NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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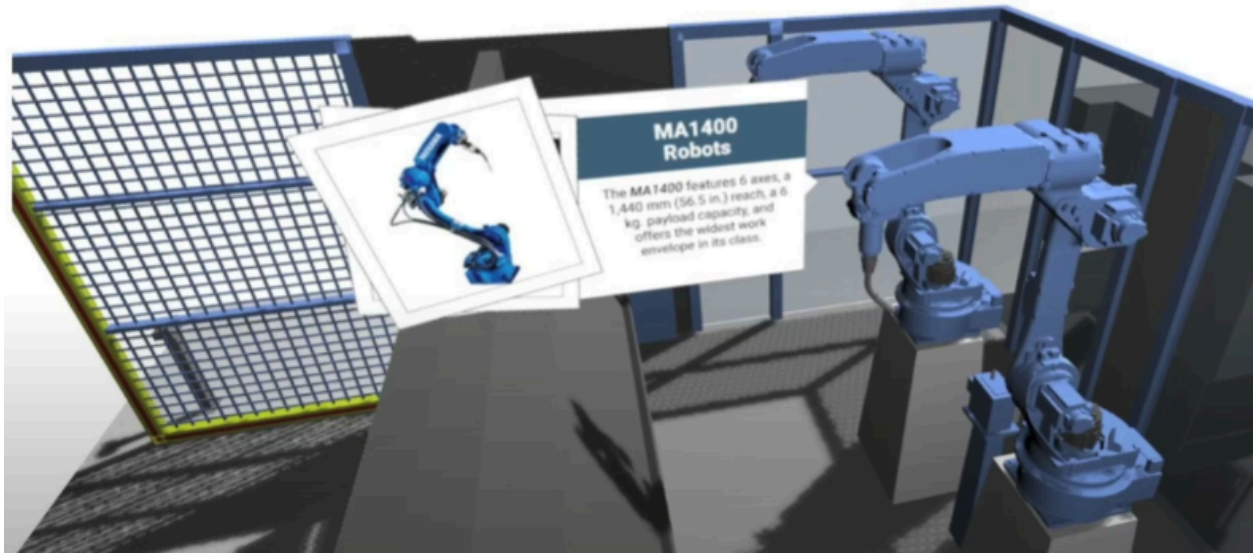
Week: 12
Lecture 48

Workspace and Operator Safety

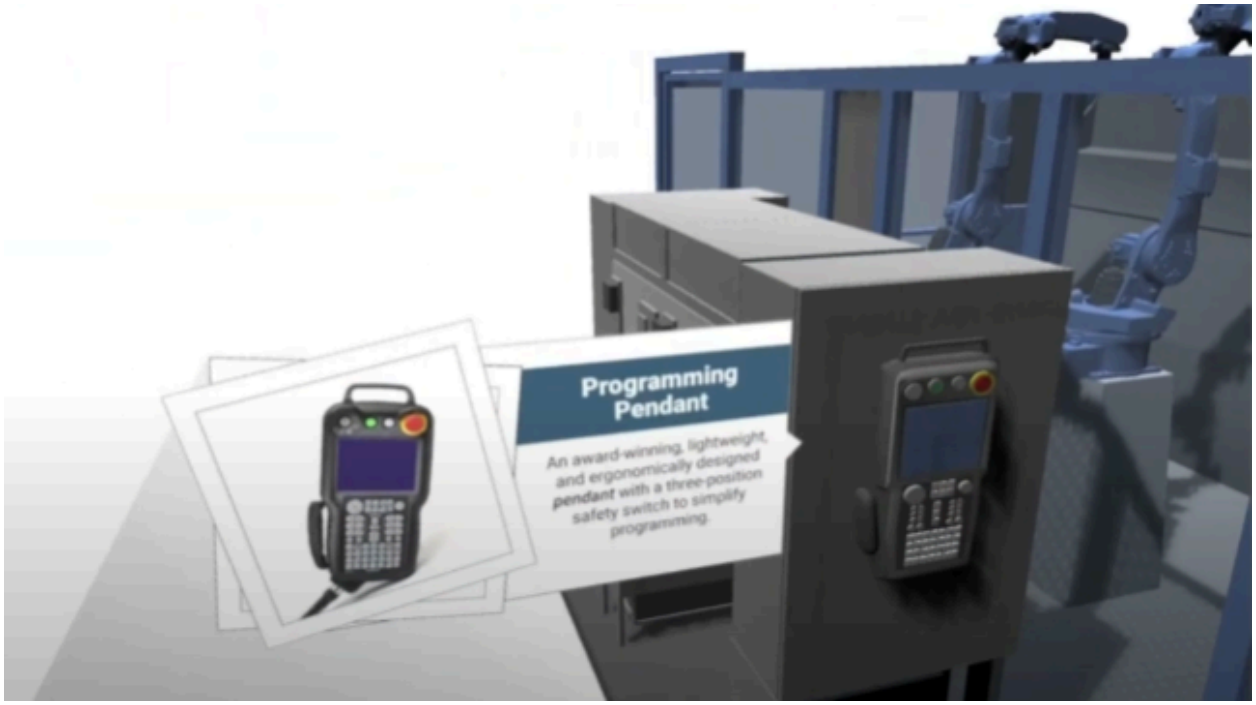
Welcome to the last module of this course. By now, we have learnt about components that make up a robot, like actuators, their drives and sensors. You learnt about kinematics, statics, dynamics, and motion analysis of a robot. You learnt how a robot is installed, calibrated and controlled. Overall, you have learnt how such a powerful robot, which is quite often very big, is created and it is put to use. Before putting it on any industrial floor and programming it to its full potential, there are various safety guidelines to protect the environment, the people working around and the property. So, let us begin with this module: Robot Safety and Programming.

So, let me just brief you about the overview of this module and all the things that we are going to cover in this module. So, we will be talking about workspace and operator safety, safety triggers and functions. Workspace monitoring and marking forbidden zones that we have seen earlier also in one of the modules when we have restricted the joint axis to move to certain angles only, where you can exclude one of the workspaces from the robot to getting in. So, that was one of the ways you also learnt how to exclude, in Cartesian spaces as well. External and internal safety devices, norms and regulations we will discuss all this in today's class, and we will learn about industrial robot programming. So, before we actually get into today's lecture, let me just demonstrate what a typical industrial scenario looks like and how an industrial robot is placed

inside the cage. Where are all the safety devices kept? Where are the controllers kept? And just watch this video and you will understand.



