UNIT IV ROBOT WORKCELL

Robot Cell Design and Control - Remote Center compliance - Safety in Robotics.

TEXTBOOKS

1. D J Todd, “Fundamentals of Robot Technology- An introduction to Industrial Robots, Teleoperators and Robot Vehicles”, Kogan Page Ltd, 1986.

2.Mikell P. Groover, Mitchell Weiss, Roger N. Nagel Nicholas G. Odrey, “Industrial Robotics Technology, Programming and Applications”, McGraw Hill Book Company 1986.

3.Fu K.S. Gonzaleaz R.C. and Lee C.S.G., “Robotics Control Sensing, Vision and Intelligence”, McGraw Hill International Editions, 1987.

TEXTBOOKS

1.Barry Leatham - Jones, ”Elements of industrial Robotics”, PITMAN Publishing , 1987.

2.Bernard Hodges and Paul Hallam, “Industrial Robotics”, British Library Cataloging in Publication 1990.

3.Deb, S.R., “Robotics Technology and flexible automation”, Tata McGraw Hill, 1994.

www.sathieshkumar.com/tutorials

INTRODUCTION

- Industrial robots generally work with other pieces of equipments.
- Equipments include conveyors, production machines, fixtures and tools.
- The robot and the associated equipment form a workcell.
- Workstation:

1. a workcell with a single robot
2. one work location along a production line consisting of several robot workstations.

- Two of the problems in robot applications engineering are:

1. Physical design of the workcell
2. Design of the control system which will coordinate the activities among the various components of the cell.

Dr. V. Sathiesh Kumar Department of Electronics Engineering, MIT, India

ROBOT CELL LAYOUTS

- Robot workcells can be organized into various arrangements or layouts.

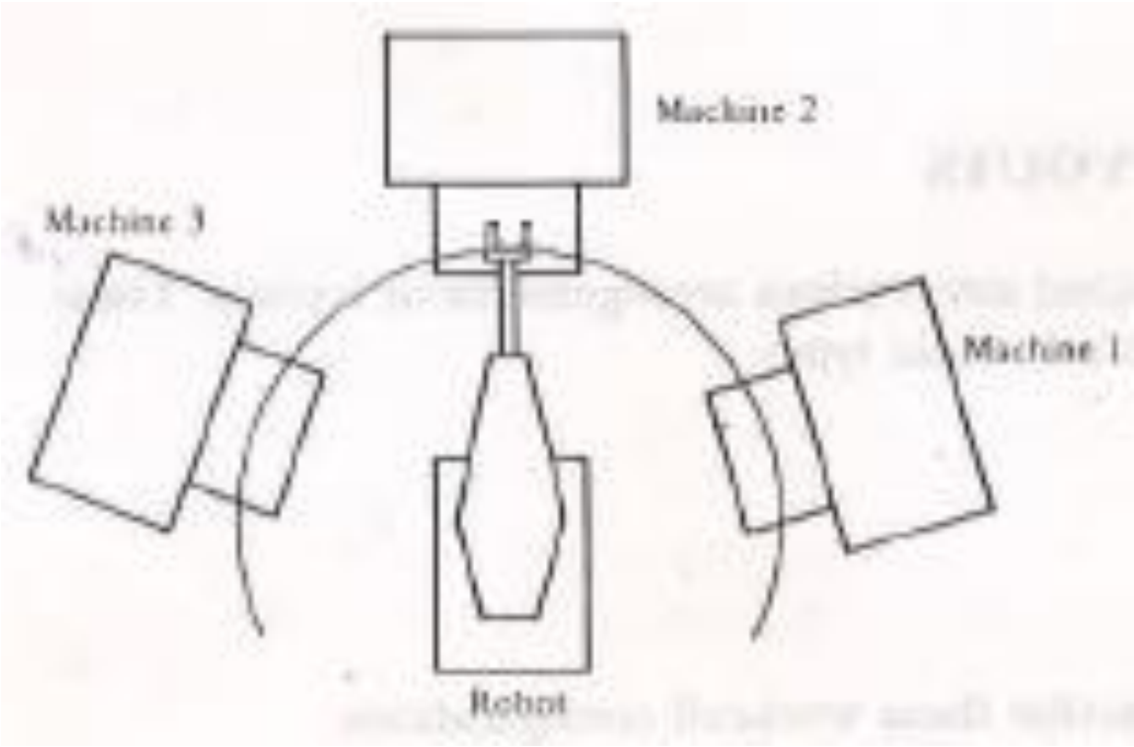
1. Robot-centered cell
2. In-line robot cell
3. Mobile robot cell

Robot-centered Workcell:

- The robot is located at the approximate center of the cell and the equipment is arranged in a particle circle around it.
- Example: One robot performs a single operation, either servicing a single production machine, or performing a single production operation.
- Example: Die casting: Robot is used to unload the part from the die after each casting cycle and dip it into a quenching bath.

ROBOT CELL LAYOUTS: ROBOT-CENTERED WORKCELL

- For some applications, the cycle times of the machine were relatively long compared to the part handling time of the robot.
- It results in low utilization of the robot.

