Safety Standards and Collaborative Robots

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Topics

• What is it?
• How did we get here?
• What has already been done?
• What still needs doing?
Standards

- ISO 10218-1:2006 (updated 2011) and ISO 10218-2:2011 are the industrial robot standards that initially covered collaborative applications
  - Part 1: Robot only (manipulator and controller)
  - Part 2: Robot system/cell and application

- ISO TS 15066 is a Technical Specification on collaborative robots that should be available in 2015

Vocabulary lesson

• A **collaborative robot** is a robot that can be used in a **collaborative operation**

  - **Collaborative operation (Part 1, 3.4)** – state in which purposely designed robots work in direct cooperation with a human within a defined workspace

*emphasis added*
What Is A Collaborative Robot?

• ...within a collaborative workspace

  - Collaborative workspace (Part 1, 3.5) – workspace within the safeguarded space where the robot and human can perform tasks simultaneously during production operation
What Is A Collaborative Robot?

So really, a **collaborative robot is defined** by...

- The **task** the robot is performing; and
- The **space** in which the task is being performed,

...and not the robot itself!
How Did We Get Here?

Google image search
August 20, 2014
Risk

Risk = Likelihood X Consequence
Risk

Model proposed by WHO to examine health risks from natural disasters
Traditional Industrial Robot Risk Reduction

In production operation or automatic mode, operators are prevented from accessing the machine with safeguarding devices.
Accessing the machine requires:
• removing the safeguards, and
• limiting, controlling or eliminating the machine’s energy.
An Alternative Risk Model

Hazard

Exposure

Vulnerability

WHO Model applied to industrial robotics applications

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**Hierarchy of Risk Reduction**

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<th>Elimination</th>
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The EU Machinery Directive, U.S. OSHA (29 CFR 1910) and other regulations require machine manufacturers to provide guarding to protect operators and employees from hazards.

Consensus standards (ISO, ANSI, CSA) provide guidance for the safe integration and application of machinery, but presume safeguarding is necessary to reduce risk.

Awareness means, administrative controls and PPE are an effective means of reducing residual risk AFTER hazards are reduced through engineered means.
Assumptions associated with Hierarchy of Risk Reduction

It is assumed that the machine poses one or more hazards that require risk reduction measures. What if this isn’t true?

It is assumed that fixed and interlocked guards are necessary risk reduction measures. What if fixed guards are not necessary?

What if awareness means, administrative controls and PPE alone are an effective means of addressing low-risk machinery applications?
Specially-designed machines can be used for pre-determined collaborative tasks involving direct operator contact when all required protective measures are active and all relevant risks have been acceptably reduced.

Exposure reduction relies on active machine protective measures. Safeguarding shall prevent operators from advancing beyond the safeguarded space, and cause hazards to cease if unacceptable conditions are detected.

Awareness means, administrative controls and PPE are an effective means of reducing risk AFTER machine hazards are reduced through engineered means.
The Standard...

Collaborative robot operations:

- **Part 1, 5.10** – Information for robot manufacturer
- **Part 2, 5.11** – Information for robot integrator
- **Part 2, Annex E and Annex G** have information on conceptual applications and verification of safety requirements

Approximately 8 pages of the 152-page standard is specific to collaborative robot operations

(Available online at RIA Bookstore)
Part 1, 5.10 Collaborative operation requirements –
5.10.1 General – Robots designed for collaborative operation shall provide a visual indication when the robot is in collaborative operation and comply with one or more of the following:

- **5.10.2 Safety-rated monitored stop** (IEC 60204-1 category 2)
- **5.10.3 Hand guiding** (requires emergency stop and enabling device)
- **5.10.4 Speed and separation monitoring**
- **5.10.5 Power and force limiting** by inherent design or control
Safety-Rated Monitored Stop

What the collaborative robot does in the presence of an operator or obstruction

• Stop-motion condition ensured
• Drive power remains on
• Motion resumes after obstruction clears
• Robot motion resumes without additional action
• Protective stop delivered if stop condition is violated

Applications

• Direct part loading or unloading
• Work-in-process inspections
• Standstill function in other collaborative operations
Hand Guiding

Where an operator leads robot movement through direct interface

• Robot stops when operator arrives (Safety-rated monitored stop)
• Operator grasps enabling device, activating motion
• Robot motion responds to operator commands
• Non-collaborative operation resumes when operator leaves collaborative workspace

Applications

• Robotic lift assist
• Highly variable applications
• Limited or small-batch productions
Where the robot speed reduces when an obstruction is detected
Separation distances are monitored (scanners, vision systems, proximity sensors)