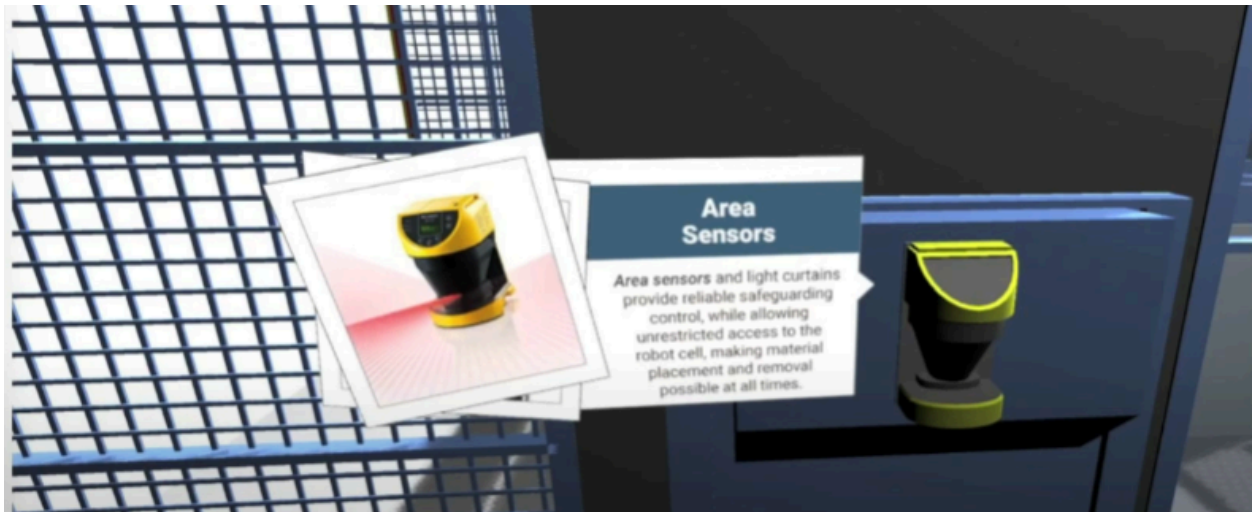
So, you see, this is a robot which is placed inside a cage. Top view of that from one of the isometric view. You can see this now.



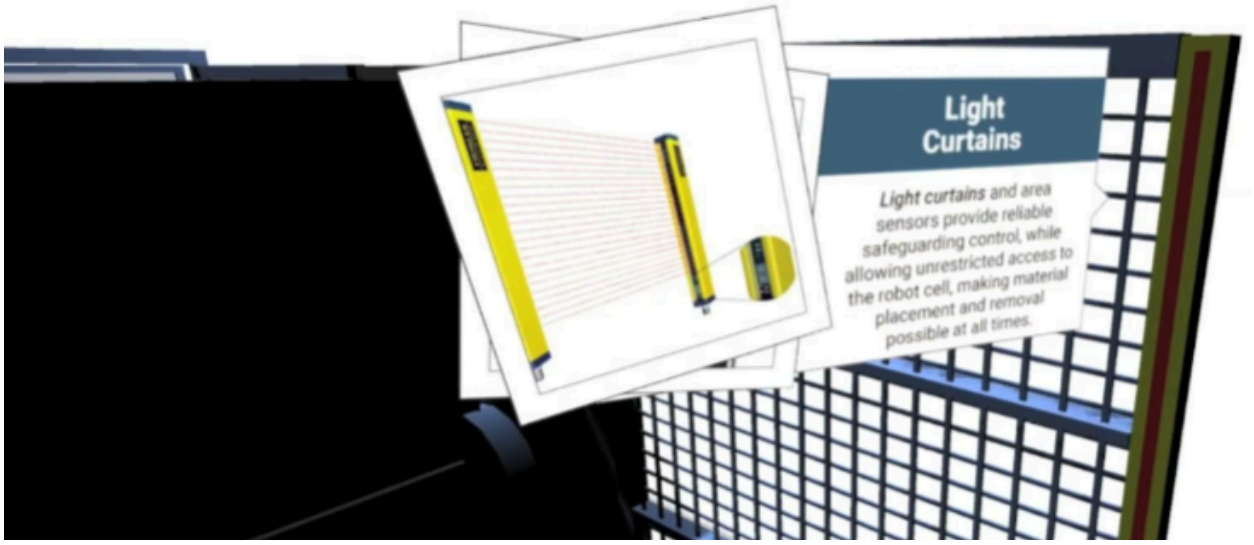
So, this is the place where you normally place your teach pendant over here. So, with this teach pendant, you normally program your robot. So, it is quite an ergonomically designed pendant with three three-position safety switches to simplify programming. So, we will discuss what three positions actually mean, what are the functions that are given by this switch, and the

different switches which are mounted on this teach pendant. So, this is a reach pendant which is kept here,

and you see, this is a robot controller. We have talked about industrial robots its accessories in the introduction module also. So, this robot controller, basically, is a controller, which actually is hardware that controls the robot, that has all the electronic circuits within which you also have a PC which is inside. So, that is normally having an operating system. So, proprietary programming software which conforms to the industrial programming architecture is actually installed, and the rest of the add-on tools are manufacturer-specifications. We will talk about industrial robot programming and others in the next lecture, and this is your robot controller.