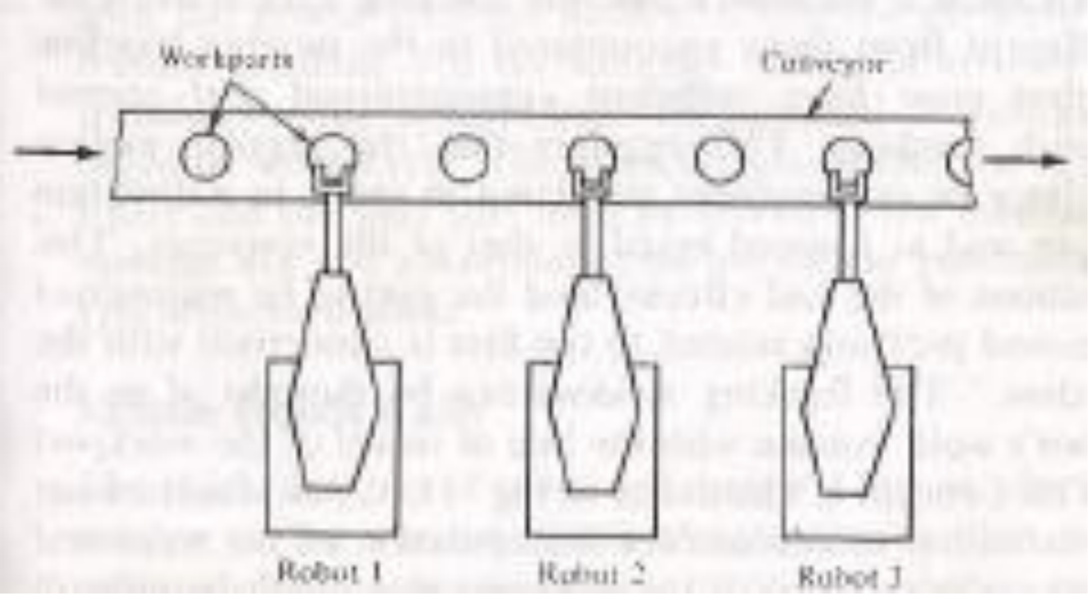


ROBOT CELL LAYOUTS: ROBOT-CENTERED WORKCELL

- In robot-centered cell arrangements, a method for delivering the workparts into and/or out of the cell must be provided.
- Conveyors, part feeders with delivery chutes, and pallets can be used to deliver the products.
- Examples: Machining, diecasting, plastic moulding.
- The devices are used to present the parts to the robot in a known location and orientation for proper pickup.

ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

- The robot is located along a moving conveyor or other handling system and performs a task on the product as it travels past on the conveyor.
- More than one robot is placed along the moving line.
- Example: Car body assembly plants in the automobile industry.



ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

- Robots are positioned along the assembly line to spot weld the car body frames and panels.
- Three categories of transfer systems are used with in-line cell configuration:

1. **Intermittent transfer**

- Moves the parts with a start and stop motion from one workstation along the line to the next.
- Also known as synchronous transfer system because all the parts are moved simultaneously and then registered at their next respective stations.
- The robot is in a stationary location and constitutes one position along the line at which a part or product stops for processing.
- Advantage: The part can be registered in a fixed location and orientation with respect to the robot during the robot workcycle.

ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

2. Continuous transfer

- Used to move parts in the cell.
- The workparts are moved continuously along the line at constant speed.
- The position and orientation of the part is continuously changing with respect to any fixed location along the line.
- Registration of the part relative to the robot becomes a problem.
- Problem can be solved by two ways:

1. A moving baseline tracking system
2. A stationary baseline tracking system

ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

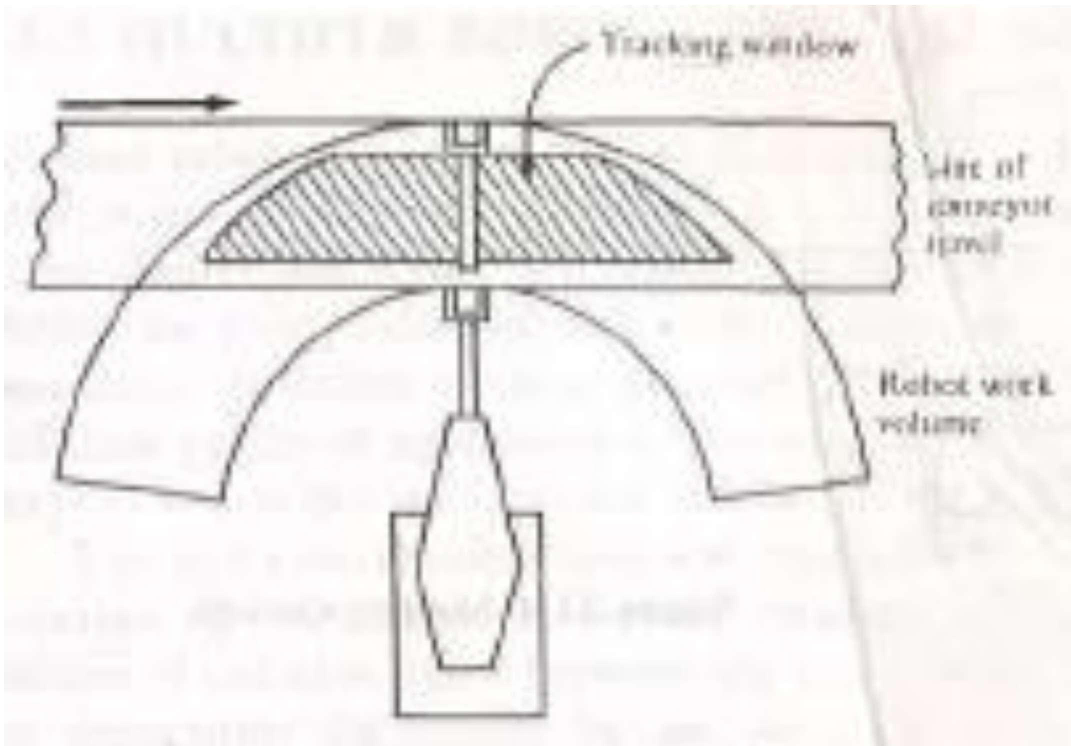
- **Moving baseline tracking system** involves the use of some sort of transport system to move the robot along a path parallel to the line of travel of the workpart while the operation is performed on the part.
- Relative position of the part and the robot remains constant during the workcycle.
- Problem: Additional degree of freedom must be provided for the robot to move along the conveyor.
- By mounting the robot on a cart which can be moved along a track or rail parallel to the conveyor.
- Collision needs to be avoided between the robot.
- This requires a significant amount of floor space.

ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

- Solution: Provide the workcell with enough intelligence that it knows where each robot is at any moment, and can control the sequence so as to avoid collisions.
- In stationary baseline tracking system, the robot is located in a stationary position along the line but its manipulator is capable of tracking the moving workpart.
- **Tracking** means that the robot is able to maintain the positions of the programmed points, including the orientation of the end effectors and the motion velocities, in relation to the workpart even though the part is moving along the conveyor.
- The robot must have sufficient computational and control capability to accomplish tracking.

ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

- The tracking window is the intersection of the robot's work volume with the line of travel of the workpart along the conveyor.
- For a robot with tracking capability, the total motion cycle in a particular application must be consistent with the tracking window for that application.



ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

- A sensor system must be used to identify which model is being delivered to the robot.
- A sensor is also required to determine that the part has entered the tracking window and that the robot can commence its workcycle.
- Other sensors are needed to track the position and velocity of the part during the cycle so as to coordinate with the robot tracking system.

