NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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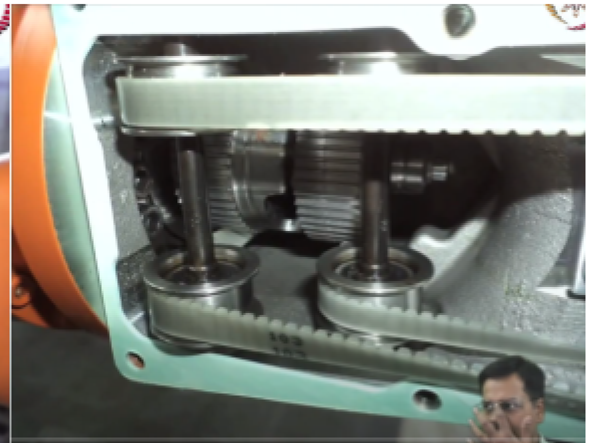
Lecture: 27

Mastering an Industrial Robot

Hi, hope you all are having fun learning industrial robots through implementation. In my last lecture, I discussed how an industrial robot is installed and it is put to use. After the installation, I showed you how a robot can move at its joint level by simply jogging. So, in today's lecture, I will be discussing some more preliminary tasks that are mandatory to put the robot to use to its full capacity. So, let us start today's class.

So, let me first introduce you to the complete problem: what it is, and why is it so important? Just watch this video carefully: how an industrial robot is constructed inside and how there are multiple transmissions which are there. Just watch carefully. So, you see, this is a simple actuator which is at the rear part of the link. You will find you have actuators. There are actuators at many other places too. So, this is an actuator with its end cover removed. So, now, let me run this video. So, you see how they are constructed and how they are interconnected.

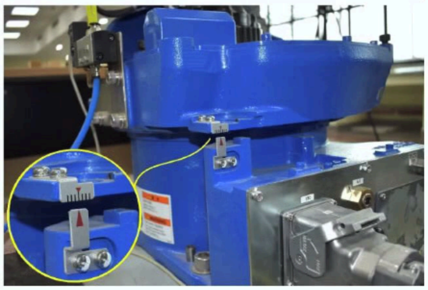


Gearboxes

These are the transmission, which is there so that it moves. There are gearboxes which are inside. There are belts. There are pulley drives. So, it has started moving with the gearbox open now. So, axis 4 is moving. Now, you can understand. See, axis 4 is moving. Now, axis 5 is getting moved, and I have just put a marker so that you can understand the movement of the belt. It is a twisted belt. It is not a straight connected belt and that is driving the pulley.
Furthermore, it is a timing belt so that it doesn't slip. There are multiple concentric shafts which are there, which are driving multiple pulleys together. So,me idling pulleys are also there. This is axis 5. Now, the internal pulley is inside.

The pulley that is inside is now getting moved. So, I have put another marker inside so that you can understand that as well. So, yes, that is driving axis 6. Got it? So axis5, axis6, axis4 was moving. That was directly coupled from the outermost part of the concentric shaft. Now, let me see from its rear part. OK, when all the end covers are open, these are three actuators, which are there, with the end fitted with resolvers. So, you see, they are now open one by one. I am moving axis4, 5 and 6. So, they are moved. So, there is some coupling. There is some transmission which is there which connects the motor to the encoder on one side of it, and motor to the transmission system, and finally to the link on the other side of it. So, you got it. It is quite complicated inside, at least for axis4, 5 and 6, where it has multiple transmissions which are there inside. So, multiple joints are getting moved. See, there are two which are moving simultaneously now.

What is Mastering?

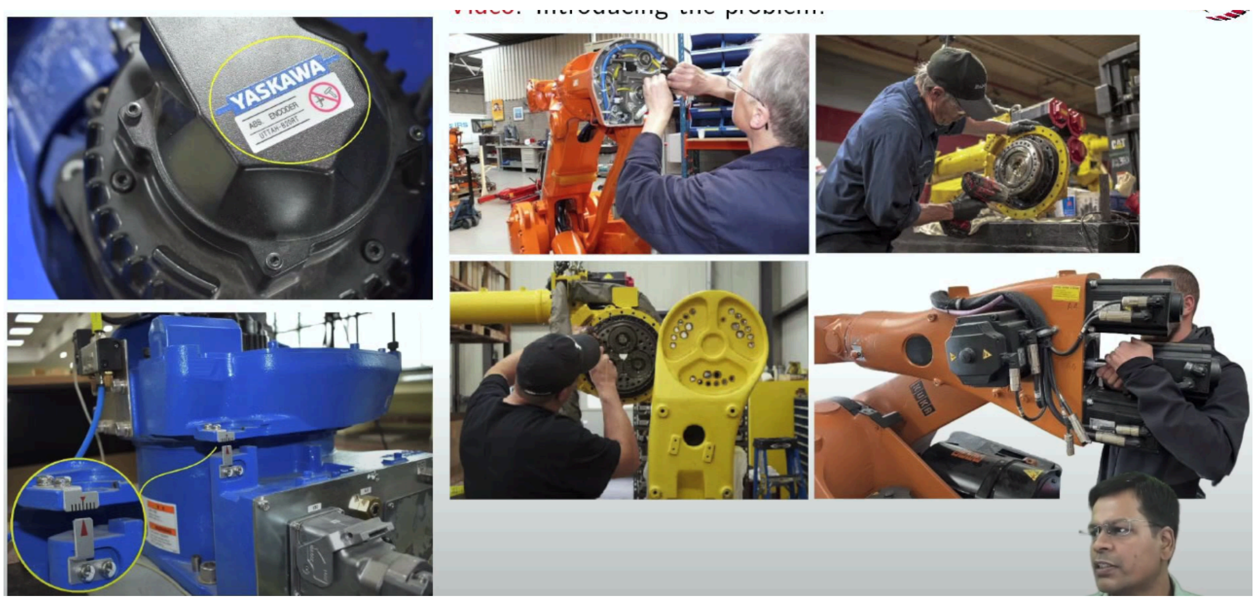


Video: Introducing the problem!

