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Working Safely With Industrial Robots

The use of industrial robots in manufacturing is becoming increasingly prevalent worldwide. This is an emerging trend driven primarily by the push for greater efficiency and higher productivity as well as falling robot prices, shortage of manpower and increasing labour costs. The reliance on automation is especially relevant for Singapore where the use of robots is a practical solution that can help address the national concern on ageing population and shrinking citizen labour force.

In general, there are two types of robots used in the manufacturing sector:

CONVENTIONAL ROBOTS

These are robots that work independently and have limited interaction with workers.

Fig 1: Example of a conventional industrial robot. (Photo courtesy of Pilz South East Asia Pte. Ltd.)

COLLABORATIVE ROBOTS

These are robots that work in collaboration with and in close proximity to workers.

Fig 2: Example of collaborative robots that can operate without causing injury to workers in the vicinity. (Photo courtesy of Rethink Robotics Inc.)

Regardless of the robot type, the introduction of new technology at the workplace inevitably brings new safety risks. This article highlights the hazards associated with robot operations in general and provides companies with an overview of the possible control measures that can be put in place to provide a safe work environment and mitigate the risks to workers.

ROBOT HAZARDS

Robots are essentially machines and the mechanical hazards typically experienced when working with a machine apply also to industrial operations involving robots. Mechanical hazards arising from robot operation are usually caused by moving parts which can exert sufficient force to cause injury to workers.

Common mechanical hazards when using machines include entanglement, cutting, crushing, impact, shearing and draw-in hazards. More details on each of these mechanical hazards can be found in the WSH Guidelines on Safe Use of Machinery. In robot operations, these hazards may come about due to unsafe robot design, improper installation, control error, mechanical part failure, power system/subsystem malfunction, environmental influence (e.g. electromagnetic or radio-frequency interference) or human error.

Accidents involving robots tend to fall into the following types:

1. **Impact Or Collision**
   Occurs when a worker is hit by a robot, for example, due to unexpected robot arm

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movement, robot component malfunction or a change in robot programming.

2. **Crushing And Entrapment**
   Occurs when a worker's limb or body part is trapped between a robot arm and other peripheral equipment, or when the worker is physically driven into and crushed by peripheral equipment.

3. **Struck By Flying Object**
   Occurs when there is a breakdown of a robot component, tooling or end-effector, or power source resulting in failure of the gripping mechanism or failure of the end-effector tool (e.g. grinding wheel, power screwdriver) resulting in the release of parts or objects. Thus, causing worker injury.

POSSIBLE CONTROL MEASURES

While the use of robots offer multiple benefits to industrial operations, they typically move fast and are strong enough to cause injury should a worker enter the robot work zone at the wrong time.

For both conventional and collaborative robots, it is important to realize that robot accidents can occur outside of normal operating conditions, e.g. during robot commissioning, programming/teaching, programme refinement, troubleshooting, maintenance, repair, testing, setup or adjustment. It is during such operations that the robot operator, programmer or maintenance worker may need to be stationed temporarily inside the robot work zone where unintended robot movement could result in an accident.

Risk assessment is absolutely necessary and each and every hazard (e.g. due to robot design, control error, part failure, human error, etc.) must be carefully considered. As part of risk assessment, a job safety analysis is recommended for each task (including routine and non-routine tasks) that requires a worker to interface with the robot. This is followed by communicating the risk assessment to all affected workers (e.g. robot operator, programmer or maintenance worker) so that there will be strong awareness of the risks associated with the job and how these risks can be minimized.

The following are risk control measures companies may consider implementing to reduce the risk of worker injury when working with robots:

1. **Lockout Tagout**
   Implement a lockout tagout (LOTO) system, wherever possible, to avoid injuries due to unexpected startup or release of stored energy (e.g. instrument air or a spring under tension) especially during robot maintenance. LOTO is, unfortunately, not able to address all safety concerns when working with a robot as the robot may need to be in the powered-up state for programming, teaching or problem diagnosis. It is therefore critical that workers know when LOTO can and should be applied.

2. **Safe Guarding**
   In general, safe guarding refers to engineering control measures taken to design any residual risks associated with on-site robot operation. It is important to ensure that safeguards are carefully designed such that workers can get their task done safely, quickly and without having to defeat the safeguarding. In particular, to facilitate robot programming, teaching or maintenance, the introduction of a safe operating mode may be achieved through the implementation of a manually activated enabling switch. A safe mode would disable selected safe guards (e.g. light curtain, safety mat and presence sensor) and enable the robot to operate at far reduced speeds, thereby allowing a worker to safely enter the work zone whilst the robot remains in a low-powered but energized state.

   Over and above the use of safeguards, warning devices (e.g., audiovisual alarms) and emergency stop buttons are typically installed within the robot work zone to indicate a hazardous condition and provide a means for workers to manually stop the robot should a safeguard fail to activate automatically.