3. Non synchronous transfer:

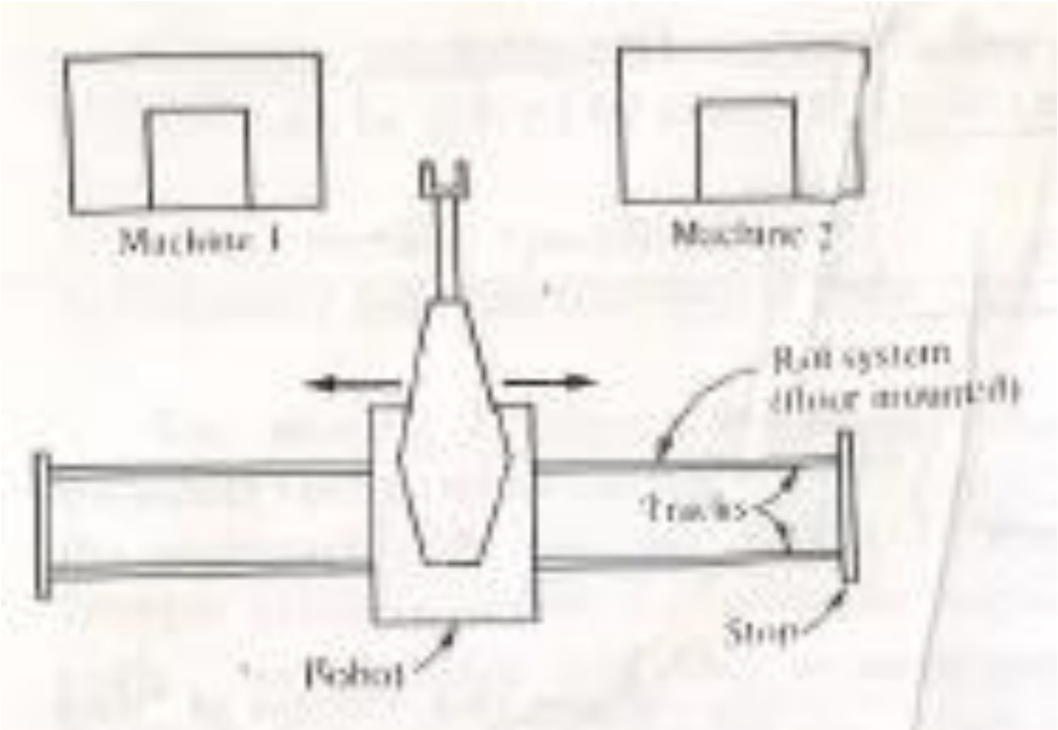
- Also referred as power and free system.
- Each part moves independently along the conveyor in a stop and go fashion.
- When a particular workstation has completed its processing of a part, that part proceeds to move toward the next workstation in the line.

ROBOT CELL LAYOUTS: IN-LINE ROBOT CELL

- Hence at any given moment, some workparts are being processed, while others are located between the stations.
- Each part must be provided with its own independently operated, moving cart.
- Sensors must be provided to indicate to the robot when to begin its workcycle.

ROBOT CELL LAYOUTS: MOBILE ROBOT CELL

- Robot is capable of moving to the various pieces of equipment within the cell.
- Accomplished by mounting the robot on a mobile base which can be transported on a rail system.
- Rail systems: Tracks fastened on the floor or overhead rail systems



ROBOT CELL LAYOUTS: MOBILE ROBOT CELL

- The advantage of overhead rail system compared to the floor mounted track system is that less floor space is required.
- The disadvantage is the increased cost of constructing the overhead system.
- A mobile robot cell would be appropriate when the robot is servicing several machine tools with long processing cycles.

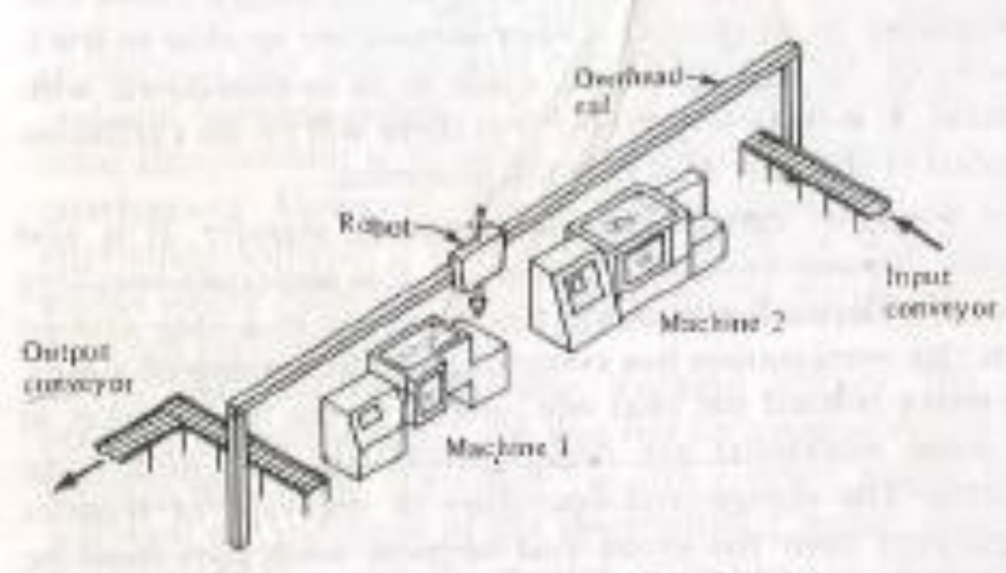


Figure 11-5 Overhead rail system for a mobile robot cell.

MULTIPLE ROBOTS AND MACHINE INTERFERENCE

- More than one robot is required to perform certain application.
- Care must be taken to ensure that the different pieces of equipment do not interfere with one another.
- There are two ways in which this inference can occur:

1. Physical interference of the robots, where the work volume of the two robots in the cell overlap each other.

- In this situation, the danger of collision exists between the robot arms.
- Prevented: By separating the robots by an adequate distance.
- In few situations, two robots needs to share the same space.
- Solution: To coordinate the programmed motion cycles of the two robots so that the arms are never close enough to risk a collision.

MULTIPLE ROBOTS AND MACHINE INTERFERENCE

2. Machine interference: When there are two or more machines being serviced by one robot, and the machine cycles are timed in such a way that idle time is experienced by one or more machines while another machine is being serviced by the robot.

- With greater variation in the cycle time and a lower effort level, the machine interference will tend to be greater.
- Machine interference can be measured as the total idle time of all the machines in the cell as compared to the operator (or robot) cycle time.
- The machine cycle is the sum of service time and run time.
- The robot cycle time is equal to the number of machines multiplied by the service time.

MULTIPLE ROBOTS AND MACHINE INTERFERENCE

- If the robot cycle time is greater than the machine cycle time, there will be resulting machine interference.
- If the machine cycle time is greater than the robot cycle time, there will be no machine interference, but he robot will be idle for part of the cycle.