Mastering: The mechanical position and the electronic position of the robot's joints are aligned.

- The process involves moving the robot to a pre-defined mechanical position, commonly known as the *Mastering Position or Home Position* and saving the encoder values.
- Mastering is required under following cases:
  → During first run/commissioning
  → After maintenance
  e.g. motor or gearbox overhauling, changing the controller
  → Robot moves without the controller,
  e.g. with some release device
  → After impact with the physical joint stops
  → After a collision.
- In case of regular stop (using Stop, Emergency Stop, or Switching off the drives) the mastering data is preserved by the controller.

What you can see now is this joint, which is there, axis1, which is there. There is a marker, you see, magnified it here, so that marker actually says the exact zero location of the axis. If you say my joint angle is 0 degrees at axis number 1. So, where is that with respect to what it is getting measured? So, it is with respect to the base, which is fixed to the ground, At least for axis 1. If the later links are to be understood, so it is always with respect to the previous link. So, that is a standard marker which is there normally in all the industrial robots so that you can exactly understand whether it is exactly at zero or it is not. So, the problem here is what is known as mastering. The mechanical position and the electrical position of the robot joints are aligned. What does it mean When you say it is at 0 degrees? Mechanical, 0-degree electronic encoders, which are fitted at the end, also should say yes, it is at 0 degrees, so that you can get correct feedback and your kinematics is well understood by the controller. So, if you command it to go to a particular position, let's say XYZ, and you calculate, theta is equal to 1 to 6, whatever angle you have calculated using inverse kinematics or any other algorithm. So, you have understood. I have to go to theta 1 to theta 6 for all the angles. Now, your controller should create a closed loop using the feedback that is coming. So, you got the complete picture now. So, in order to go to any joint angle, the joint itself should give you correct feedback, and that is given by electronic encoders. So, that is what is electronic zeroing, that we can say, so that encoder should also give you an 0 degree. Got it? So that is what is a process of mastering. So, when you attach an encoder at the end of our robot, it doesn't need to be always matched with the mechanical 0 axes. It can be a little offset in terms of angles. So, in that case, you have just to understand this much is my offset and if I say 0, I will start from, let's say, 10 if it is 10, it is 20. If it is 20, it is 30. So, that's what. That is how that offset will continuously remain there. So, that offset is to be understood well and the same in both clockwise and counterclockwise directions. So, that is what is mastered when both the mechanical position and the electronic position of the robot joints are aligned. OK, so this is the encoder which is fitted at the real part of your actuator. So, this is the actuator. The process involves moving the robot to a predefined mechanical position, that is, the zero position, which is commonly known as the mastering position or sometimes has a home position also, and saving the encoder values for that. So, this is the offset that you are going to save. So, if you are at zero, your encoder says something, and that is what is to be stored. So, that is the first thing that we are going to do, and mastering is required, at least when you have first installed your robot. OK, because it has come through long transportation. Maybe in that case, it might have hit somewhere and whatever manufacturer might have set this zero position, it must have further turned, or maybe there is some gear shift, maybe some error that has happened. So, you have to recalibrate that particular offset. So, during the first run, it is mandatory, and the robot, sometimes the controller, has an interlock so that you cannot move ahead without the first time mastering your system. So, this is the first time that you do it. And after maintenance, you see, if you have removed the motor, that also will remove the encoder and the transmission. You are engaged in some gearbox condition, and next time you engage it differently so that offset is also generated. Your belt, if you have taken it out, connects the input and the outputs, so once you put it back, there must be some offset between the input and output. When you open it and when you put it back they are not the same. So, while overhauling any transmission system, while overhauling the motor, while overhauling the gearbox or maybe encoder or any part of the system that can affect the feedback, you have to do mastering.



So, this picture shows typical maintenance which is carried out in the robot encoder and sometimes in the gearbox and some other. The whole of the motor is getting removed, you see. this kind of maintenance which are normally done if the robot has surpassed some definite amount of running hours, so planned maintenance also you do it sometimes after the breakdown.

So that this robot can move without the controller. Your controller has arrived in a different package and your robot has come in a different package, and your robot can move without the controller actually commanded the robot to move, and that doesn't know that the robot has already moved. So, that feedback is lost, whatever the value that the manufacturer might have configured during the first run of this controller and the robot pair, that is lost. So, your robot should not move without the controller. So, many times, it can be moved for maintenance purposes using some special release arrangement which is there in some robots. OK, if that release mechanism is used and the robot moves without the controller, then you also need to do this, and after an impact with the physical joint stops. So, your each joint.

I'll show you the picture first. So, this is a. these are the physical stops which are there. So, that is there in this robot, in my toy robot, that is the demo robot also. That is there, you see, it is here. So, that hits this body. So, if it comes like this, very hard, OK, while moving, it hits like this very hard. In that case also, it may have lost its mastery. OK, so this is the physical stop. You see, after a big collision, maybe. So, I'll show you another video which shows a collision. This is a coordinate, coordinate motion between the tool and the system. You see, the robot was programmed in some way, and it found the system in some other way. So, these are some of the instances which are very, very common in the industry. It should not happen. But if it does happen, you have to take care, and you have to remaster your robot, so in the case of regular stops, at least when you handle your robot in a standard way, using emergency stop, if you stop it, using a dedicated stop button, if you are doing it, switching off the drives. So, in those cases, your mastering is preserved by the controller, so the controller continuously gets the feedback. It even gets the feedback. Yes, now my emergency stop is pressed, and I have to save the values which are there. So, while the motor moves, your feedback continuously changes. So, I hope you understand that. So, this is what is mastering and that is the problem, and you have to deal with it. It is very, very simple to understand the problem. Once it is understood, well, there are n number of ways to do it, there are a few standard ways as well, so we'll discuss that.

