Collaborative Robot Technical Specification ISO/TS 15066 Update

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International COLLABORATIVE ROBOTS WORKSHOP

Philosophical Background

- *"Why not have a human contact a robot **system** if the result is no harm to the human(s)?"*
  - Contact similar to touching a stopped robot?
  - When does repeated contact, that is initially without pain or injury, become painful and not acceptable?
    - Human factors, ergonomics…
  - Hence "collaborative operation"
- If the robot is wimpy (or called "safe") and application is juggling explosives or knives, is this is an acceptable collaborative application? **NO**

What is ISO/TS 15066?

- ISO/TS Technical Specification
  - A *normative document* representing *technical consensus* within an ISO committee
  - It is “more” than a technical report, expected to become a standard – but not quite ready to be a standard.
- Provides guidance currently not in ISO 10218-1 & -2
  - Collaborative operation consist of approximately eight pages out of 152 total pages.
  - ISO 10218-1 first introduced in 2006, revised in 2011.
  - Collaborative was originally anticipated to be a unique operating condition for “typical” industrial robots.

Now Available!

- ISO/TS 15066: Robots and robotic devices – Collaborative robots
  - Expands on collaborative guidance in ISO 10218-1 and ISO 10218-2: 2011
    - ANSI/ RIA R15.06:2012 is ISO 10218-1 & -2.
- What is learned from using TS 15066, and continued research will be rolled into the next revision of ISO 10218-1 and -2 (ANSI/RIA R15.06)

ISO & R15.06 “Words”

Shall	Normative or mandatory requirement
Should	Recommendation or good practice
May	Permissive or allowed
Can	Possible or capable – statement of fact

Notes are informative: provides information or explain concepts.

If you see a “shall,” “should” or “may” in a note – it is an error.

ANNEXES can be NORMATIVE or INFORMATIVE

All annexes can contain shalls/ shoulds/ mays and cans. If you CHOOSE to use an informative annex, you use all of it as written (no “cherry picking”)

Terminology

Robot – Robot arm & robot control *(does **NOT** include **end-effector or part**)*

Robot System – Robot, end-effector and workpiece +

Maximum space

- Space within which a robot system CAN move

Restricted space

- **Portion of the maximum space** restricted by limiting devices that establish limits which will not be exceeded

Operating space

- **Portion of the restricted space** that is actually used while performing all motions commanded by the task program