OTHER CONSIDERATIONS IN WORKCELL DESIGN

1. Changes to other equipment in the cell
2. Part position and orientation
3. Part identification problem (Use optical techniques or limit switches to sense the difference in size or part geometry)
4. Protection of the robot from its environment (e.g., spray painting, hot metal working operations)
5. Utilities (electricity, air pressure, gas for furnace., etc)
6. Control of the workcell (activities of the robot must be coordinated with those of other equipments in the cell)
7. Safety (A means of protecting human personal from harm in and around the robot workcell must be provided)

WORKCELL CONTROL

- Coordinating the various activities that occur in the workcell is another challenging problem.
- Most of these activities occur sequentially, but simultaneous activities can also occur.
- Coordination of various activities is accomplished by a device called the workcell controller or workstation controller.
- The functions performed by the workcell controller are:

1. Sequence Control
2. Operator Interface
3. Safety Monitoring

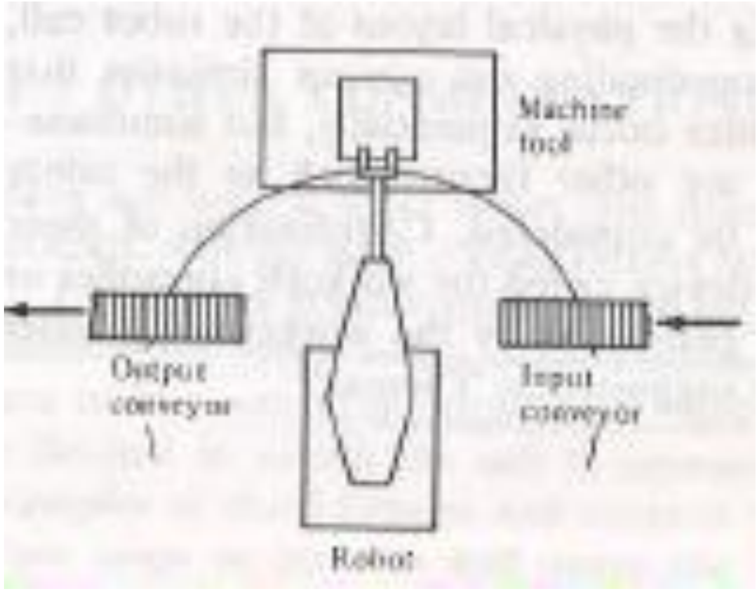
WORKCELL CONTROL

- The robot controller has a limited input/output capability to permit interfacing with other pieces of equipment in the cell.
- The implementation of an effective workcell controller is dependent largely on the programming capabilities of the robots used.

WORKCELL CONTROL: SEQUENCE CONTROL

- The sequence control functions are:

1. Control of the sequence of activities in the workcell
2. Control of simultaneous activities
3. Making decisions to proceed with the workcycle based on events that occur in the cell
4. Making decisions to stop or delay the workcycle based on events that occur in the cell.



WORKCELL CONTROL: SEQUENCE CONTROL

- Example: Sequence Control

1. Robot picks up raw work part from conveyor which has delivered the part to a known pickup position (Machine idle)
2. Robot loads part into fixture at machining center (Machine idle)
3. Machining center begins automatic machining cycle (Robot idle)
4. Machine completes automatic machining cycle. Robot unloads machine and places part on the pallet (Machine idle)
5. Robot moves back to pickup point (Machine idle)

- Either the robot or the machine tool is idle for a significant portion of the cycle.

WORKCELL CONTROL: SEQUENCE CONTROL

- The workcell controller can perform certain additional functions such as,

1. Performing computations
2. Dealing with exceptional events such as equipment breakdowns
3. Perform irregular cycles, such as tool changing at periodic intervals

WORKCELL CONTROL: OPERATOR INTERFACE

- The purpose of the operator interface in workstation control is to provide a means for human operators to interact with the operations of the cell.
- Several situations where his would be required:

1. The human is an integral part of the work cell

- Human and robot performs a portion of the work cycle.
- In a robotic cell, this can be easily accomplished by means of stop/start controls placed conveniently for the operator.
- The operator uses these controls to regulate the robot cycle as required by the situation.

WORKCELL CONTROL: OPERATOR INTERFACE

2. Emergency stop condition

- This situation involves an emergency in which the human worker needs to prevent continued operation of the robot cycle.
- Safety problem or an irregularity in the work cycle.

3. Program editing or data input by operator.

- To perform editing of the program or other similar input functions.
- Some robot controllers require that the robot be in a nonoperational mode when changes are made in the program.
- The more flexible controllers allow for editing to be accomplished while the robot is performing its regular cycle.

WORKCELL CONTROL: SAFETY MONITORING

- The work cell controller should also be capable of monitoring its own operation for unsafe or potentially unsafe conditions in the cell.
- This function is called safety monitoring or hazard monitoring.

INTERLOCKS

- An interlock in robotic work cell design is a method of preventing the work cycle sequence from continuing unless a certain conditions or set of conditions are satisfied.
- Interlocks would be used for the following purposes:

1. To make sure that a raw work part was at the pickup location on the conveyor before the robot tried to grasp that part.
2. To determine when the machine cycle was completed before the robot attempts to load the part into the fixture.
3. To indicate that the part has been successfully loaded so that the automatic machining cycle can begin

INTERLOCKS

- It is critical that one element of the cycle has been completed before any attempt is made to begin the next element.
- The method of regulating the sequence of the elements would involve the use of interlocks.
- Interlocks can be divided into two categories: Output interlocks and input interlocks.
- An output interlock involves the use of a signal sent from the workstation controller to one of the machines or other devices in the workcell (Eg., SIGNAL).
- An input interlock makes use of a signal sent from one of the components in the cell to the workstation controller (E.g., WAIT).

INTERLOCKS

- Interlocks are essential in nearly all robotic work cells consisting of several operating pieces of equipment that must all work in a coordinated fashion.
- Their use provides a synchronization and pacing of the activities in the cell which could not be accomplished through timing alone in the work cycle.
- They help to prevent damage of the various components of the cell.
- Interlocks are often implemented by means of limit switches and other simple devices that serve as sensors.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

- Examine the peg-in-hole assembly task.
- When a peg is inserted into a hole there are two possible positioning errors for the peg:

  (i) a lateral position error

  (ii) an angular error.