Notes on Mastering

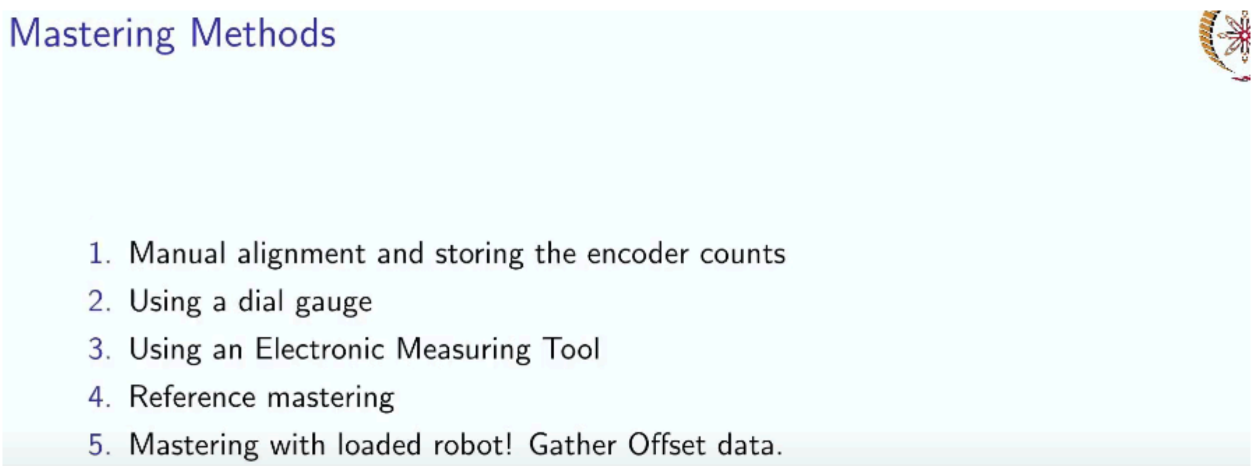
- A mastered robot can be programmed to move to any positions **accurately**.
- A mastered robot can be moved using Cartesian coordinates.
- Even two identical robots can have different encoder counts for the same pose.
- Ambient conditions must be maintained during the complete procedure.
- Mastering external axis: Required if the controller is attached with any external axis.
- **Mastering data vary with loaded and unloaded robot!**
  → Multiple mastering is required for robot that is meant to carry multiple loads.

So some of the important notes that I'll make here. A mastered robot can be programmed to move to any position quite accurately over a period of time. There may be some gear backlash. That has happened. Your belt might have become a little loose, and you can tighten it, and then, in those cases, it loses its precision. So, you have to recalibrate your robot, you have to remaster your system so that it keeps on working to a very good accuracy. So, maintain the accuracy of your robot. It is very much required after a certain amount of time. A mastered robot can be moved to the Cartesian coordinates because you know inverse kinematics is going to give you angles, if at all. You have commanded us to go to X, Y and Z. You have calculated theta 1 to theta 6, so you have to command for this, and this cannot be achieved without continuous feedback from your encoders, that is the feedback angle feedback device. So, that feedback should be matched with the mechanical angles which are to be commanded so that continuous servo can be done, even two identical robots, you know, which have the same type of encoders fitted, the counts can vary for the same pose. So, you have to recalibrate.

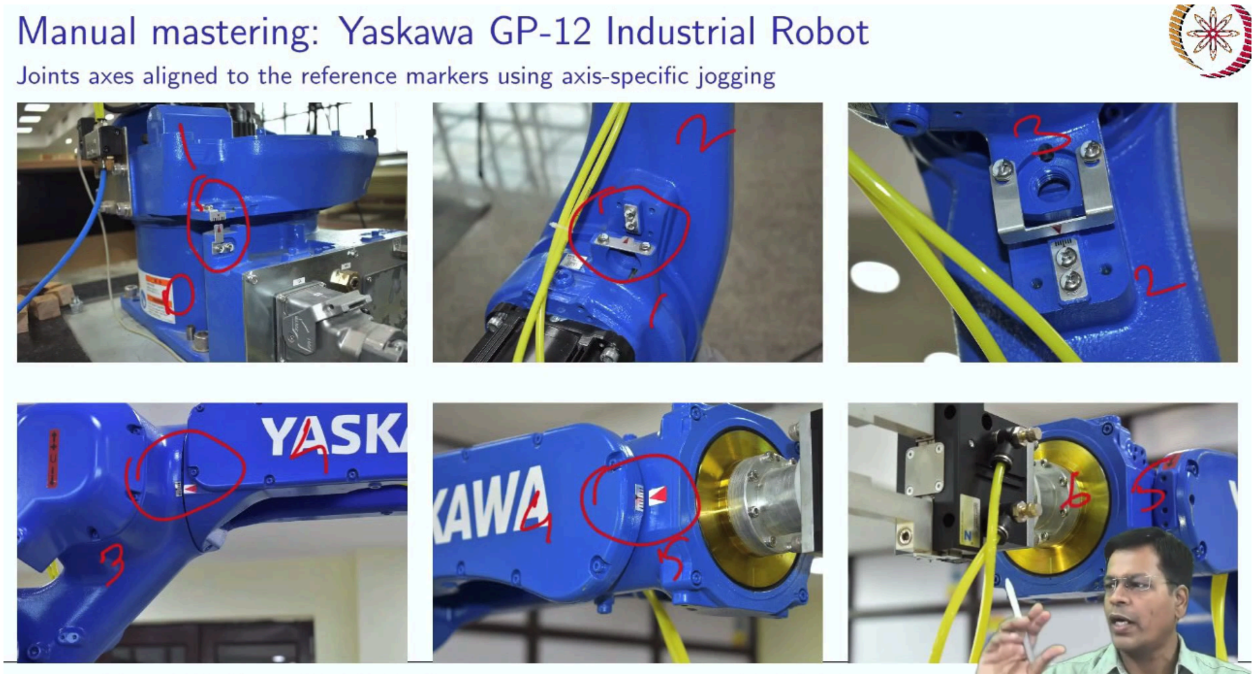
Even you cannot save the value from one of the robots to the other robot. So, it is mandatory even for twin robots, which are here in the industry quite commonly. Ambient conditions must be maintained during the complete procedure of mastering. Now, you understand why because of your arms, your transmission system, there are some dimensional changes, if at all temperature is changed. If temperature has changed, that dimensional change can cause some relative change in the angles or the displacement which are there and in order to accurately match it with the whole of the system, so you have to take care that ambient condition, at least the temperature, should be maintained throughout the calibration procedure.

