immediately, which basically limits the number of steps per number of steps per second that is changed in pulses. You cannot move at very high speed because it has its own rotor has its own moment of inertia. It cannot quickly pick up and reach, so if you go beyond that, it will start slipping, which means your poles will move, but your rotor will not move. It would not be able to follow that.

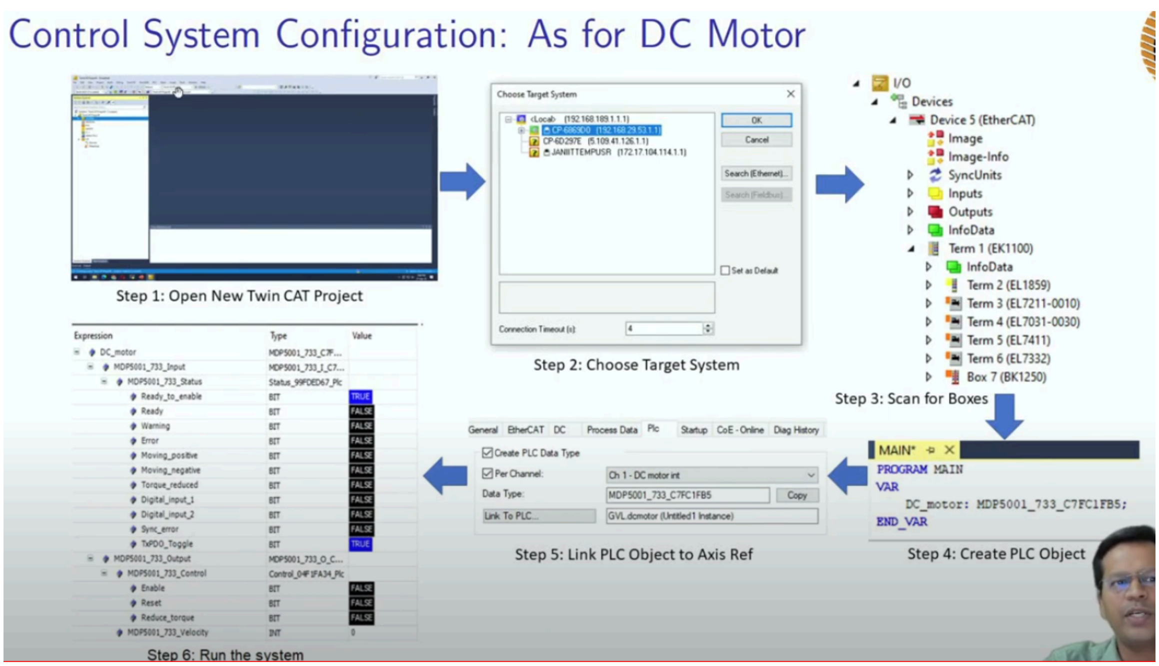
So, electrical isolation 500-volt axial load also is very, very important because most of the time, stepper motors are used to pull and push some sort of pinion drives ok, so screw and pinion drive where it can pull a bed may be a tool sometimes. So, an axial load of more than 15N is not acceptable. Any stepper motor or normal servo motor also are specified, and sizes are specified like this, so it is NEMA23, which is National Electrical Manufacturers Association NEMA. 23 means 2.3 inches, which is approximately 56 millimetres. 58, but if it says N2, it is 56 millimetres. The protection class is IP54. You see, these are all industrial specifications. Things are the same, ok? So, different micro folds are possible. So, increasing the micro folds will ultimately reduce the maximum speed possible you see. So, the maximum speed is the bigger the steps, the higher the speed. That is quite obvious. So, that works with this also.



So, this is the circuitry which is there, I have rigged up. It is very, very similar to the way we rigged up for DC motors. So, you see, this is the power which is supplying 24 volt power, 120 watt is the maximum which it can supply. This is going to your EtherCAT coupler also, which is connected to an industrial PC. The green one is the communication wire, whereas the red one is the power wire. So, power is drawn from the UPS. UPS takes power from this power supply SMPS, and finally, from the UPS, it goes to your different devices and in between, you also have EL9550, which is now the power supply, nothing but a filter, noise filter that is again it is here, and from filter, it goes to the driver. It goes to the motor driver EL7031, the one which you saw here EL7031 ok. Ultimately, this card (EL7031) is there. It finally connects your stepper motor phase A, that is, A1 A2, and phase B, B1 B2. 4 wires of the stepper motor are okay. So, this is the setup which I have used.