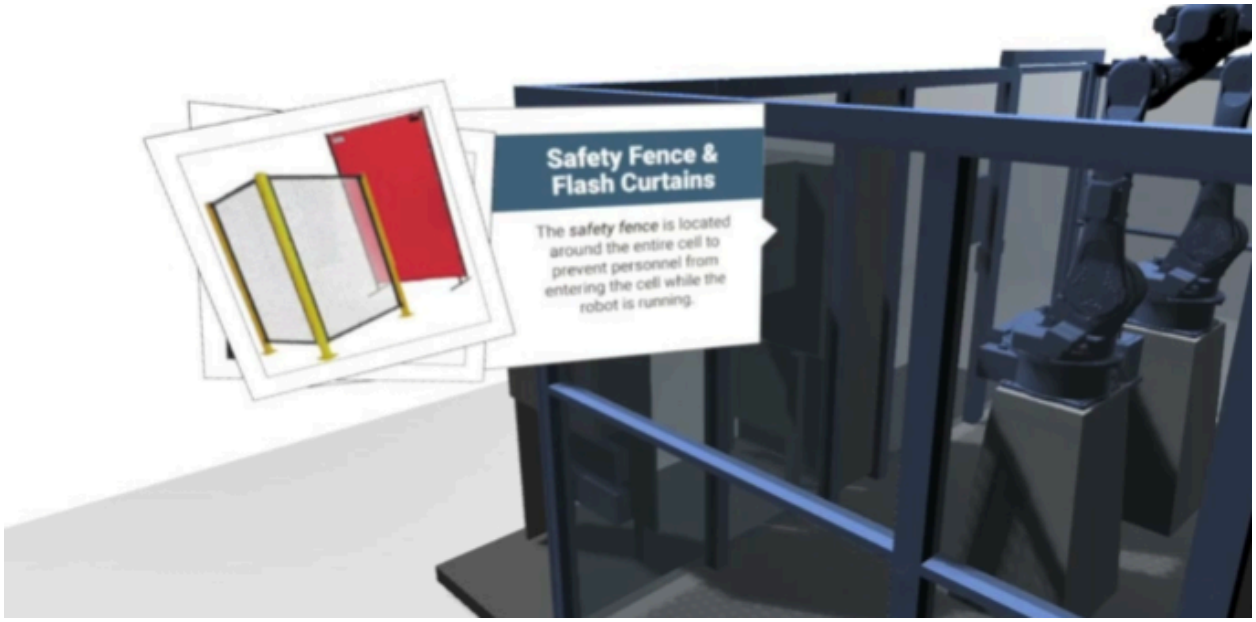


Then you have, you see, this is an area sensor. This is the sensor with which you can detect any motion, any movement of any object, if it gets into the robot work cell. So, that is the area sensor. It is basically a laser range finder, like that.

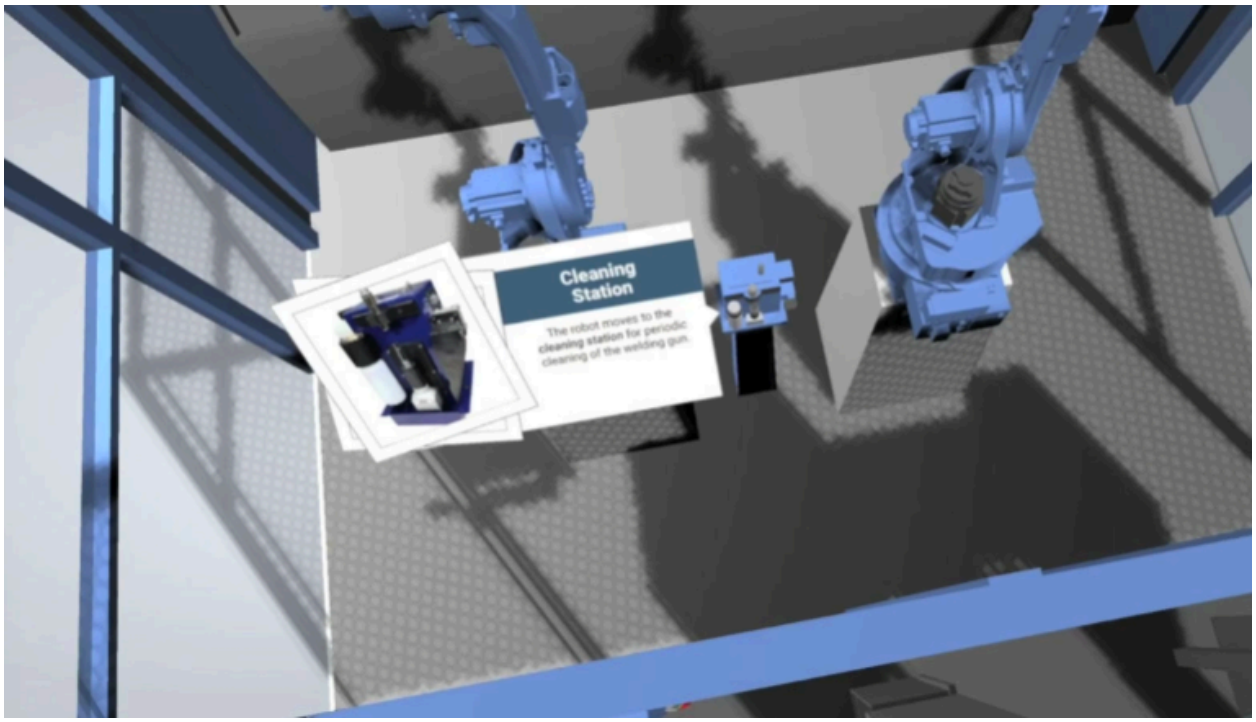


And this is the light curtain. You see, there is a red strip over here that basically emits a laser light and that falls on the other side of it, which actually detects it. So, if anything crosses this invisible curtain, it gets detected and the robot stops or whatever. If it is programmed to do, it will do. This is a light curtain.

This is where you have the operator station, where you have a push button or touch screen display that is used as an interface with the robot cell to facilitate user intention, which is normally to interact with the robot through this electronic device. You can do it from here,