Safeguarded space

- space defined by the perimeter safeguarding

Operator(s) – **All personnel,** not simply production operators**.**

Includes maintenance, troubleshooting, setup, cleaning, production…

Spaces *from R15.06 and ISO 10218*

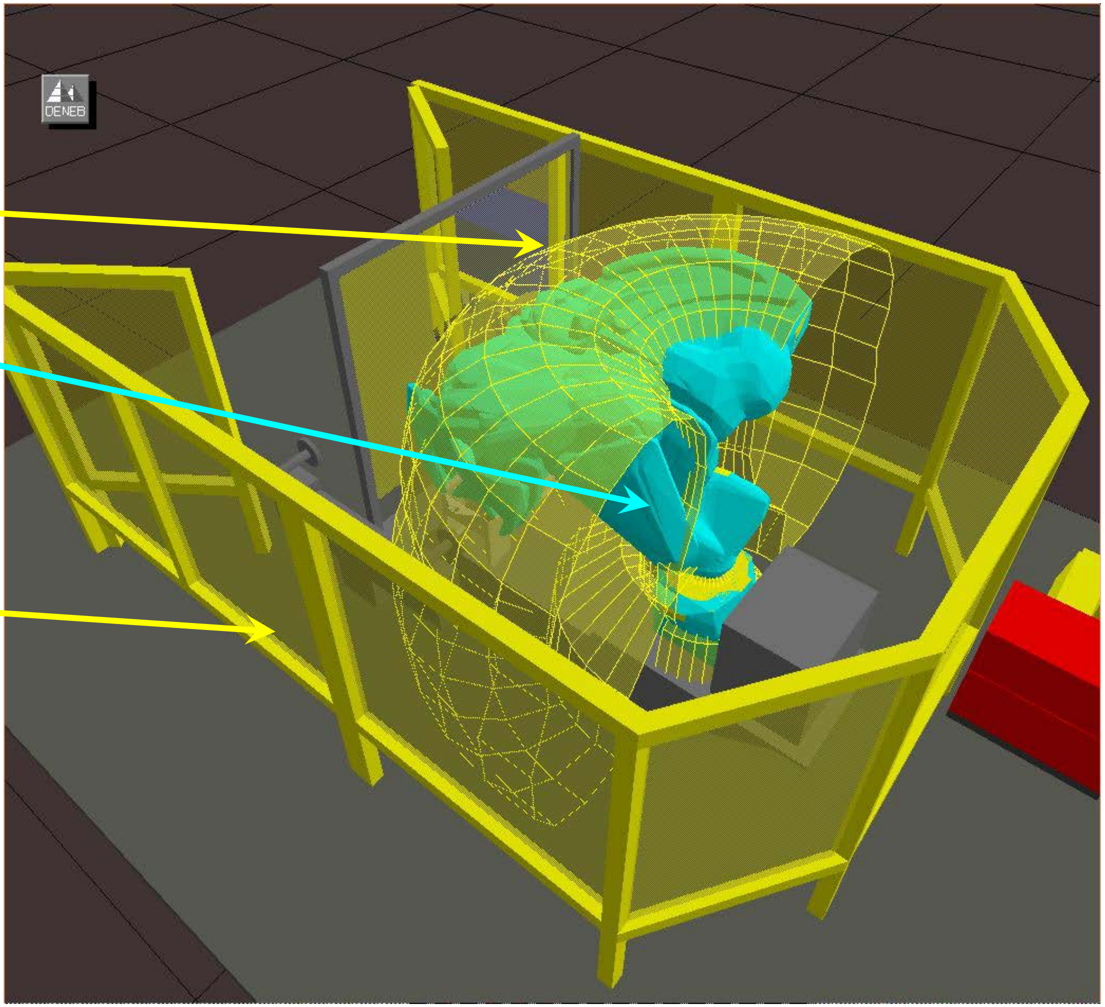
Restricted

Operating

programmed space

(not safety-rated)

Safeguarded

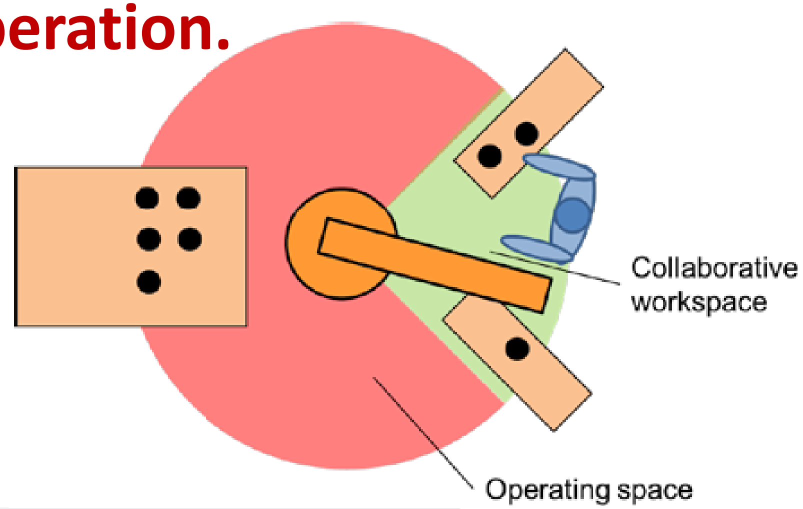


Terminology *from R15.06 and ISO 10218*

- A **collaborative robot** is a robot that **CAN** (capable) for use in a **collaborative operation**
  - **Collaborative operation (Part 1, 3.4)** – where purposely designed robots work in direct cooperation with a human within a defined workspace
    - Uncovered come inconsistencies to correct:
      robot vs robot system,
      collaborative vs co-located.

