ISO/TS 15066
Introduction

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Universal Robots
What is ISO/TS 15066?

- ISO/TS Technical Specification
  - A *voluntary document with normative language* representing *technical consensus* of the committee
  - “More” than a technical report, expected to become a standard but *not quite ready to be a standard* now

- Provides guidance not in ISO 10218-1 & -2
  - Collaborative operation consist of approximately 8 pages out of 152 total pages in ISO 10218-1 & -2
  - ISO 10218-1 first introduced the concept of collaborative applications in 2006, which was revised in 2011
    - 2006 had 80 watt / 150 N P&F limit; these were removed in 2011

\[ \text{ISO 10218-1} + \text{ISO 10218-2} = \text{R15.06 (includes parts 1 and 2)} \]
Terminology from ISO 10218

**Robot:** Robot arm & robot control

**Robot System:** Robot, end-effector & workpiece

What is being done is the application!

*This example: manipulating an object*

The end-effector could be a sealant applicator which applies sealant to the workpiece
• A **collaborative robot** is a robot that CAN be used (capability) for **collaborative operation** <it enables...>

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

• There are some inconsistencies to be corrected in next revision: sloppy use of robot vs robot system & that collaborative could be co-located
Collaborative Operation

Defined by

– The **TASK**: what the robot **SYSTEM** (robot, end-effector and part) is doing

– The **SPACE** in which the task is being performed

NOT THE ROBOT ALONE
Philosophical Background

• "Why not have a human contact a robot **system** if the result is no harm to the human(s)?"
  – Is this different than contacting a stopped robot system?
  – Contact while robot system is moving/operating should be infrequent (low exposure).

• If the robot is wimpy ("inherently safe") OR a power & force limited robot **AND the application** is manipulating a knife, is this an acceptable collaborative application?
  **NO!** It should be safeguarded as a "traditional" robot system (people are separated from it)
The Journey...

Heavy, dirty, difficult work for people. Robot systems result in less hazardous workplace than people doing the work. Any impact by the robot system is **high risk**.

Sensors and safety (protective devices and safety-related functions) are mostly **EXTERNAL** to the robot systems.

Complex systems and installations.

Awkward and non-ergonomic work for people. Robot does the hazardous work (load/unload part).

**Power/force limited robot** impact is **LOW RISK** (no pain, no injury) from robot; must use with appropriate end-effector & part.

Sensors and safety-related functions (protective functions) are mostly **INTERNAL** to the robot and used for safely controlling risks of the robot system.

Can be used for very simple → complex applications; many applications are partial task automation.
<table>
<thead>
<tr>
<th>“Traditional” Applications</th>
<th>Collaborative Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inherently Safe Design Measures</strong></td>
<td></td>
</tr>
<tr>
<td>Process design, limiting access, layout</td>
<td>Process modifications, reduced energy, compliant (soft) materials</td>
</tr>
<tr>
<td><strong>Safeguards and SRP/CS</strong></td>
<td></td>
</tr>
<tr>
<td>Fixed &amp; interlocked guards</td>
<td>Can include safety-rated:</td>
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<tr>
<td>Sensitive protective equipment</td>
<td>TCP: speed, position, force</td>
</tr>
<tr>
<td>Hard axis limits or safety-rated soft axis and space limits</td>
<td>Joint: angular position &amp; speed</td>
</tr>
<tr>
<td>Safety functions for the integration of protective (safety) devices</td>
<td>Robot: max momentum &amp; applied force</td>
</tr>
<tr>
<td></td>
<td><strong>If needed, more...</strong>, e.g. guards &amp; protective devices + safety functions</td>
</tr>
<tr>
<td><strong>Information for Use</strong></td>
<td></td>
</tr>
<tr>
<td>SAME or SIMILAR</td>
<td></td>
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</tbody>
</table>
4 Types of Collaborative Operation

• Safety-rated Monitored Stop
  – A stop is assured without removal of power

• Hand-guided
  – Essentially a manually controlled robot system

• Speed & Separation Monitoring
  – Robot system speed will be controlled based on the separation between it and any intrusion
    • Now accomplished by external safety devices (e.g. safety laser scanner, safe vision system)
    • Future will integrate the robot system with safety devices

• Power and Force Limited
  – Robot speed, torque, motion controlled so that impact will not hurt or injure
Who Moves?

Safety-rated monitored stop
Either the robot system OR the person moves, not both at the same time.

Hand-guiding operation
Both can move at the same time.
Robot system is directly controlled by the operator (person).

Speed & separation monitoring
Both can move at the same time.
Robot system will slow upon approach.
Controlled such that it will stop before impact (or meet P&FL requirements before contact).

Power & force limiting
Both can move at the same time. Forces, speeds, motion... controlled so there can be applications with no pain or injury and no need of traditional guards & protective devices.
*risk assessment determines suitability
Safety-Rated Monitored Stop

Allows for direct operator interaction with the robot system under specific circumstances

- Safety-rated stop condition before operator enters
- Drive power remains on
- Motion resumes after operator leaves workspace
  - Robot motion resumes without additional action
- Protective stop issued if stop condition is violated

Applications

- Direct part loading or unloading to end-effector
- Work-in-process inspections
- When 1 moves (not both) in collaborative workspace
- Used with other collaborative techniques
Hand-Guiding *automatic, not teaching*

Operator uses a hand-operated device to allow operation

- BEFORE the operator enters the collaborative workspace, the robot <system> achieves a safety-rated monitored stop
  - Drive power remains on
- Operator grasps hand-operated device (includes an enabling device), activating motion/operation
- Non-collaborative operation resumes when the operator leaves the collaborative workspace

Applications

- Robotic lift assist
- Highly variable applications (like a manual operated “tool”)
- Limited or small-batch production
Speed & Separation Monitoring

Operator and robot system may move concurrently in the collaborative workspace...