- Robot speed directly correlates to separation distance—zones dictate allowable speed
- Stop condition given if direct contact proximity is attained (Safety-rated monitored stop)

Applications
- Simultaneous tasks
- Direct operator interface
Safe separation distance is a function of:

- The speed of the person moving toward the robot
- The speed of the robot moving toward the person
- The reaction time of the robot system to detect an undesirable condition and initiate a stop
- The intrusion distance that a part of the body can move past the safeguard toward the hazard zone prior to actuation of the safeguard
- Position uncertainty for both the robot and operator

A proposed model includes calculations that represent:

1. The change in separation distance due to the person’s motion
2. The rate of change in separation distance due to the robot’s motion up to the robot requesting a stop and braking.
3. The change in separation distance while the robot is reacting and stopping.

\[ S_{current}(t) \geq \int_{\tau=t}^{\tau=t+T_R+T_B} K_H(\tau) d\tau + \int_{\tau=t}^{\tau=t+T_R} K_R(\tau) d\tau + \int_{\tau=t}^{\tau=t+T_R+T_B} K_R(\tau) d\tau + C + Z_S + Z_R \]
Power And Force Limiting

Where incidental contact initiated by robot are limited in energy to not cause operator harm

- Forces robot can exert are limited
- Robot system design eliminates pinch points, sharp edges, etc.
- Robot complies and reacts when contact is made

Applications

- Small or highly variable applications
- Conditions requiring frequent operator presence
- Machine tending
- Loading/unloading
Power And Force Limits?

80 watt/150 Newton P&F limits were in ISO 10218-1:2006 but were removed in ISO 10218-1:2011.

\[ 1 \, W = 1 \, N \frac{m}{s} = 1 \frac{kg \, m^2}{s^3} \]

Watts applied to mechanical power, not motor ratings.

\[ F = ma \]

Force applied where? Could be hazardous, depending on where on the body the force was applied.

Does applied power or force result in clamping?
Part 2 requires a risk assessment for collaborative applications to evaluate task/hazard combinations and set appropriate limits

- Means of anticipating tasks and hazards with the goal of applying suitable risk reduction measures
- Uses an iterative process as a means to determine that risk reduction measures applied can achieve their desired effect
- Avoids “one size fits all” prescriptive measures, which can either be too restrictive or can require defeating safeguards in order to accomplish certain tasks
Risk Assessment

- **Initial risk** of collaborative task/hazard pairs must be sufficiently low as a condition for risk reduction without guards.
- Elimination, substitution or guarding are required for task/hazard pairs that exhibit higher initial risks.
- Guarding may also be necessary to address non-collaborative tasks using the same equipment.

Tables: RIA TR R15.306
ANSI/B11.0
Power and force limits can be affected or modified by:

- Eliminating pinch points
- Reducing robot velocity, thereby reducing transfer energy
  \[ E = \frac{1}{2}mv^2 \]
- Reducing robot inertia or mass
- Modifying robot posture, such that possible exposure surface area is increased
- Avoiding sensitive body areas (i.e. head and neck)

**The application, not the robot, is key!**
TS 15066: Onset Of Pain Study

- TS 15066 will include guidance for power and force limits based on a study examining power and force conditions and the onset of pain in 29 body regions.
- The study is being conducted at the University of Mainz in Germany.

See: [http://www.dguv.de/ifa/Fachinfos/Kollaborierende-Roboter/index-2.jsp](http://www.dguv.de/ifa/Fachinfos/Kollaborierende-Roboter/index-2.jsp)
Search: “Mainz collaborative robot”
The pain threshold map can be used to set power and force limits for P&F limiting robot applications, based on anticipated body contact location.

Energy transfer models will calculate maximum allowable robot velocity for given contact scenario.

Images: www.dguv.de
Summary

• What is it?
  – Collaborative robotics is a new robotic application allowing direct robot and operator interface without traditional safeguarding under specific conditions

• How did we get here?
  – Improvements in controls and machine technology created opportunities to create machines that could safely operate without external safeguards
  – Standards activities, including adoption of risk assessments and controls systems validation are identifying conditions where collaborative applications can be performed safely
Summary

• What has already been done?
  – International ISO and ANSI robot safety standards have identified specific applications and criteria where collaborative operations can occur

• What still needs doing?
  – ISO TS 15066 will provide additional guidance on the safe implementation of each collaborative robot operation
  – Regulatory acceptance of robots not utilizing traditional safeguards has not been determined
Thank You

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