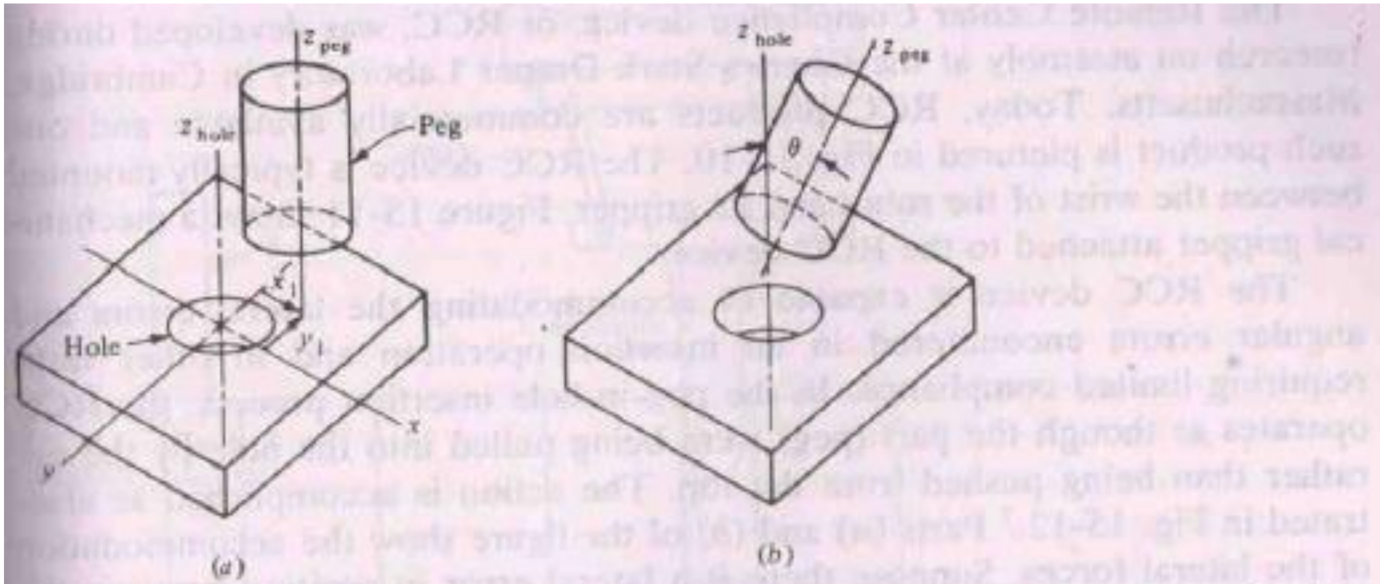


Figure 15-8 Two possible positioning errors for the peg-in-hole insertion task. (a) lateral position error, and (b) angular error.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

- When the parts are chamfered and there is a position error small enough to allow insertion to begin, it is still likely that an angular error will result during chamfer crossing as the peg rotates about the grip point at the top of the peg.

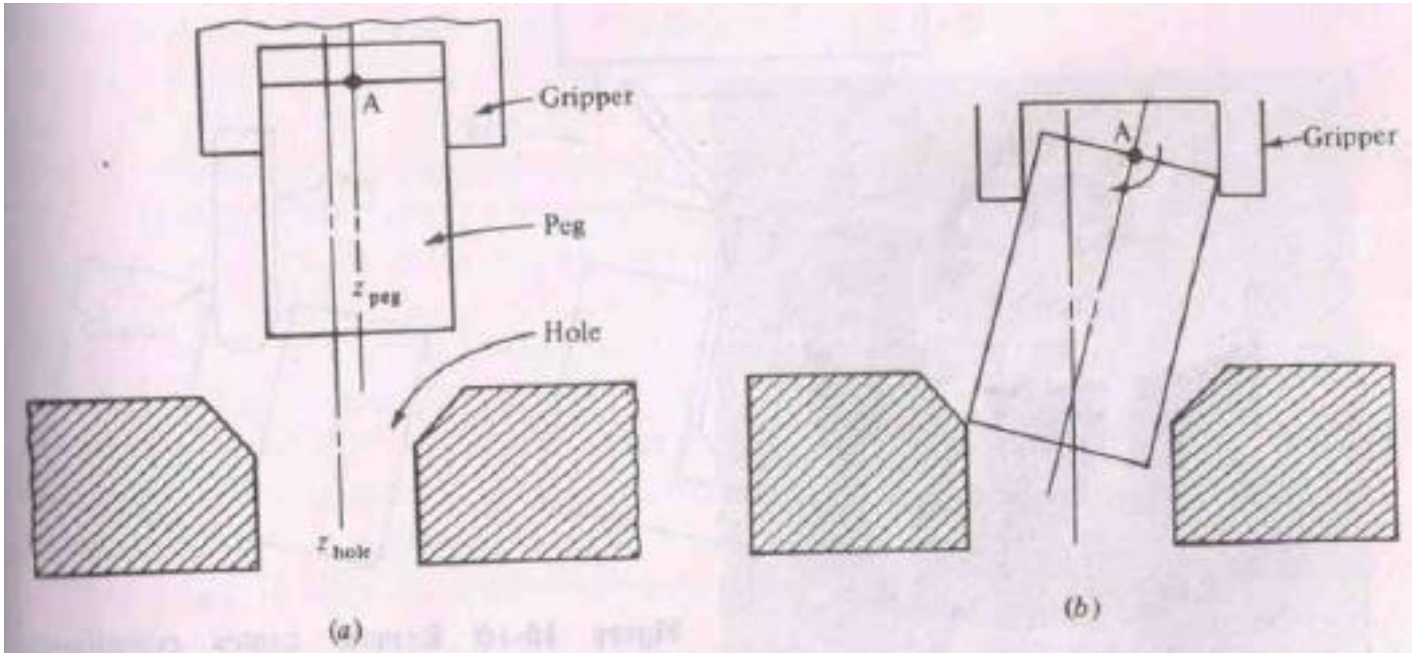


Figure 15-9 Peg-in-hole insertion task. (a) effect of small position error with chamfered parts. (b) small angular error results during chamfer crossing as the peg rotates about the grip point at the top of the peg.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