So, mastering the external axis: sometimes your robot also has got an external axis like a turntable. It is there, so in that case, that turntable is also controlled by the robot controller. So, that becomes the seventh axis. So, that also needs to be mastered. You should know the zero, and you should understand there is some kinematic linkage between the robot and the external axis as well so that it can be worked together. So, that is the reason mastering is also required for any external axis, if it is there.

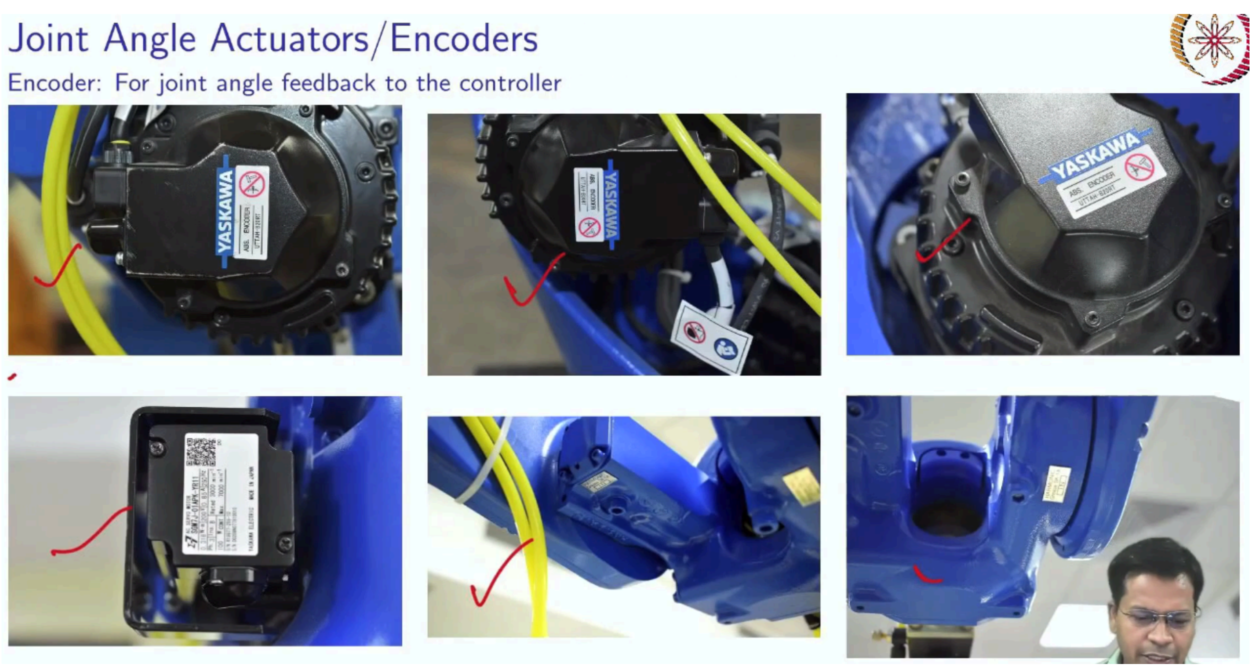
Mastering data varies with the loaded and unloaded robot. So, if at all your robot is loaded with, let's say, 200 kg over here, that must have caused some sort of angular changes due to the amount of torsion that is coming to the shaft, gear shaft, and to the belts, to all the transmission that is there between the robot and the end effector. So, that has caused some shift. So, that also needs to be recorded, so that when you master with the bare robot, without the load, it can perform well then. But when you have loaded it, there must be some kind of flexibility, which is there. It is not very sturdy enough to hold that load sometimes. So, a bit of lack of stiffness is there sometimes. So, those are also to be recorded. In order to do that, you have to put the robot with a dedicated load, which is for which it is designed or the load with which you want to work with. OK, you have to put that load here and then master it. So, you need to know the offset. Your controller needs to know the offset with the loaded robot and the unloaded robot got it. So, if your robot is going to carry multiple loads during its job, you have to calibrate your robot for all the different loads that it is going to carry. So, sometimes it is very, very important if it is a very, very precise task which is to be performed by the robot.



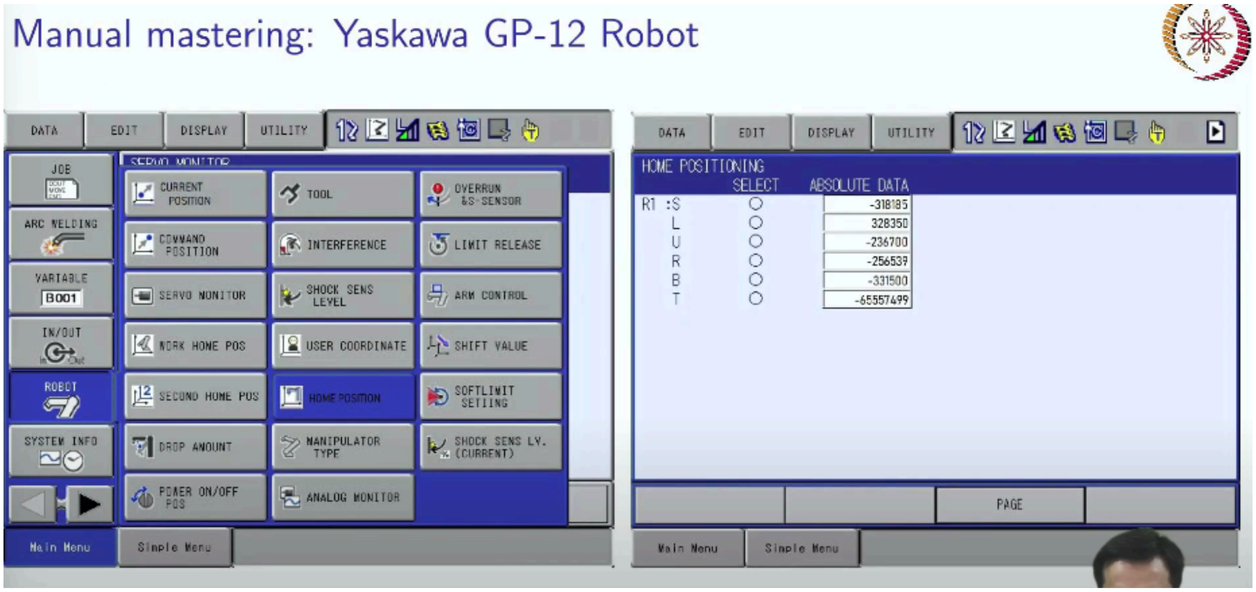
Now, there are many mastering methods which are there. A few of them are listed here. First, four will be doing this with the loaded and unloaded that I have just told you. So, that is there. The rest are four methods I'll discuss now.