What is a Collaborative Workspace?

- **From TS 15066, 3.3**
  Modified from what is in R15.06 and ISO 10218
  - space within the **operating space** where the **robot system** (including the workpiece) **and a human can perform tasks concurrently** during **production operation.**



Collaborative Operation

Defined by

- The **TASK**:
  what the robot **SYSTEM** is doing

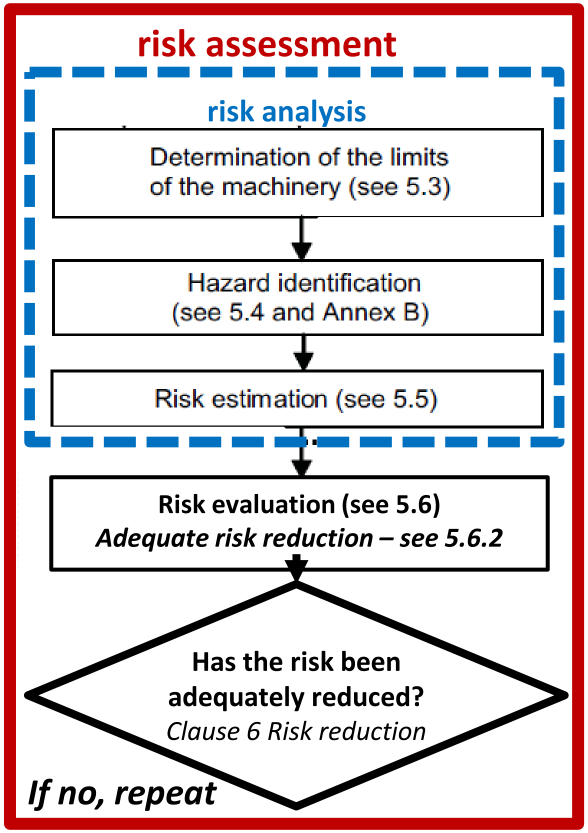
- The **SPACE** in which the task is being performed

NOT THE ROBOT ALONE

Collaborative Risk Assessment

- Same process/methodology as "standard" (non-collaborative) application
- Plus need to assess added conditions (TS, 4.2)
  - Intended and reasonably foreseeable contact(s) between portions of the robot system and an operator (human)
  - Contact type to be determined (transient or quasi-static) for each body part(s) affected
  - Frequency and duration of contact
  - …

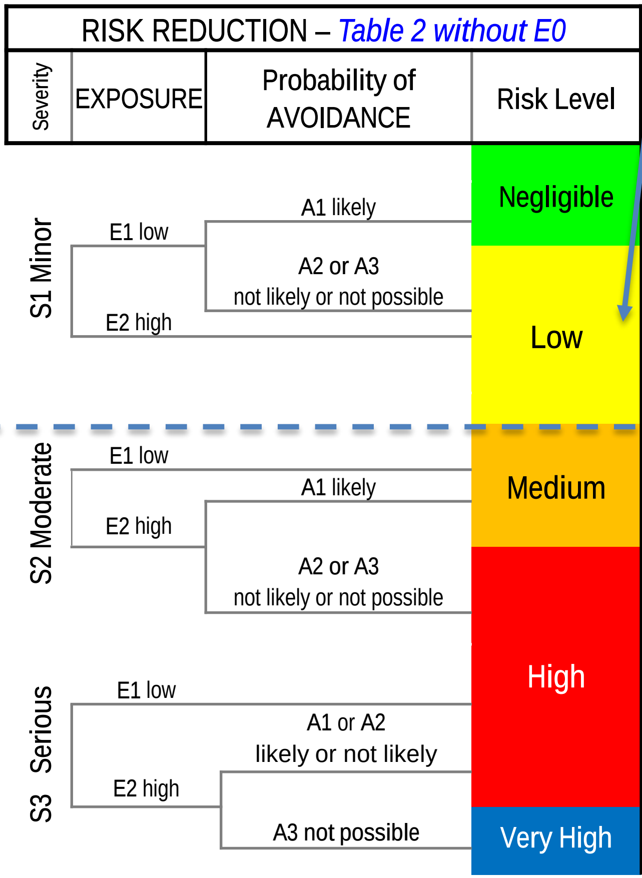
Risk Assessment



- Identify tasks and hazards with the goal of applying risk reduction measures
- Can address some non-production tasks resulting in minimal disruption
- Is an iterative process to determine that the risk reduction measures selected ACHIEVE their desired effect
- Avoids “one size fits all”, which can either be too restrictive or can require defeating safeguards in order to accomplish certain tasks