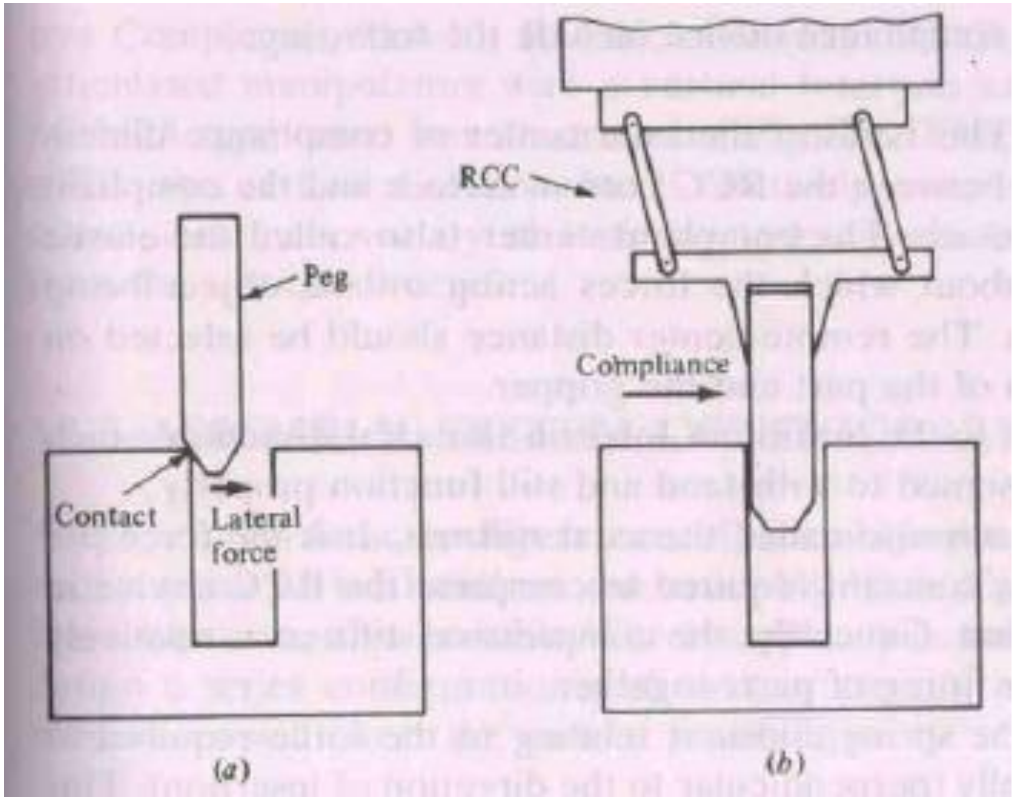
- The angular error allowable on the peg is a function of the clearance of the hole and the depth of the insertion. (i.e; deeper the part is inserted into the hole, the less angular error can be tolerated. Smaller the clearance between the parts and the hole, the smaller the angular error).
- To perform a successful peg-in-hole insertion task is to correct for the lateral and angular errors during assembly.
- A common solution is the use of Remote Center Compliance device.
- RCC products are commercially available.
- The RCC device is typically mounted between the wrist of the robot and its gripper.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

- The RCC device is capable of accommodating the lateral errors and angular errors encountered in an insertion operation and in other tasks requiring limited compliance.
- In the peg-in-hole insertion process, the RCC device operates as though the part (peg) were being pulled into the hole by the tip, rather than being pushed from the top.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

- Suppose there is a lateral error in position between the peg and the hole.
- Because of the chamfer on the hole, the error will cause a lateral force on the peg.
- This force causes the RCC to translate the peg so that it can be inserted into the hole.



COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

- Suppose the axis of the hole is not parallel with the axis of the peg.
- The peg will enter the hole (assuming the necessary lateral compliance occurs), but its leading edge will contact one side of the hole, while the edge of the hole will contact the other side of the shaft.
- This will cause a moment on the peg.
- The RCC will accommodate the moment by means of a rotation about the compliant center.

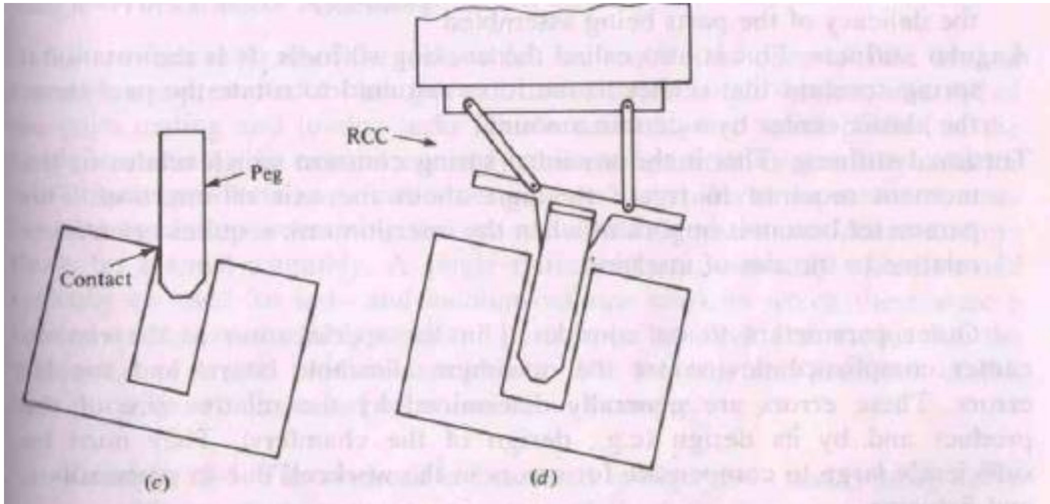


Figure 15-12 Action of a remote center compliance device in peg-in-hole insertion task. (a) action of RCC for lateral displacement, (b) action of RCC for angular displacement. (Reprinted by permission courtesy of Lord Corporation [7])

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

- RCCs are typically constructed using elastomer springs rather than the mechanical linkages.
- This has resulted in designs that are simple, small and lightweight.
- The parameters to be considered when selecting a remote center compliance device include:

1. Remote center distance or center of compliance dimension:

- It is the distance between the RCC bottom surface and the compliant center of the RCC device.
- The compliant center or elasic center is the point about which the forces acting on the object being inserted are minimum.
- The remote center distance should be selected on the basis of the length of the part and the gripper.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

2. Axial force capacity: This is the maximum force in the axial direction which the RCC device is designed to withstand and still function properly.
3. Compressive stiffness or axial stiffness: It is the force per unit distance or spring constant required to compress the RCC device in the direction of insertion.
4. Lateral stiffness: This is the spring constant relating to the force required to deflect the RCC laterally (perpendicular to the direction of insertion). Depends on the stiffness of the robot and the delicacy of the parts being assembled.
5. Angular stiffness or cocking stiffness: It is the rotational spring constant that relates to the force required to rotate the part about the elastic center by a certain amount.