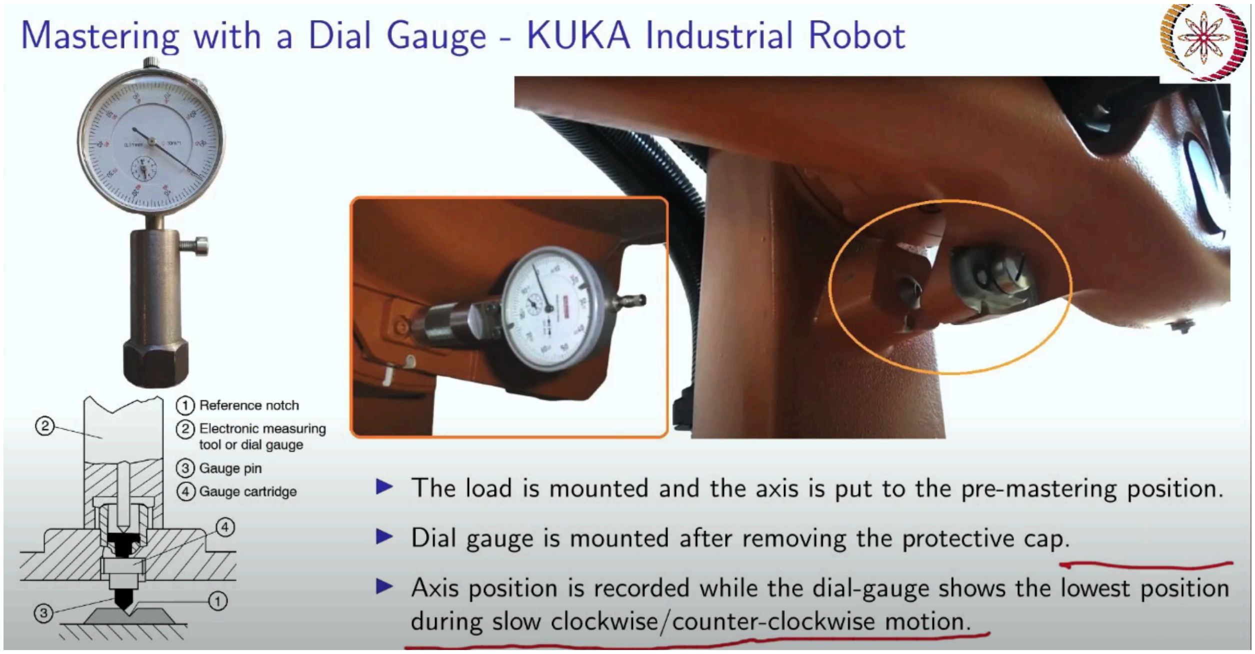
So, this is the clear picture of all the axes with their zero position, shown by the relative zero position marked over here between the third link and the fourth. One zero and one, one and two, two and three, three and four, four and five, five and six. So, you got its angle markers are there. You can see, and your joints also have encoders which are here for all the axes one to six of Yaskawa GP-12 arm. So, this is not very necessary to see this exact location, and I all only saying this is helpful, at least for manual mastering. So, this is just for your knowledge.



These are the actuators which are fitted with encoders at the end. These are not quite visible here, whereas this is a very, very clearly written encoder. So, these are for axes five and six. Those are small motors which are there.