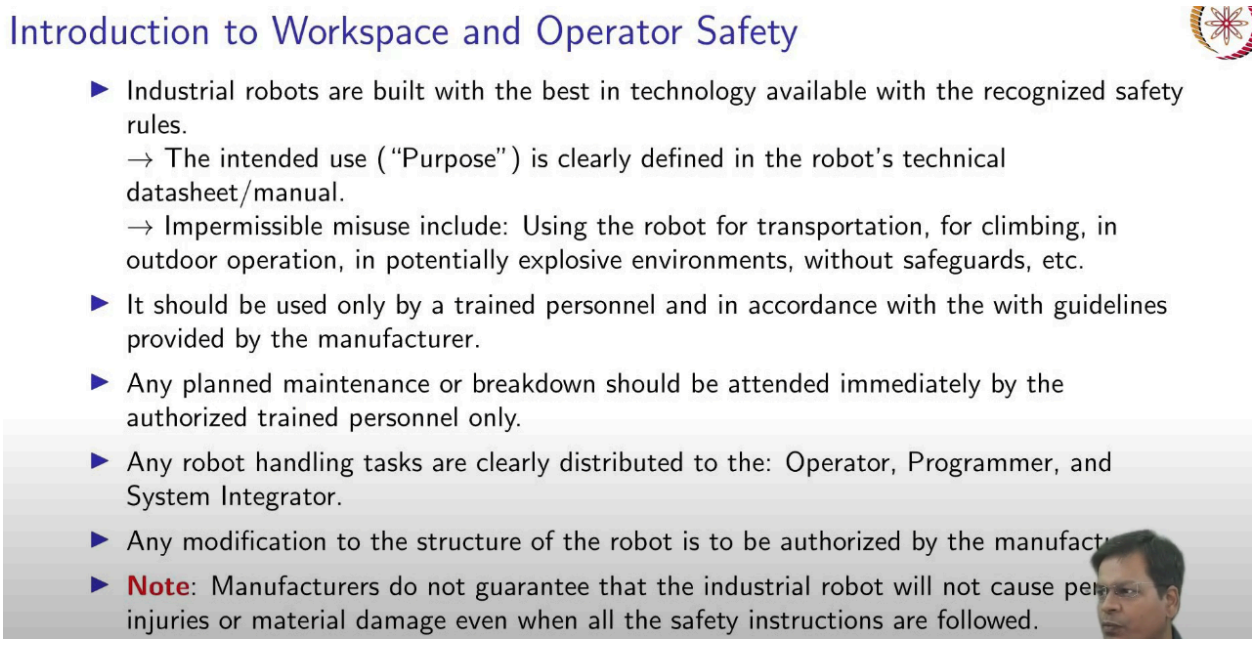


and then you have a safety fence and flash curtains.



Finally, you have a cleaning station. This is specific to welding robots, where a robot moves to the cleaning station for periodic cleaning of the welding gun, but it can be a two-maintenance station also, where you can have a spot welding gun getting cleaned or a painting gun getting refilled. This is right inside the cage, and you have a power supply.

This power supply is designed specifically for robot welding in a wide range of applications. This is specific to spot welding, but it can be a power supply for spot welding also. This is a place which is outside of the cage. This is how a typical industrial robot is placed, and it is covered with various safety functions, safety switches and accessories, which make it fully functional. Let us begin with today's class.



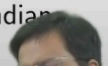
So yes, introduction to Workspace and Operator Safety. Industrial robots are built with the best in technology available today, with the recognised safety rules. Normally, they are made with whatever best you can do that is now utilised to make such robots. So yes, that has almost everything that you can find in the industry because, you see, the industrial scenario is very much demanding in nature to increase the product life cycle, the production, your workflow, to

facilitate the workers, to work with the environment, to work with the robot. So, it has almost everything that you can find in today's scenario because money is not always a limitation in the industry. If it can increase productivity to a high volume. So yes, that is always there, and recognise safety, which is if it is designed to date, so all the safeties which are recognised till date are utilised to make such robots. The intended use is the purpose of the robot is clearly defined in the robot's technical data sheet or the manual. This we have discussed earlier also while we were discussing the technical specifications of the robot. So, as per ISO standards, this is to be mentioned. If it is for a welding robot, it is a painting robot, or whatever the purpose is, that should be clearly mentioned in the data sheet of the robot. Any impermissible misuse that includes the use of robots for transportation should not be done. You can definitely climb on top of the robot and go from one place to another, but that is not an intended purpose, and it is not allowed. So, if your robot malfunctions due to this reason, it is definitely out of the safety boundary, and nobody will guarantee that the robot performs to its fullest, or you are safe in that case. For climbing purposes, to go from the lower floor to the upper floor, if the robot is big enough, you could do that, but it is not meant to do that. In outdoor operation if it is not mentioned in the purpose of the technical manual of the robot, it should not be used in the outdoor environment. In a potentially explosive environment without any safeguard, this type of robot should not be used. It should be used only by trained personnel and in accordance with the guidelines provided by the manufacturer. The performance of the robot is guaranteed if it is working with the guidelines provided by the manufacturer. Any planned maintenance or any breakdown should be attended to immediately by authorised trained personnel. Any robot-handling tasks are clearly distributed to the operator, programmer and system integrator. So, set of jobs. What an operator can do is clearly defined in the industry software, whereas a Programmer can do programming. Their objectives and their functions are clearly defined. Integrators are the overall managers who integrate the system into other types of equipment in the environment, other accessories which are there in the robot, to the gripper, controller, linear rail, maybe. So, all the jobs are system integrators jobs. They integrate the robot into other, like conveyor also. So, basically, the programmer comes below that who program. He makes use of the integrated system and operator he finally runs the program only. He cannot further change the program, modify the program, or maybe reprogram the system. Any modification to the structure of the robot is to be authorised by the manufacturer only so that it performs to its fullest Manufacturers, even after following all these above guidelines. Please note that manufacturers do not guarantee that industrial robots will not cause any personal injuries or any material damage, even when all the safety instructions are followed. They cannot guarantee because it is very much user-specific. So, they never guarantee such. So, that is the reason why safety comes in. You have to follow all the guidelines given by the manufacturer and the internationally recognised guidelines which are there. So, we will discuss that now.

Introduction to Workspace and Operator Safety

Conformity to the Directives published by European Agency for Safety and Health at Work, BIS, or ISI

- Any industrial robot constitutes partly completed machinery as defined by the EC Machinery Directive 2006/42/EC.
  → The industrial robot is integrated into a complete system.
  → Together with other machinery, constitutes a complete system.
  → Safety functions and safeguards are required for operation are added as defined by EC Machine directive
- The compliance to EC Machine Directive needs to be confirmed by means of an assessment of conformity.
  → This forms the basis for the CE mark for the system
  → *CE mark* (European Conformity) appear on any commercial product that are traded on the extended Single Market in the European Economic Area (EEA).
  → In India it is also required to comply with the local standard like Bureau of Indian Standards *BIS* or Indian Standards Institute *ISI*.