Implement the following safeguards (in combination) to protect workers from robot hazards:

Location	Safe guard	How this works
ZONE 1 Perimeter of work zone	Adequate clearance	This is the minimum safety distance from all moving parts of the robot. The floor should be marked clearly to indicate the robot work zone. This defines the perimeter of the work zone. The work zone must be designed to be free of obstructions that can interfere with robot operations or cause worker entrapment.
	Fence	This refers to physical fencing (or barrier) installed to deter access to the work zone. Every gate in the fencing should be interlocked to the control system such that the robot will either slow down or come to a stop once any gate is opened.
	Light curtain	This entails the use of photoelectric transmitters and receivers that work together to protect a hazardous work zone. The robot should be designed to either slow down or come to a stop once any light beam emitted by the transmitter is "broken" (e.g., blocked by any part of a person's body). The gates in physical fencing may be replaced by light curtains if unobstructed access into the robot work zone is required.

ZONE 2 Inside the work zone	Safety mat	This refers to the placement of pressure-sensitive mats on the floor inside the robot work zone. Safety mats contain a normally-open switch which closes the moment a person steps on the mat. A signal will be sent to stop robot movement once the switch is closed.
	Presence sensor	These are motion-sensing detectors (based on 2-dimensional or 3-dimensional camera or laser scanning technology) that can detect human presence. Once a person is detected inside the work zone, a signal is sent to either reduce the speed at which the robot is operating or stop it completely.
ZONE 3 On the robot (particularly important for collaborative robots)	Limiting device	These are devices that help to define the robot operating envelope and restrict (either mechanically or through programming) the maximum distance and speed at which the robot arm can move during operations. These restrictions may be designed to be active at all times or to kick in once human presence is detected.
	Collision sensor	These are pressure-sensitive sensors on the robot arm or surface that will send an emergency signal to stop robot movement and limit its power or force once unintended contact (collision) is detected. Upon contact, any force exerted by the robot on a person's body must be controlled to be low enough not to cause significant injury.

See Fig 3 for a visual summary of locations where the above safeguarding measures can be put in place to protect workers from robot hazards.

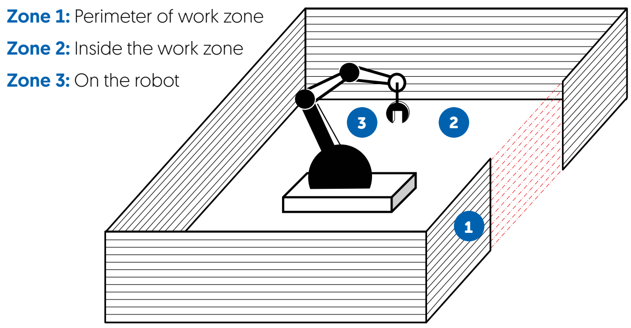

Fig 3: Locations where safeguarding measures can be implemented to facilitate safer working with robots.

3. Safety Signage

Install warning signs to indicate areas where robots are in operation and the presence of hazards. Robot work zones must be adequately illuminated so that signs and floor markings are clearly visible and workers are able to read written instructions and see the robot controls.

4. Worker Training

Provide workers* with training on the specific robot being used. The training should include familiarization with the full range of robot movement, on-site hazard identification, permit-to-work system, safe work procedures, understanding the safeguarding measures in place, and knowing when LOTO should be applied.

* This includes the robot operator, programmer and maintainer.

5. Authorized Access

Allow only competent and authorized personnel to enter a robot work zone. All persons unfamiliar with robot hazards (this includes visitors as well as untrained staff) must be supervised while on the premises and kept away from the vicinity of a robot in operation at all times.

Further Information:

- SS ISO 10218: 2016 Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1: Robots; Part 2: Robot Systems and Integration
- ISO TS 15066: 2016 Robots and Robotic Devices – Collaborative Robots
- ANSI RIA R15.06: 2012 Industrial Robots and Robot Systems – Safety Requirements
- ISO 13849–1: 2015 Safety of Machinery – Safety-Related Parts of Control Systems – Part 1: General Principles for Design
- IEC 62061 – Amd 1&2 CSV ed 1.2: 2005 Safety of Machinery – Functional Safety of Safety-Related Electrical, Electronic and Programmable Electronic Control Systems
- SS 537–1: 2008 Code of Practice for the Safe Use of Machinery – General Requirements
- SS 571: 2011 Code of Practice for Energy Lockout and Tagout
- Workplace Safety and Health (WSH) Guidelines on Safe Use of Machinery

GLOSSARY	
Industrial robot	A reprogrammable multi-functional multi-axis manipulating machine designed for use in manufacturing and industrial automation applications to move materials, parts or tools to perform a variety of programmed tasks.
End-effector	An accessory device or tool (e.g., gripper, weld gun, spray paint gun) specifically designed for attachment to the robot wrist or tool mounting plate to enable the robot to perform its intended task.
Interlocked	An arrangement where the operation of one control or mechanism brings about or prevents the operation of another.
Operating envelope	The volume of space used by the robot (including the end-effector, work piece, and any attachments) while carrying out the tasks it was programmed to accomplish.