- Minimum protective separation distance between the operator & robot system is maintained at all times
- Requires protective devices that are used to determine approach (lessening protective separation distance)
- Speed is lowered (safety-rated), to keep minimum protective separation distance
- If minimum protective separation distance is violated, protective stop required safety-rated

Applications
- Simultaneous tasks
- Direct operator interface

Looks easy, right?
Power and Force Limiting

Physical contact between the **robot system** (including the workpiece) and an operator can occur either intentionally or unintentionally.

- **Robot systems** required to be specifically designed for power & force limiting if P&FL is relied upon for safety
- Forces that can be exerted are required to be limited
  - *robot, end-effector, workpiece*
- Robot system reacts when contact occurs
  - **Quasi-static** (pressure/clamping) or transient (dynamic)

Applications

- Small or highly variable applications
- Conditions requiring frequent operator presence
Collaborative Robot System Applications...

<table>
<thead>
<tr>
<th>Collaborative type</th>
<th>Benefit</th>
<th>High Risk Applications?</th>
<th>Low Risk Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety-rated monitored stop</td>
<td>Quicker resumption of operation (power retained)</td>
<td>Yes safeguarding required</td>
<td>Yes</td>
</tr>
<tr>
<td>Hand-guided</td>
<td>Personal control &amp; responsibility by operator; high variability of programs &amp; quick changes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Speed &amp; Separation Monitoring</td>
<td>Reduced space for application; Immediate resumption of higher speeds</td>
<td>Yes safeguarding required for intrusion/approach</td>
<td>Yes</td>
</tr>
<tr>
<td>Power &amp; Force Limiting (without protective devices)</td>
<td>Reduced space for application; if easy to program, then personal control by operator</td>
<td>Yes, but LOW speed (might be VERY SLOW)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Safety Resources For Collaborative?

• **ISO 10218-1 Robot & ISO 10218-2 Integration ISO/TS 15066 Collaborative operation**
  - Includes extensive details about speed & separation monitoring and power/force limited applications.
  - For Power / Force Limiting: annex with conservative values (threshold to pain) based on contact between a person and part of a robot system, where the body part ...

  **quasi-static contact**
  ... can be clamped between a moving part of the robot system & another fixed or moving part of the robot cell.

  **transient contact**
  ... is NOT clamped and can recoil or retract from the moving part of the robot system.

• **ISO 10218-1 & -2: revision start expected in 2017**
Onset of Pain Study

ISO TS 15066:2016 figure 3
Study by University of Mainz: 100 subjects, 29 body regions
ISO TS 15066: Onset of Pain Study

P&F Collaborative OK

Touch sensation

Pain sensation (pain onset)

Threshold for...

Minor injury

Reversible injury

Irreversible injury

Applied force or energy

Decrease exposure

Use guards and protective devices

Reduce risks

maybe Power/Force Limited Collaborative Operation

NO
Collaborative Risk Assessment

• Same process/methodology as “standard” (non-collaborative) application

Other presentations address Risk Assessment

• For PFL, also assess PFL conditions (TS, 4.2)
  – Intended and reasonably foreseeable contact(s) between portions of the robot system and a person
  – Contact type to be determined (transient or quasi-static) for each body part(s) affected
  – Frequency and duration of contact

Sounds complicated!
PFL Risk Assessment

• It is EASIER than it might seem.
  ❑ TS 15066 Annex A: avoid contact from the neck up.
    ❑ Paths and motions are below/ not towards head/ neck
    ❑ Typically eye protection would be needed
  ❑ Are there any interference points between the robot arm (robot manufacturer will inform) or between the robot arm and the end-effector or part?
    ❑ Limit the robot motion to eliminate any of the interferences. Requires safety-rated soft axis and space limiting *part 1, 5.12.3
  ❑ What is the smallest profile that a person could contact of the end-effector and part?
    ❑ Evaluate as this is the worst case.
  ❑ Validation can be done using hot dogs (instead of fingers)
  ❑ Providing “ease” is needed in the next revision.
**TS 15066: P&F Limiting Example**

Limits can be affected or modified by:

1. Eliminating pinch and crush points
2. Reducing robot system inertia or mass
3. Reducing robot system velocity, thereby reducing transfer energy
4. Modifying robot system posture such that contact surface area is increased
5. Spreading contact surface area/compliance

Avoid sensitive body areas using robot system motion control (*paths, direction, exclusion*)

*Insufficient* to say “do not bend over” or “keep away”

The APPLICATION is key!
Collaborative robotics is NEW!

- It is a paradigm shift where previously we separated the robot system from people.
  - Puts the robot system into the control of operators!
- Improvements in safety controls and added safety-related functions and features in robots (and robot systems).
  - Rather than safety features being mostly external from the machine, many safety features are NOW internal/ integral to the robot/system.
- Allows more interaction & sometimes contact between the robot system and people.
  - Low risk applications do not require “traditional safeguarding”.
- Requires risk assessment.
  - Do NOT presume that a robot can be used for collaborative operation – the application determines whether the robot system can be collaborative.
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Thank you!