So, conformity to the directives published by the European Agency for Safety and Health at Work, as well as BIS and ISI, which are in India. So, these are some guidelines. So, any robot as such is a partly completed machinery as defined by the EC Machinery Directive 2006/42/EC. So, it says the robot in itself is not completed machinery. So the robot is to be integrated into other equipment in the environment so as to make it a complete system and fully functional. Let us say a robot without a grid purview is nothing. It cannot do any job. Robot without, maybe, a work table, which is there. It is nothing. So, it has to have a set of environments with which it is to be programmed, it is to be integrated to make it a complete machinery which does something. So, if it is a spot welding robot, it has to be mounted with a spot welding system, not just the spot welding gun. Similar in the case of any welding system. It can be a painting system, and it can be anything. Even just a simple gripper is to be there. So, as such, it is not a complete machinery. So, together with other machinery, it constitutes a complete system. Safety functions and safeguards required for operation are added, as defined by the EC machine directive. The compliance with the EC machine directive needs to be confirmed by means of an assessment of an authority. So, that is a third-party agent. It is not the manufacturer, and it is not the user. So, normally it can be a sub-part of the industry which only does this job. They inspect the whole of the machinery and its system, including the robot, and they basically confirm whether it is confirming the EC machine directive. This forms the basis for the CE mark of the system. What is a CE mark? CE mark is European conformity. It appears on any commercial product that is traded on the extended single market in the European economic area. If it is targeted for that, it has to be CE-certified. You must have seen, sometimes even in your mouse, it may be written somewhere. CE symbol is there. So that is also the same In India. It is also required to comply with local standards like the Bureau of Indian Standards, BIS, or Indian Standard Institute ISI marks. In India, this also is required.

Important Terminologies

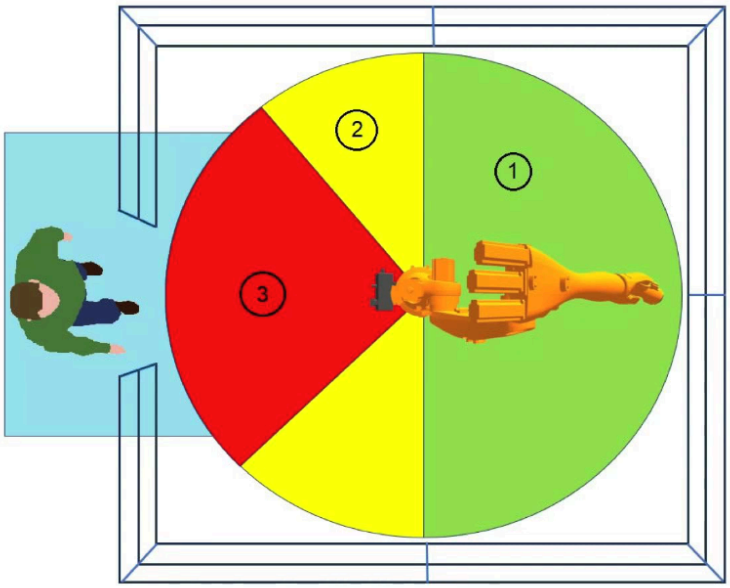
Triggers for stop reactions, Stop categories as per ISO 13850: Safety of machinery

- **Danger Zone**: The robot workspace and the stopping distances.
- **Stopping distance** include reaction distance and the braking distance.
  This is a part of the *Danger zone*
- **Safety zone** is the zone outside the *Danger zone*.
- **Stop category 0**: The drives are deactivated immediately and the brakes are applied.
  → The robot performs path-oriented braking.
  → Triggered upon releasing the drives enabling switch, switching off the robot, power failure, encoder error, mode change, and/or pressing of emergency stop.
- **Stop category 1**: The robot performs path-maintaining braking.
  → The drives are deactivated after 1*s* and the brakes are applied.
  → Triggered upon opening of safety gate and pressing of emergency stop.
- **Stop category 2**: The drives remains activated and no brakes are applied.
  → The robot stops with a normal braking ramp.
  → Triggered upon pressing the stop switch or release of start button.

So, there are a few important terminologies that we will discuss now. Basically, triggers for stop reactions. We will discuss this also. Stop categories, which are defined as per ISO 13850, that is, safety of machinery guidelines. The first of them is the danger zone. It is the robot's workspace and the stopping distance. So, let me just show you one picture over here. So, this is here. So, you see danger zone is marked over here as green. That is in front of the robot. That is one is the danger zones where a human should not enter at any cost. When the robot, as long as the robot is on, you cannot enter that region. So, that is the danger zone. It is the robot workspace and the stopping distance. Also, if you apply a brake, it takes some time to stop. So, that distance is known as the stopping distance. So, stopping distance that includes the reaction distance, So the time you sent the stopping command to, actually, when it started reacting to it. So, that is the reaction distance, and when it actually applies the brake, it further gets carried off to a certain distance. So, that is the braking distance. So, the reaction distance and the braking distance combined are the stopping distance. So, this is part of the danger zone. So, apart from the robot workspace, the stopping distance is completed. So, that is the whole of that is one. So, the stopping distance here is two. So, one and two make it completely a danger zone. So, the robot workspace is the front one. So, it may be possible that the first axis goes more than 180 degrees, as it is marked in this. So, it can further increase also. It can sometimes be software limited to not move beyond this boundary. So, this is stopping distance. Finally, the safety zone is the zone outside the danger zone. So, that is region three, which is here where humans can at least get in, but definitely not when the robot is running. So, in that case, the opening that you see from where the human is entering here is shown. So, that is, there is a gate where you have a safety interlock. If you open that gate, the robot may stop, too. So now, talking about stop category zero. In this case, these stop categories are defined as stop category zero, one and two. These are defined as per ISO 13850 guidelines that are defined in the safety of machinery guidelines. So, that is safety stop category zero. This means that drives are deactivated immediately, and the