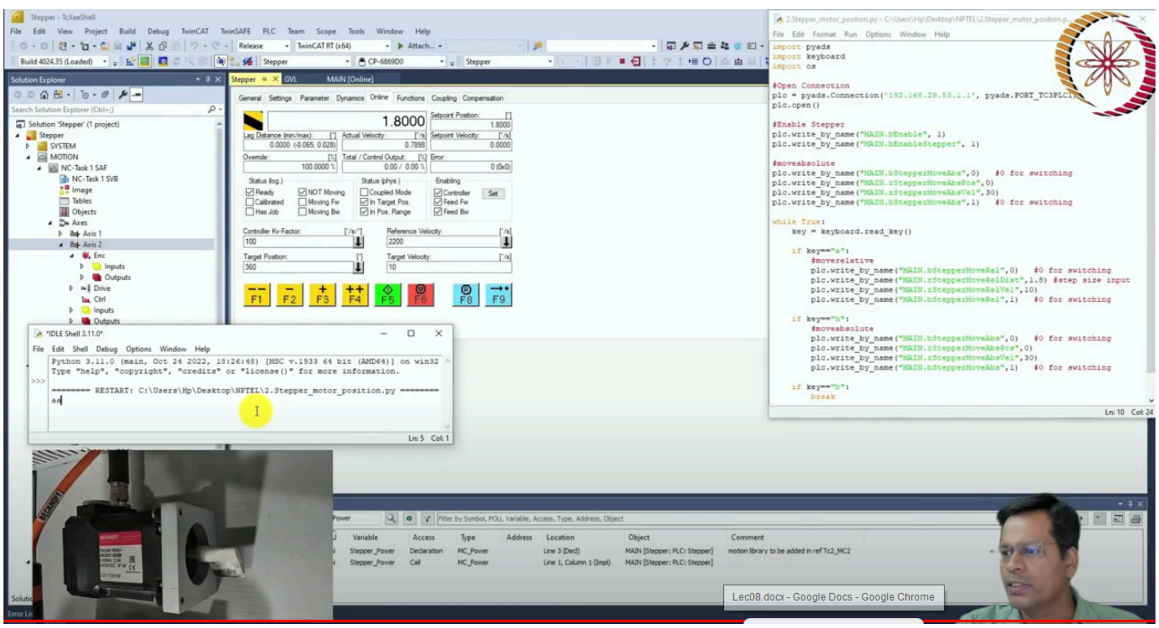


It is the physical setup that you can see. Forget about the DC motor and BLDC here. So, the stepper motor is fitted here. These are all EtherCAT. This first one is the EtherCAT coupler, then you have a filter, and then you have the rest of the motor drivers. So, this is your industrial PC. So, on the top, you have HMI. So yes, now I will communicate this to a regular PC not using the HMI here.



So same way you have to do configuration, you just open up a TwinCAT environment when you can select your system, which is connected to this through EtherCAT. So, that is the IPC which was connected. IPC is further connected to different IO boxes and the motor drivers. So, I have just selected my system ok chosen the target system. I have scanned all the boxes. I selected it right right-click scan for the boxes. It has been found out, yes these are the components which are now fitted one after the other. If you look carefully, it has different IO boxes and it also has different motor drivers. So, it has detected all of them. One of them is EL7031. EL7031 is for this one terminal 4. EL7031 is your stepper motor driver. So, this driver can be declared it has an object which has all the variables.

As you know, you can say I will show you also. So, you have to link this particular terminal and make it an axis. You link this PLC object axis to a physical environment. So, now this linking is done to the physical environment. Now, this object allows you to handle all these parameters, so this is the status that is through the feedback ok. This is the status that is through the feedback, and this is what can be controlled. So, you see, you can control the torque, you can enable, you can do velocity control right and more so you can give it a pulse, pulse, pulse, pulse, and it can move ok. So, that is the input side of it you can give ok.



So now, directly going to the video demonstration of it, ok. So now, you see, I will just restart this one, ok? Just watch carefully. So, yes, you see, initially, it was at 0, 1.8 degrees, then 3.6, then 5.4. So, you see, it is moving in steps. It is moving in steps 1.8 degrees, 3.6 degrees, 5.4 degrees. So, this is coded like this if you can look carefully. If I press A, it goes by one full step, that is, 1.8 degrees with a predetermined velocity, which is fed here. That is the velocity parameter, which I have updated from here. So, it starts like you have a PLC object which is created by creating a connection to the IP which uses, which is through which EtherCAT, through which it is connected. Your device is connected ok, and that is the port. So, you just create an object. Open it, access its variables and just set the stepper motor status as one. You have also created this object; set this as enabled. It has made it one ok. So, finally, every time you go, you have to set its velocity and set the angle, velocity and angle. So, for A, it is defined as going with some velocity. You see, it is here, and then I have just fed it with 1.8. So, every time I press A, it moves. It just watches, so it is 7.2, then nine, and so on and so forth.

So, finally I made it move, go totally to 360 degrees. So, for that to happen, I have defined the W parameter. So, if that happens, it will quickly go to 360 degrees. One full revolution with a predefined velocity. So, now I will press W. So, it goes directly from 0 to 360 degrees with a particular velocity of 360 degrees, and from again from 360 degrees, it will go back to 0. If I press another key sequence, which is defined in this code, you look carefully, and then the same sequence is repeated with a higher velocity. This time, it is moving with a higher velocity. So, this is how I have made it run.

So, yes, now you know very well how a stepper motor is. It can be made to run different types of stepper motors. How they are internally connected, and how they are constructed. So yes, not much in detail for micro stepping you have learnt. Still, yes, you at least got the philosophy here that, yes, it is very much like a bipolar stepper motor. You can gradually shift the pole using the current chopper drive. That is all for this class. In the next class, we will be discussing more about brushless DC motors, that is all thanks a lot.