COMPLIANCE AND REMOTE CENTER COMPLIANCE (RCC) DEVICE

6. Torsional stiffness: This is the torsional spring constant which relates to the moment required to rotate the part about the axis of insertion. Important when the insertion task requires orientation relative to the axis of insertion.

- A second approach to provide compliance would be to measure the forces and moments encountered by the part and to servo the robot to compensate for these forces.
- The Instrumented Remote Center Compliance (IRCC) is an RCC device that has been instrumented to measure deflections.
- These deflections provide an indication of the forces and moments being applied to the wrist. This permits high-speed part insertion owing to the compliance of the RCC while allowing monitoring and data collection of forces during operation of the system.

SAFETY IN ROBOTICS

- Two aspects of safety issue in robotics:

1. Justification of robots:

- Fundamental reason for using robots in industrial applications is to remove human operators from potentially hazardous work environments (heat, fumes, and other discomforts, physical dangers, radiation, toxic atmospheres, and other health hazards).
- Applications: Welding, Forging, Spray painting and Die casting.

2. The potential hazards to humans posed by the robot itself.

- Reasonable to question when during the use of the robot are humans in contact or close proximity to it.

SAFETY IN ROBOTICS

- Three occasions when humans are close enough to the machine to be exposed to danger are:

1. During programming of the robot
2. During operation of the robot cell when humans work in the cell
3. During maintenance of the robot

- Types of risks encountered are: physical injury from collision between the human and the robot, electrical shock, objects (parts or tools) dropped from the robot gripper, and loose power cables or hydraulic lines on the floor.
- Safety measures: Proper grounding of electrical cables to prevent shock, and raised floor platforms to cover power cables and hydraulic lines.
- When the robot is being programmed, the speed of the arm should be set at a low level during teaching and testing.

SAFETY IN ROBOTICS

- During maintenance, the power to the machine should be turned off under normal circumstances.
- Many of these safety measures must be designed into the workcell, either as part of the workplace design or as a part of the workcell control system.

SAFETY IN ROBOTICS: WORKPLACE DESIGN CONSIDERATIONS

- Safety features can be designed into the robot workcell are:

1. Physical barriers to limit intrusion in the cell

- The periphery of the robot cell must be defined to be outside the farthest reach of the robot in all directions with end effectors attached to the wrist.
- The workcell would also include any equipment in the cell which operates with the robot.
- The barrier has the effect of preventing human intruders from entering the vicinity of the robot while it is operating.
- The barrier often consists of a fence with a gate for access to the workcell.
- The gate is equipped with an interlock device so that the work cycle is interrupted when the gate is open.

SAFETY IN ROBOTICS: WORKPLACE DESIGN CONSIDERATIONS

- A positive restart procedure is designed into the cell for resumption of the cycle, rather than using the gate closure for restarting.
- Another approach: A physical barrier is made by the steel post in the floor at the limits of the programmed motion cycle, so that an out-of-control robot arm crashes into the post rather than go beyond its allowed space.
- Certain undesirable aspects of this technique are: If the robot arm crashes into the steel post at high speed, it will no doubt be damaged or destroyed.
- It does not prevent intruders from entering the robot cell.
- Human could be pinned between the robot arm and the post, results in greater injury to human than by simply being struck in open space by the robot arm.

Dr. V. Sathiesh Kumar Department of Electronics Engineering, MIT, India

SAFETY IN ROBOTICS: WORKPLACE DESIGN CONSIDERATIONS

- Robot cell must be designed to operate with humans as co-workers in the production process.
- Human workers are employed to load and unload work parts in the cell and the robot is used to perform a processing operation such as arc welding or grinding.
- In such cases, some form of two-position parts manipulator can be used to exchange parts between the robot and the worker.
- It uses a rotary indexing table to move raw work parts from the human operator’s position to the robot position for processing, an simultaneously moves completed parts from the robot position to the operators position for unloading.
- Prevents inadvertent collision between the worker and the robot.

SAFETY IN ROBOTICS: WORKPLACE DESIGN CONSIDERATIONS

- This type of layout has the additional advantage of production efficiency.
- The loading and unloading of parts by the human operator takes place simultaneously with the processing of parts by the robot.

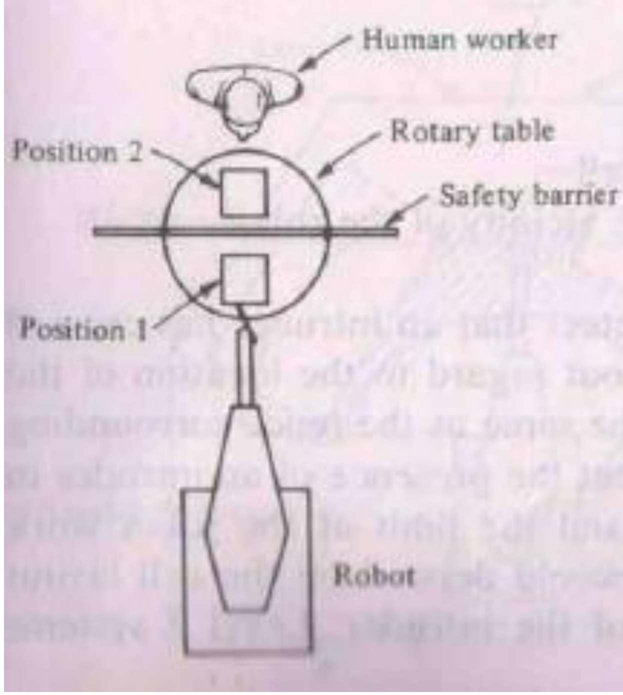


Figure 17-1 Cell layout using part manipulator to separate human worker from robot for safety and production efficiency.

2. Emergency stop buttons to halt the cell operation
3. Laying out the equipment in the cell for maximum safety.

SAFETY IN ROBOTICS: SAFETY SENSORS AND SAFETY MONITORING

- Safety monitoring involves the use of sensors to indicate conditions or events that are unsafe or potentially unsafe.
- The objective of safety monitoring include not only the protection of humans who happen to be in the cell, but also the protection of the equipment in the cell.
- Sensors range from simple limit switches to make sure that certain steps in the sequence control have been carried out, to sophisticated vision systems that are able to scan the workplace for intruders and other deviations from normal operating conditions.
- Workcell controller is limited in its monitoring capability to irregularities that have been foreseen by the designer of the cell control system.