brakes are applied. The robot performs the path-oriented braking. In this case, let us say, if it is a welding robot it was maintaining a path. It won't maintain that. It can just try to stop as early as possible. So, that is the stop category zero. So, the robot performs path-oriented braking. This is triggered upon releasing the drive-enabling switch. There is an enabling switch in the back part of your teach pendant. If you can see that, I will show you that. So, if you just release that enabling switch, what happens? It will immediately apply stop category zero braking. Switching off the robot. If you switch off the robot stop category zero, it falls under the stop category zero. Power failure, any encoder error- you see all these fall under emergency braking. In this case, if the robot continues to work, it is very much a hazardous right. Mode change - there is a mode change switch on top of your teach pendant. If you change that mode, stop category zero is applied, and or pressing the emergency stop switch. In this case also, stop zero is applied. Stop category one- in this case, the robot performs path-maintaining braking. So, in the case of a welding robot or a pelting robot, the robot will try to, without deviating from the actual path which it was maintaining. It will try to stop the robot. The drives are deactivated after one second, and then the brakes are applied. It is reasonably safe. You see, this is not an emergency, but due to some reason, somebody might have pressed the emergency stop switch. This is triggered upon opening the safety gate. So, as soon as you open the safety gate you need not enter into the robot workspace immediately. So, there is some gap which is there. So, that is the reason stop category one is applied in this case. Pressing of an emergency stop switch intentionally, not in case of an actual emergency. In that case, stop category one is applied. Stop category two: the drives are activated, and no brakes are applied. So, this is normal braking. Basically, the robot stops with the normal braking ramp. Maybe your program has finished? It has done its job. So, that is the stop category two. So, all these stop categories are defined in ISO 13850 safety of machinery guidelines, and this is stopped category two is triggered upon pressing the stop switch or releasing the start button. So, you don't intentionally want the robot to run so that you will release the switch, or you just press the stop button, or the program stops normally. In all these cases, stop category two is applied.

Robot zones



1. Robot workspace
   → The workspace is safeguarded using appropriate human barriers like fences, or a cage.
2. Stopping distance.
3. Safety zone.
   → Any workspace entry gates (with safety interlocks) are placed here.

Note: Axis 1 may be limited using software limits to restrict the robot entering into forbidden workspaces.

External safeguards (gates) must meet the requirements of EN 953: Safety of machinery - Guards

So, these are the robot zones that we have seen just now. The workspace is safeguarded using appropriate human barriers like fences or a cage. You have seen this in the small video that I showed earlier while we were starting this module, which is a robot workspace. So, that is this space. Stopping distance that is this space (2nd), and the safety zone that is this space (3rd). Any workspace entry gates with safety interlocks, so that goes here. So, these are any gates that will go here-are placed here. They normally have an interlock, which is there. It may have some limit switches. As soon as you open the gate, a brake is applied. It gets into one of the stop categories that you have seen earlier in the previous slide. So, on axis one, you see the major movement that takes you to different zones is axis one. That is the first axis which is there in the robot. That is vertically upward. Axis one may be limited using software limits to restrict the robot from entering into a forbidden workspace. So, this may be one of the forbidden workspaces where you may have some objects also. You don't want your robot to go there. In that case, on axis one, that joint angle may be limited. That feature is there in the robot. We have discussed it earlier. External safeguards: mostly the gates must meet the requirements of EN 953, that is, the safety of machinery guards. That is for the guards. So, let me just vanish a bit. So, external safeguards: the gates must meet the requirement of EN 953, that is, the safety of machinery guards.

Safety Functions

Safety functions that conform to the requirements of Performance Level d and category 3 of ISO 13849-1:2023 Safety of machinery.

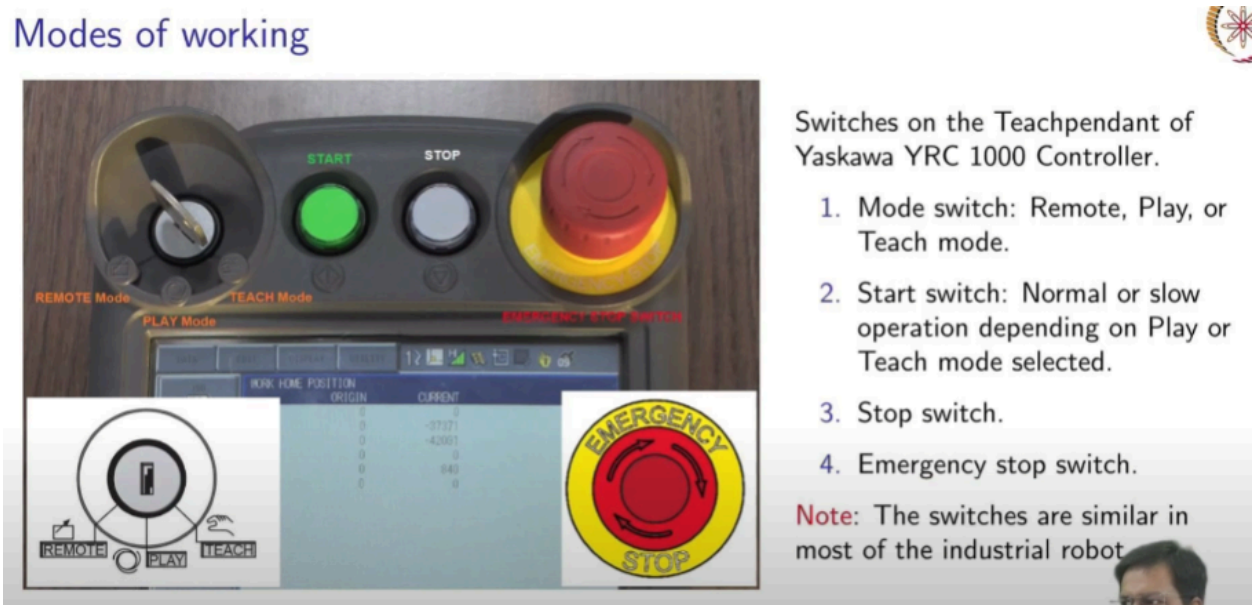
- Mode selection.
- Operator safety: connected to the guard interlock.
- Local EMERGENCY STOP device: On the control panel.
- External EMERGENCY STOP device: Outside the fence/gate, On the Teach Pendant (TP).
- Enabling switch on the TP: For servo.
- External enabling switch.
- Local safety stop via any qualifying input

Note: These functions are handled by a dedicated Electronic Safety Circuit within the rob controller hardware. It continuously monitors the system while the robot is ON.

Various function tests are carried out before start-up and recommissioning.