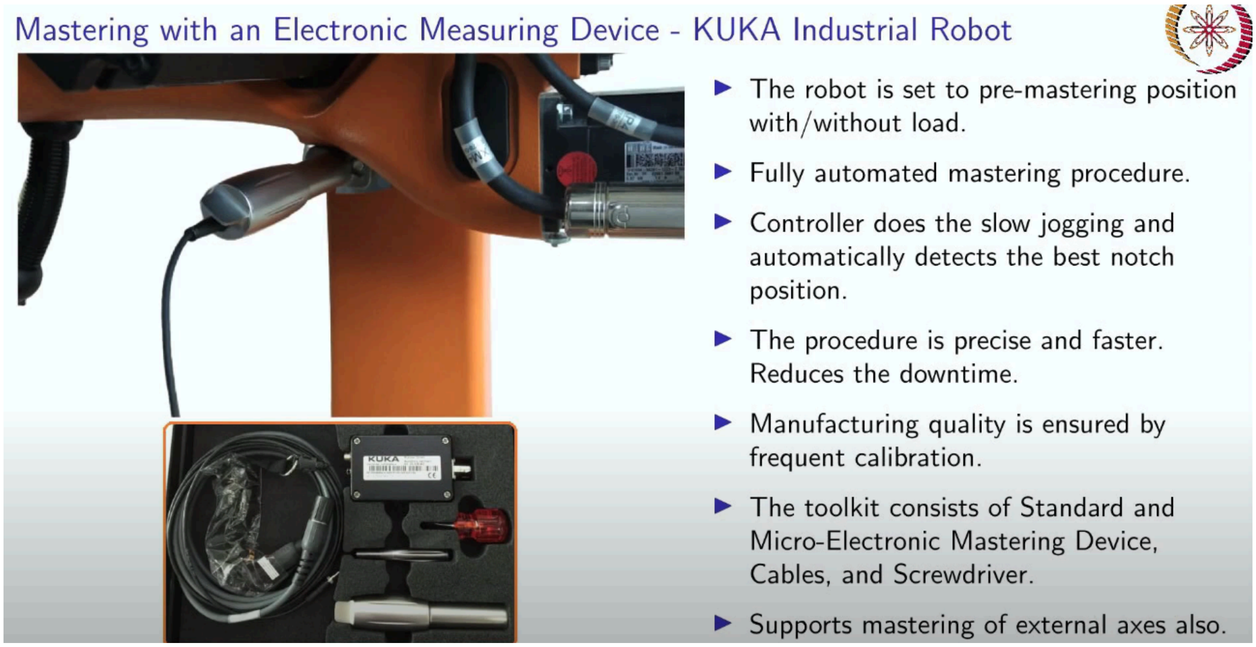


So yes, Yaskawa GP-12 robot, it allows mastering using the teach pendant and manual mastering using the teach pendant. So, you're just using this menu-driven system, GUI or HMI, and you can call it or teach pendant is there. So, you select the robot, and you select the homing for the position you want to do. So, it quickly shows all the joint encoder data over here. So, what you have to do you have to manually make all the axes aligned to 0: 0 position for all the axes, and you can simultaneously master them all. You can select them all over here, all the checkboxes. You can save all the encoder values which are there for the given 0, 0, 0, 0, 0 position for all the joints. So, the controller saves it, and then it is ready to record the joint angles. Actually it records, it gives the encoder, gives you the encoder count, and then it is further converted to the joint angles. That is shown as roll pitch yaw, whatever joint angles and all. So, that is shown after converting the encoder to the joint angle positions. So, this is quite trivial and quite easy to understand. You just take the robot to 0 and record whatever is the joint encoder values, and you are done. So, that is a manual calibration or mastering.



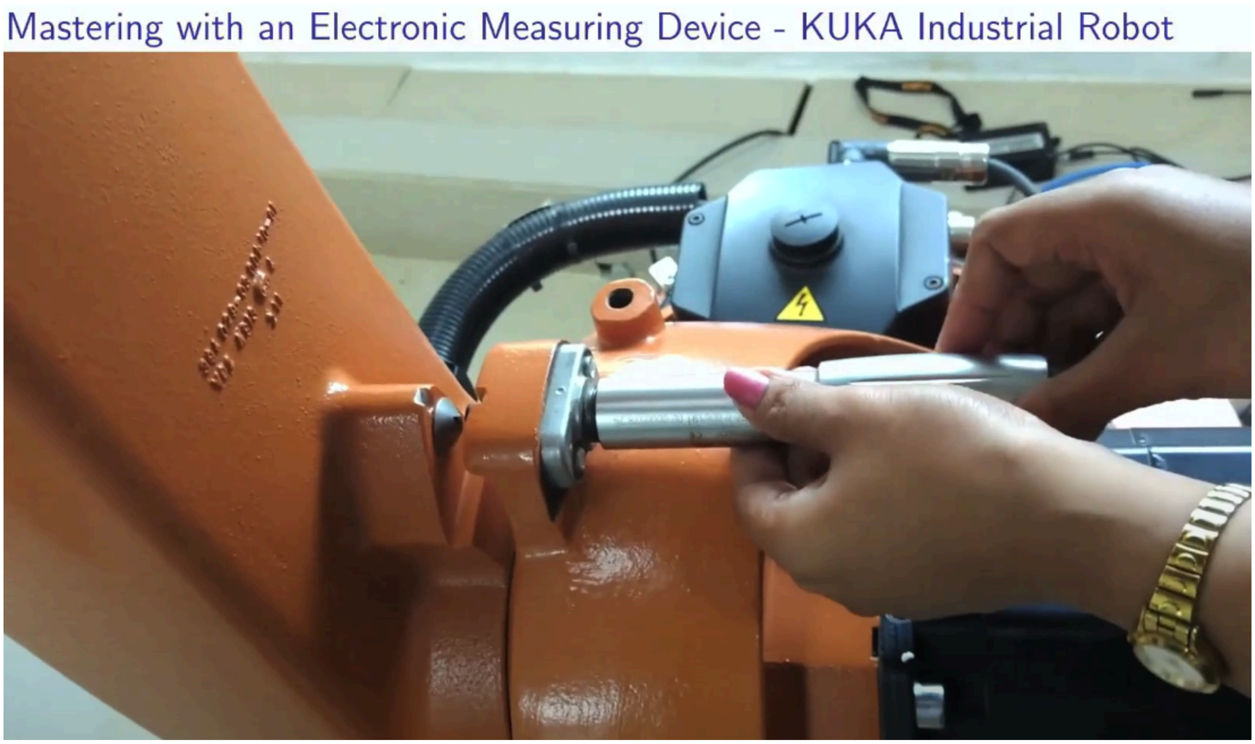
So, there is another very good way of doing it. The KUKA industrial robot that allows you to do that way, so maybe many other robots also. They do allow it. So, a dial gauge can be used. There is a special arrangement which is here that you see. So, it is nothing but a plug. You remove that plug and put the dial gauge over there. So, internally it is arranged like this, the dial gauge looks like this: it has a probe somewhere at the bottom over here. So, that is actually a spring-loaded thing. So, this is your spring-loaded pin. So, that is the gauge pin, which you can see here. So, that gauge pin, basically, you see, there is a platform over here. That platform is something like this, this is a notch. So, your pin gets inserted here. So, then it shows the lowermost position. If it is landing somewhere over here, it is a little higher up. If it is here, it is higher up. So, when it sees the lowermost position, your pin sees the lowermost position. So, you can understand by looking at the dial gauge. So, it is on the platform, platform and all of a sudden, and it will give you a jib: okay, goes very much deeper into the notch, and then you see a significant lowest value, and then it comes back to the platform. So, while rotating the joint, it slides over the platform, platform, and finally it gets into this pocket, and then it again comes back to the platform. So, the lowermost value while rotating when you get it, you just record that and save it as a joint angular position, or encoder value. So, that is your offset, that gives you an exact zero position. And there are physical markers also you see. This also will let you know that you are at the 0: 0 position. So, physical markers are for manual recording. And if you have a dial gauge that gives you a better picture of it, these are all manual processes. You have to jog it manually. So, the process goes like you. Then the load is mounted, the robot is to be mounted with the load for which you want to master it, and the access is put on to the pre-master position.