SAFETY IN ROBOTICS: SAFETY SENSORS AND SAFETY MONITORING

- Greater care must be taken in the workcell design to anticipate all of the possible mishaps that might occur during the operation of the cell, and to design safeguards to prevent or limit the damage resulting from these mishaps.
- The National Bureau of Standards defines three levels of safety sensor system in robotics:

1. Level 1- Perimeter penetration detection
2. Level 2- Intruder detection inside the workcell
3. Level 3- Intruder detection in the immediate vicinity of the robot

- Third category must be capable of detecting an imminent collision between the worker and the robot, and of executing a strategy for avoiding the collision.

SAFETY IN ROBOTICS: SAFETY SENSORS AND SAFETY MONITORING

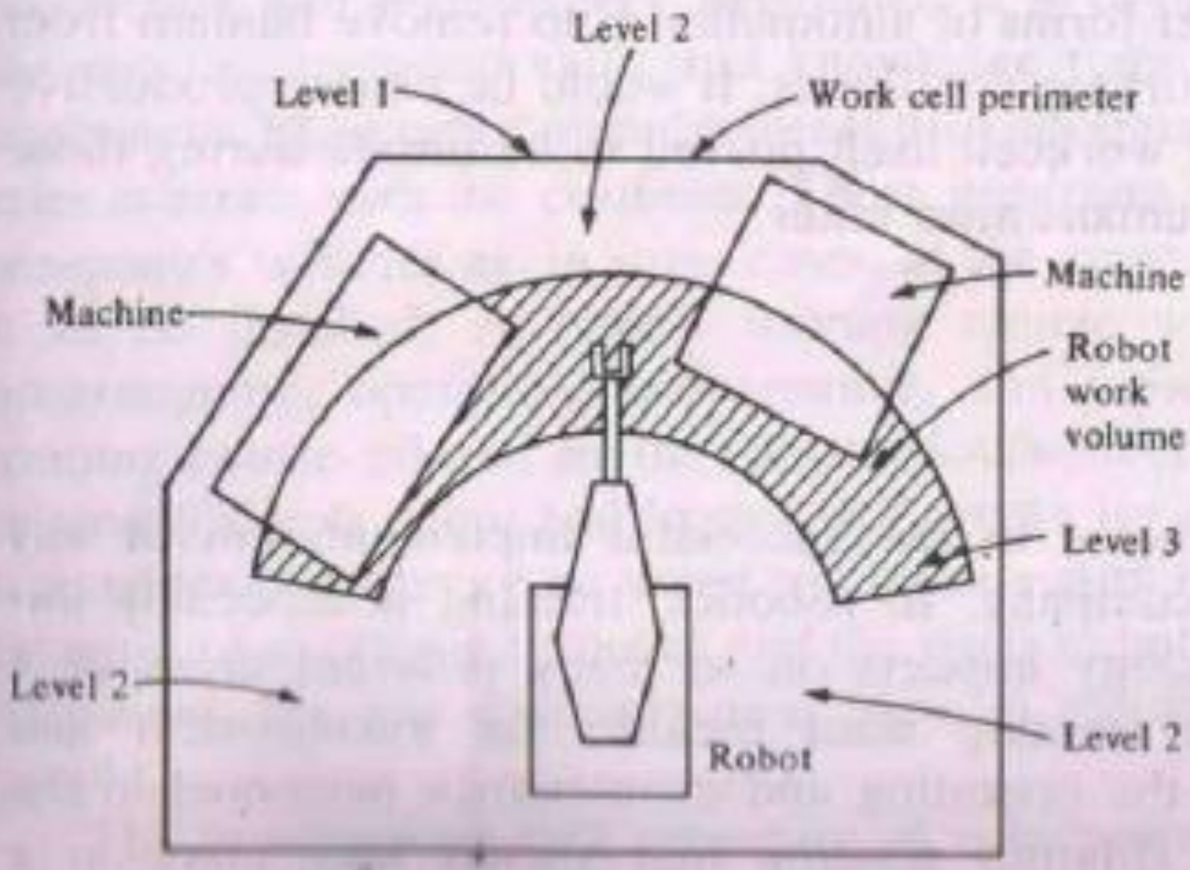


Figure 17-2 Three levels of safety sensor systems: Level 1—perimeter penetration; Level 2—intruder detection in the workcell; Level 3—intruder detection inside the robot work volume.

SAFETY IN ROBOTICS: SAFETY SENSORS AND SAFETY MONITORING

- Two common methods of robot safety sensing system are: Pressure sensitive floor mats and light curtains.
- Pressure sensitive mats (Level 1 or 2) are area pads placed on the floor around the workcell which sense the weight of someone standing on the mat.
- Light curtains (Level 1) consists of light beams and photosensitive devices placed around the workcell that sense the presence of an intruder by an interruption of the light beam.
- Proximity sensors located on the robot arm could be utilized as level 3 sensors.

SAFETY IN ROBOTICS: SAFETY SENSORS AND SAFETY MONITORING

- Some of the safety monitoring strategy are:

1. Complete shutdown of the robot upon detection of an intruder.
2. Activation of warning alarms
3. Reduction in the speed of the robot to a “safe” level
4. Obstacle Avoidance: Directing the robot to move its arm away from the intruder to avoid collision
5. Directing the robot to perform tasks in anther region of the workcell away from the intruder.

Dr. V. Sathiesh Kumar Department of Electronics Engineering, MIT, India

SAFETY IN ROBOTICS: SAFETY SENSORS AND SAFETY MONITORING

- A more sophisticate system used in safety monitoring is called a "fail safe hazard detector"
- Concept: This detector is based on the recognition that some component of the basic hazard sensor system might fail and that this failure might not be found out until some safety emergency occurred.
- The detector consists of the usual sensor subsystem for monitoring some potential hazard in the cell, but it also possesses the capability to periodically and automatically check the sensor subsystem to make certain it is operating properly.
- This capability is achieved by means of challenge subsystem which simulates the hazard that the sensors are supposed to detect, and then checking for any interruptions in the anticipated response of the sensor subsystem.

Dr. V. Sathiesh Kumar Department of Electronics Engineering, MIT, India

SAFETY IN ROBOTICS: OTHER SAFETY MEASURES

- Emergency stop button or panic button are usually located on both the main control panel and the robot teach pendant.
- The stop control should be capable of stopping not only the robot itself, but also the other moving equipment (e.g., conveyors) in the cell.
- A "deadman switch" is a useful control feature during lead through programming.
- It is a trigger or toggle switch device generally located on the teach pendant which requires active pressure to be applied to the device in order to drive the manipulator.
- If the pressure is removed from the trigger or toggle switch, then the device springs back to its neutral position which stops all robot movements.

SUMMARY

1. Design and control of Workcell
2. Remote center compliance (RCC)
3. Safety measures in robotics