Now, let us discuss some of the safety functions of the robot in any industrial robot. Safety functions conform to the requirements of performance level d and category 3 of ISO 13849-1:2023. So, this is the latest one which is there to date safety of machinery. So, all the guidelines are here. So, the first one is the mode selection switch. What is a mode selection switch? Just see in this image. So, you see you have a key which is there, and you have that can turn to three positions. One is a remote mode, play mode, and teach mode. So there can be different other modes also in the case of the different robots. This is from the Yaskawa GP12 robot YRC 1000 controller. So, this is the mode selection switch, and then you have operator safety that is connected to the guard interlock. So, that is there in case of the gate, if it is there as soon as that opens. So, there is an interlock that stops the robot. That is for the operator's safety. So, that is there, and the local emergency stop switch. That also you have seen. So, you have an emergency stop switch on to teach the pendant. It may be there locally somewhere in the workspace outside the grill. Maybe It can be placed at different locations depending on its use and the user flexibility. An external emergency stop switch is also there, that is outside the fence or the gate, on to teach pendant and on the control panel. So, at least three of them are always there. That is outside the fence or the gate, on to teach pendant and on the control panel. So, the control panel is called a local emergency stop device, whereas others are known as external emergency stop devices. Next is your enabling switch to teach pendant that is for the servo. So, it is this. So, you see, on the reverse side of your teach pendant, there is a switch, which is a black rubber thing that you can see here. So, that is enabling a switch as soon as you press that so it starts. If you further press it down, it is a three state switch, so that has three states. So, when it is normal, it is off as soon as you press if it is on. If you further press it down it will be off. So, it has three positions. So, the first is to enable the drive. So, in case of panic, either you throw it off in that case also it is off, or if you pull it further, you are in a panic situation. So, even if you pull

it further and press it further, it is in the off state. So, you have to be very conscious to keep it on. So, that is what is enabling switch. That is there on to teach pendant, that is for the servo, so that is shown here in to teach pendant, reverse side of it, you see you have a hand strap from where you can insert your hand from the front, and you can press the enabling switch. So, that is there, and you have an external enabling switch also that may be there outside the case, outside the grill. So, that is there, and you have a local safety stop via any qualifying input, so it can be possible that some other machine is controlling this robot. So, maybe that input is a qualified input that can trigger the safety stop so that may be triggering any other safety which is there in the environment. So, it is taking care of that. Maybe your conveyors have some problem. There is any proximity switch that has detected some failure in the conveyor so that input can also be fed to the robot so that the robot also stops in sync with the conveyor. So, local safety stops via any qualifying input can also be there. So, these functions are handled by the dedicated electronic safety circuit which is within the robot controller. It is there. It continuously monitors the system that is the robot. While the robot is working. As long as the robot is on, it keeps on monitoring all these switches. So, these are known as the safety functions. Various function tests are carried out before start-up and recommissioning. So, as soon as you install your robot for the first time, there are safety function tests that basically check each of the functions one by one and confirm whether they are all working. After start-up and after recommissioning, safety function tests are to be carried out. That provision is there in the robot itself.



So yes, this is the mode of working. Various modes are shown here. So, this is your key, which you can see. It is normally a key once it is put into one of the modes by an operator. So, the operator normally works in play mode, and only the operator comes here. A programmer can take it to this also. Once the programmer is done with his job, he will turn the switch to this position and take out the key. Keep it with him so that the operator can only run the program which he has already done. This is a remote mode. A programmer can also put the robot in

remote mode. What is remote mode? In this case, the robot is run by external inputs. It may be by some proximity switch. You are getting the signal or something like that. So, one by one, we will discuss that. So, this is the mode switch which can go to the remote mode in which the robot runs its program by external inputs and outputs, and you have a play button also. That is, an operator can run this play button. He can execute any code if it is there, any program, if it is there which is done by the programmer. The operator can use this mode, and the programmer normally takes it to the teach mode and does the programming. So, the operator can also handle the start button and the stop button if it is in play mode. So, mode will govern what other switches will be active. This is active always, but this is active only when it is in this mode or this mode. The start switch basically starts the program. If a programmer has a program to do certain operations, this is the switch which actually starts it. Mind it. This is for GP12 Yaskawa YRC 1000 controllers. The switches are very much the same for other robots also, for maybe the KUKA robot, for the FANUC robot. Things are very, very much the same. Locations may be different, or the orientation of these may be different. This key may be at the top somewhere, emergency stop may be located somewhere over here, but the idea remains the same. So, nothing very specific to Yaskawa over here. So, start the switch. Normal or slow operation, depending on the play or teach mode, is selected. So, start switch, if you press this button. If the robot is in teach mode, the robot goes very, very slow to confirm whether the program is correct or not. So, that is in the case of teach mode. But if it is in play mode, as soon as you press start, the robot does it do job to its full potential and at full speed. Even in the case of remote mode, the robot works at full speed. Only in the case of teach mode, the start switch will take it to slow speed. Slow speed so that you can observe whether it is working correctly or not. So, that is the start switch. Similarly, you have a stop switch that is to stop the operation and an emergency stop switch that is in case of any emergency, or while you are leaving the robot without any job to be done, you can keep it pressed. So, you know there are at least three locations where you can find it. This one is on to teach pendant, and you also have this outside the workspace, outside the cage that you have seen, and it is also there on the top of the controller. Hardware controller that is there for this robot. The switches are very similar in most of the industrial robots.