So, you have to locate your robot somewhere on the platform. If you are sliding, you have to slide on this. You cannot slide if it is too much off, okay, so you have to be on the platform. That is the pre-mastering position. So, when you rotate, it simply can slide and get into the notch. So, that is the pre-mastering position, so load it and take it to the pre-mastering position, then put the dial gauge, and then the dial gauge is mounted after removing the protective cap, so it is now fitted with a cap, so that cap is to be taken out, and then you can put your dial gauge there. The access position is recorded, while the dial gauge shows the lowest position during the slow clockwise or counterclockwise motion. You have to move it very, very slow, otherwise unnecessary vibrations will come, and it will be difficult to actually understand which one was the lowest one. You cannot keep on going back and forth, back and forth like that. Let me just move myself off for a moment. So, now, this is the dial gauge-based mastering technique.



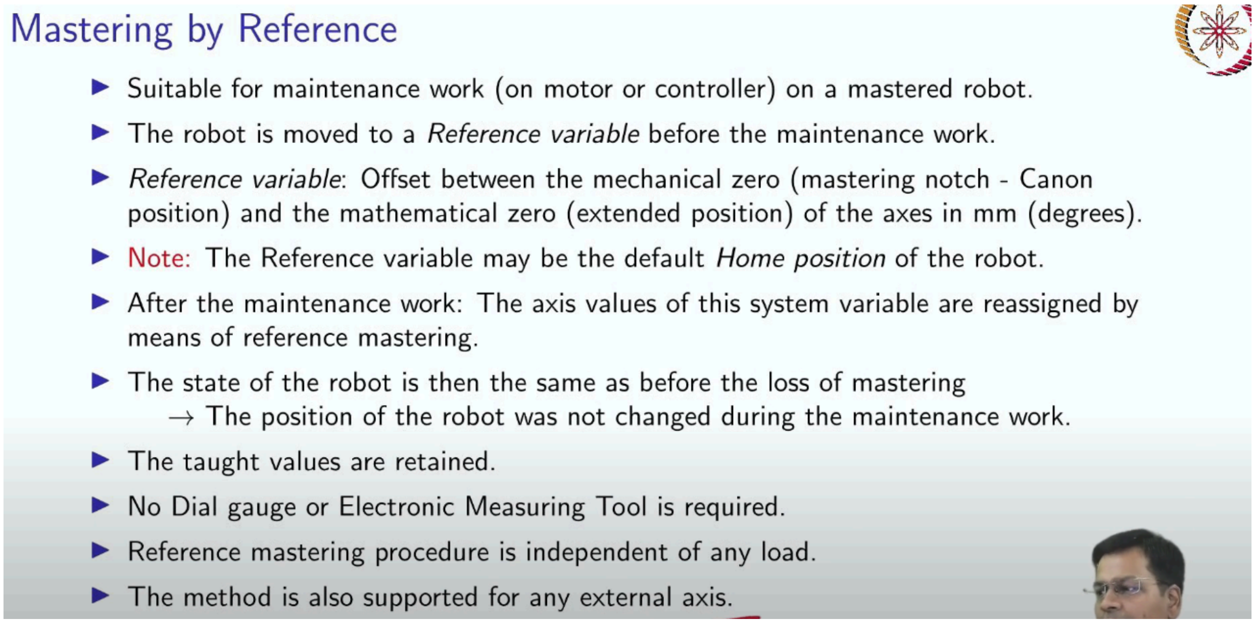
The second one is the electronic measuring device, again offered by KUKAN industrial robots. So, what it does in the same pocket, instead of putting the dial gauge, you also can put this electronic measuring device. It comes in a pack like this with various attachments. So, this is the electric EMD device, Electronic measuring device. So, from here, it is put here. You have a screwdriver kind of thing that allows you, using it like a screwdriver, to open the plug which was there. There is a dedicated screw dryer. Also, this is a simple transducer, maybe, so that actually connects the electronic measuring device to this, and finally, you have a long cable that actually goes, finally goes to the robot. This is a smaller micro version of that. So, this is the standard one, and this is the micro one. So, this is how it comes in a pack, and it can be used.

So, the robot is set to the pre-mastered position again because it uses the same notch, which is there. Now, this time, your standard tool has got that pin, okay, so, which gets into the hole and electronically, with the electronic feedback, your robot understands: yes, you are at the minimum, you are into this notch now, that is the lower, lowermost height that you can get. It is a fully automated mastering procedure. So, let me just quickly show you one of one such video.

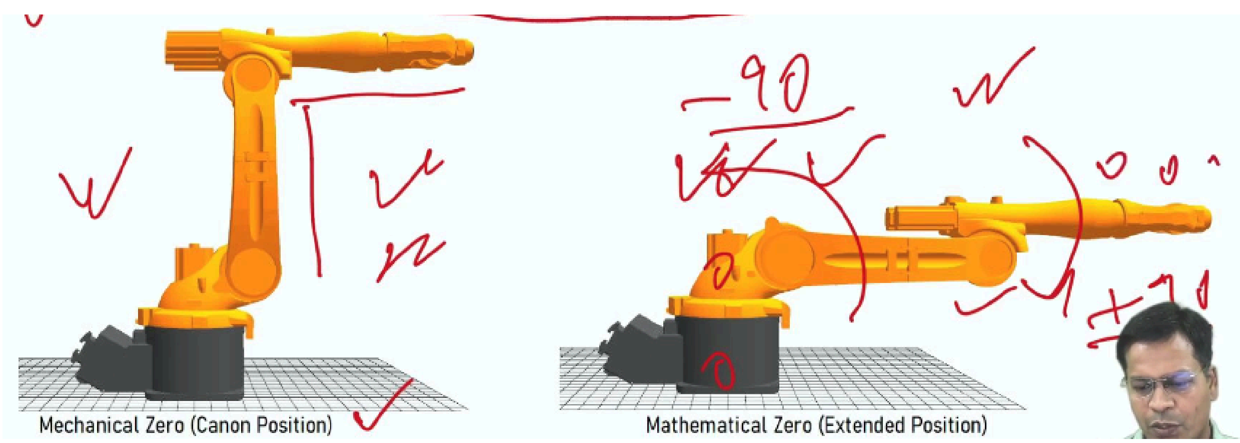


So, you see, this is the plug which is taken off now and standard EMD is now put over there. You can see the notch clearly here, so you go. Now, you will put that wire here. So, you see, now the robot is automatically. Once the process is initialised, it is gradually moving the link, and it gets into the hole, into the notch. Now, you can take it out. So, it is quite a faster procedure. Now, put back the cap and now EMD can be put to the next axis. So, one by one, you can keep putting this. See now, an opposite side of the device is used as a screwdriver. So, you see, you can now see the other axis getting opened up. So, you can just remove the plug, put the device again, and put the wire. So, thanks for this video which is there on YouTube. I have given you the full video link here so that you can follow it. Well, okay, so hope you understand how this works. So, let us move ahead.

Now, the controller does the slow jogging and automatically detects the best notch position. It is no more manual. It is fully automatic. So, the procedure is very, very precise, and it is faster. Also, it reduces the downtime. You know, when you have to master after maybe some running hours for different robots, it is. So, you have to remaster it so that it kills the time of the assembly line or any production unit. So, that downtime is now reduced if you are using such kinds of tools. So, the same tool can be used to configure multiple robots, to calibrate multiple robots. So, it is not a robot that is specific most of the time. So, there is a micro version also. There is a standard version also that fits into the different locations for different robots. So, manufacturing quality is ensured by frequent calibration. I told you, you have to keep on doing mastering it quite often. So, that way you can maintain the quality of work which is done by this robot. This toolkit, as I told it, consists of the standard and the micro EMD device, that is, the cable and a screwdriver. Those things are there. Again, it supposes mastering the external axis also. You can use the same tool to do some external axis mastering, provided you can create a similar kind of mass there, too.



Mastering by reference is another very good technique. Let us say you don't have a dial gauge which can go to that pocket. You don't. You don't even have your EMD device kind of thing, an electronic measuring device. So, this is suitable for maintenance work on a mastered robot. Let us say your robot is already mastered. This is a good robot. Now you want to remaster it. So, you must be wondering why it needs to be remastered. It may be a simple preventive mastering that you want to do, so what you can do, you can. So, I'll just make you understand is important terminologies before that. So, the robot is now moved to a reference pose before the maintenance work. So, instead of being anywhere in the workspace now the robot is taken to a standard pose. Position and orientation. You can take it to a standard pose before the maintenance work. What does this standard pose?



So, reference poses, or a variable which is there in the controller. What is that? It is an offset between the mechanical zero. That includes the mastering noise. So, mechanical zero, you know, it is the notch position. It is 0, 0, which is marked on the links, all the links, and the relative links. You can find them. So, they are there in the Canon position. So, the robot is normally like this, as it is shown. This position is known as a Canon position. This is the mechanical zero position and the mathematical zero. It is a mathematical zero, and it is a fully extended position when it has a mathematical zero. So, from this to this, that is the reference which is saved in this variable. So, if this is 0, 0, 0, it may be minus 90, and then you go to plus 90 and rest, everything is 0, 0, 0, so this becomes your reference pose. So, your reference pose is told a value between 0 and 180 degrees or something like that, so in most of the cases.

So, if, from here to here, it is quickly visible, it is 0, 0 minus 90 plus 90, 0, 0, 0, so like that. So, that variable will be stored here. So, you have to take your robot to this position before the maintenance work. So, you got it. The reference variable may be the default home position of the robot, but not always necessary. So, once you have done the maintenance. So, now you keep this robot here, take out the motor, put back the new one, and whatever the angle which it shows, you know it should be 90 degrees or whatever angle which is at which this robot is now. So, you just make your angle if it shows, let's say, 45 degrees, but I am at 90 degrees, I know. So, that 45-degree offset is now saved to the controller. So, after the manual maintenance or whatever maintenance work is done, the axis value of this system variable is reassigned by the reference variables. The reference variables that were saved earlier before the maintenance are now put back to the joints. So, you got it. So, you don't need to move the robot in between. Robots should not be moved in between. If at all it moves, everything is gone.

So, the state of the robot is then the same as before the loss of mastering. So, the loss of mastering is happening when you remove the motor or actuator or transmission system, whatever. So, the position of the robot was not changed during the maintenance work. This means you have to ensure the top values are retained, in this case, all the top values. Let's say you have programmed for doing some pick and place start tasks using PTP, point-to-point learning. So, all those values are retained. So, all the programs can run as it is, even after doing the maintenance job. If it is done by reference mastering.
No dial gauge or electronic measuring tool is required for this, and this also. This procedure is also independent of any load variation. So, it is independent of node. So, this type of mastering is very, very simple. But again you must be wondering why we should go for, let's say, EMD tool, or, any kind of dial gauge, kind of mastering tool. So, yes, if at all you have got your system new, then you have to stick to those methods. Still, and maybe if you had a breakdown in between due to conspiracy, you cannot go for this method. This can only be applied if it is a planned maintenance, got it? So still, those are valuable. Those methods are still valuable. So, this method also supports any external access mastering.

That's all for mastering and putting your robot to use. So, in the next lecture, I will be discussing the calibration of industrial robots. So, we'll be using tool center point calibration, which I will be covering in my next lecture, using the four-point method and external reference method. That's all. Thanks a lot.