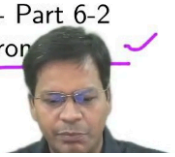
Modes of working: so what is that? So, you have additional safety modes. That is there. Jog mode: what does the robot do in case of jog? There are various jog buttons, you see. So, this is for x plus x minus y plus y minus z plus z minus right, and there are axis jogs also. So, that is there. That enables you to do programming very easily. It can move the robot safely. So, this is also considered as additional safety thing. You need not take the robot from one place to another by any program. You can directly use these keys and take the robot safely to those positions. So, as long as you keep this button pressed, it is on. If you release it, it is off by default. It is off, so this is a jog mode, and you have software limits also. So, software limits are there. That is there. You have learnt earlier also in one of the modules. When you can limit the joint motions to move within a certain angle only, it won't go beyond a certain angle. Let's say if it is our first joint, you want it to go plus minus 90 degrees. That is only in front of the robot you want your robot to move. It won't go behind, right, so that can be done. That is through the software limit of the axis one. You can also define a workspace where you have a cuboidal workspace, and you can restrict your robot from entering into this cuboid. There may be some object which is there, or you can program your robot through software limits to work only within this cube. The robot won't go out also. So, that also is doable. So, that is known as software limits in Cartesian as well as joint mode. It is possible. Mechanical and stops are there by default joints. They have mechanical and stop. But that is not very safe to use. You should not take your robot to those mechanical stops. Once it goes there, the robot can lose its master, also right, due to the high amount of jerk which is there once it collides with that mechanical and stops. External couplers are there so that they can be coupled, which can be used to connect the robot to any external input and output. Those couplers are there that I have shown you while introducing the robot in one of the videos in module one. So, using those external couplers, you can take input and output from the environment, from other equipment which is there, which are also integrated into the robot. So, that is external couplers, and there are labels. This is very, very important. They are passive

safety features. You have rating plates that basically state what is the rating of this robot so that you don't connect this robot to a low-rating supply. Warning labels are there. Safety symbols are there, designation labels, cable marking, and identification plates, and what kind of robot is it? So, all these labels are mandatory as per the safety guidelines of the manufacturers, as per ISO guidelines and also as per the company which is using this robot. So, it is mandatory to be there. Apart from these, please note different operating modes. They activate different safety functions. So, if you see you are switching to mode to this, this will enable, let's say, a few of the buttons. Let's say the start and stop switch is only activated once it is there in play mode. Otherwise, in the case of the remote, once it is started, it is on forever as long as you change the mode. Similarly, the start and stop switch is activated and deactivated depends on what is the mode. Same with the emergency stops. The emergency stop is always on. It doesn't depend on the modes.

Norms and regulations

- **2006/42/EC** Machinery Directive: ...partly completed machinery...
- **2004/108/EC** EMC Directive: Electromagnetic compatibility of the robot controller
- **97/23/EC** Pressure Equipment Directive: robot that are equipped with a hydropneumatic, spring or gas cylinder counterbalancing system.
- **EN 614-1** Safety of machinery: Ergonomic design principles
- **ISO 10218-1: 2011** Safety requirements for industrial robots
- **ISO 12100-1:2023 and ISO 12100-2: 2012**: Safety of machinery - Safety-related parts of control systems. General principles for design, and validation
- **ISO 13850: 2015**: Safety of machinery - Emergency stop function - Principles for design
- **IEC 60204-1:2018** Safety of machinery. Electrical machines - General requirements
- **IEC 61000-6-2:2016, 61000-6-4:2011**: Electromagnetic compatibility (EMC) - Part 6-2 and 6-4: Generic standards - Immunity, and Emission standard for industrial environ

Note: **IEC** - International Electrotechnical Commission, Geneva, Switzerland.
EC - Directives of the European Parliament and of the Council.



So now, let us talk about the norms and regulations which are there. That actually covers all the things that I have talked about so far. So, the first of them is 2006/42/ EC, that is, the Machinery Directive. So, the statement that I said: the robot is a partly completed machinery. That is actually defined here in this directive: Machinery Directive. This is a European directive that actually states, and you can understand as well, robot by itself is not a fully functional machine, right, without having any attachment to it, right? The next one is 2004/108/EC, which is the EMC directive, electromagnetic compatibility of the robot controller, so that is defined here, right, and 97/23/EC, so that is the pressure equipment directive. This applies to the robot that is equipped with a hydropneumatic spring or a gas cylinder constant counterbalance system. Normally, you see, your robot is counterbalanced by its own link. so the extension of this link normally has. You see, you have motors which are hanging here. So, whatever load that comes here can be compensated by the additional load that goes here. But this is not always possible, at

least in case of this. You see, you have all of a spring-loaded spring mass damper system, which you see here. This basically is the gas cylinder constant counterbalance system. So, in order to design this, in order to maintain this part, you have to dismantle this. You should be familiar with pressure equipment directives, that is, 97/23/EC guidelines. 97 here means it was established in the year 1997. Same here in 2004 and 2006, and then you have EN 614-1: safety of machinery: Ergonomic design principles. So, here all, everything related to the ergonomic aspects of the robot is designed. So, that is for the sake of the safety of this machinery. That is the part which is here. ISO 10218-1:2011: safety requirements of the industrial robot. That is what is to be followed by all these guidelines that are put forward to you now, that is put to the poster. That is followed by the manufacturer, by the maintenance engineer, by the manufacturer of the robot, and everyone else who is using this robot. ISO 12100-1, which is 2023, and 12100-2, that is in 2012. That is the safety of machinery and safety-related parts of the control system. So, it includes general principles for design and validation for the design. This is there for validation. The second one is there. So, these two ISOs clearly define the general principles of design and validation of safety related parts that are related to the control systems, and then you have ISO 13850, established in 2015. That is, actually. It was not established in 2015. This is the latest one which is here. That is followed to date as of now. There were much earlier revisions also. That finally is updated, and it is at this stage now. This is what has now followed. Safety of machinery for emergency stop function- principles of design. So, all the stop-category 0 is top. Category 1 is top. Category 2 is defined in this particular ISO guideline, and then you have IEC guidelines 60204-1 in 2018, which is the safety of machinery that treats the robot as an electrical machine. General requirements are all discussed here. So, even if the robot is electric, if it is electrically powered, it is an electrical machine. So, it has to follow this guideline also, and then you have IEC 61000-6-2, which is in 2016 and 61000-6-4 in 2011. So, they basically discuss electromagnetic compatibility EMC guidelines. The general standards for immunity and emission standards for industrial environments. Both of them are discussed in these two ISO standards. So, what is the IEC, basically? IEC is the International Electrotechnical Commission is there in Geneva, Switzerland. It was founded in London, UK, and later on, its headquarters are in Geneva, Switzerland. Similarly, the EC is a directive of the European Parliament and the Councils. E and C are here. So, that is all. So, that is for EC directives. That is there, and all these norms basically lay up the foundation for the safety of humans in the workspace.

So, that's all for today's class. Thanks a lot. So, in the next lecture, we'll see how industrial robots are programmed. That's all. Thanks a lot.