Table: ISO 12100, figure 1

Risk Assessment



Risk Reduction Measure	Risk Level: VERY HIGH / HIGH / MEDIUM	Risk Level: LOW / NEGLIGIBLE
Elimination Substitution Limit Interaction	Use of 1 or a combination of these risk reduction measures are required as a primary means to reduce risks.	**Use of one or a combination of any of the risk reduction measures that would reduce risks to an acceptable level may be used.**
Safeguarding/ SRP/CS		
Complementary Protective Measures	Use of one or a combination of these risk reduction measures may be used in conjunction with the above risk reduction measures but shall not be used as the primary risk reduction measure.	
Warnings and Awareness Means		
Administrative Controls		
PPE		

RIA TR R15.306, Table 2 without E0 & Table 4

Risk Reduction Measures

Most preferred →							*Least preferred*
Inherently Safe Design Measures			**Safeguarding & Complementary Protective Measures**		**Information for Use**		
Elimination	**Substitution**	**Limit Interaction**	**Safeguard**	**Comp Protective Measures**	**Warnings & Awareness Means**	**Administrative (organizational) Controls**	**PPE**
Process or layout design, redesign or modification	• Less hazardous materials • Intrinsically safe • Reduce energy • …	• Eliminate or reduce human interaction • Automate tasks • Modify layout or process flow • …	• Guards • Interlocks • Protective Devices • Safety controls, logic & functions • Safety parameters & configurations • …	• Fall prevention • Escape & rescue • Safe access • Safe handling • Energy isolation • Enabling devices • Estops …	• Lights, beacons and strobes • Audible alarms • Signs, labels or markings	• Training and SOPs • Inspections • Rotation of workers • Changing schedules • Control of Haz Energy • HazCom • Confined Space • Management	Clothing, footwear, glasses, respirators gloves & more for specific safety purposes

Typical…

“Traditional” Applications	Collaborative Applications
Inherently Safe Design Measures	
Process design, limiting access, layout	Process modifications, reduced energy, compliant (soft) materials
Safeguards and SRP/CS	
Fixed & interlocked guards	Safety-rated speed, position
Sensitive protective equipment	Safety-rated soft axis and space limits
Hard axis limits or safety-rated soft axis and space limits	Safety-rated torque sensing (impact)
Safety functions for protective devices and reducing risks	More…
Information for Use	
SAME or SIMILAR	

Searching for collaborative…

Google image search
April 16, 2016

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Collaborative Operation

- Four (4) techniques for collaborative operation (Part 1, 5.10; Part 2, 5.11) for collaborative applications (can be a mix of the following)
  while in AUTOMATIC mode:

- A collaborative application could use 1 or more of the following techniques.

Collaborative Operation

Safety-rated monitored stop

Hand-guiding operation

Speed & separation monitoring

Power & force limiting

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

Robot System Requirement

Robot <system> motion or stop function		Operator's proximity to collaborative workspace	
		Outside	Inside
Robot's <system> proximity to collaborative workspace	Outside	Continue	Continue
	Inside and moving	Continue	Protective stop
	Inside, at Safety-Rated Monitored Stop	Continue	Continue

ISO TS 15066:2016, table 1

Hand-Guiding **automatic, not teaching*

Operator uses a hand-operated device to transmit motion commands

- 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), activing motion/ operation
- Non-collaborative operation resumes when the operator leaves the collaborative workspace

Applications

- Robotic lift assist
- Highly variable applications (acts like a manually "tool")
- Limited or small-batch production

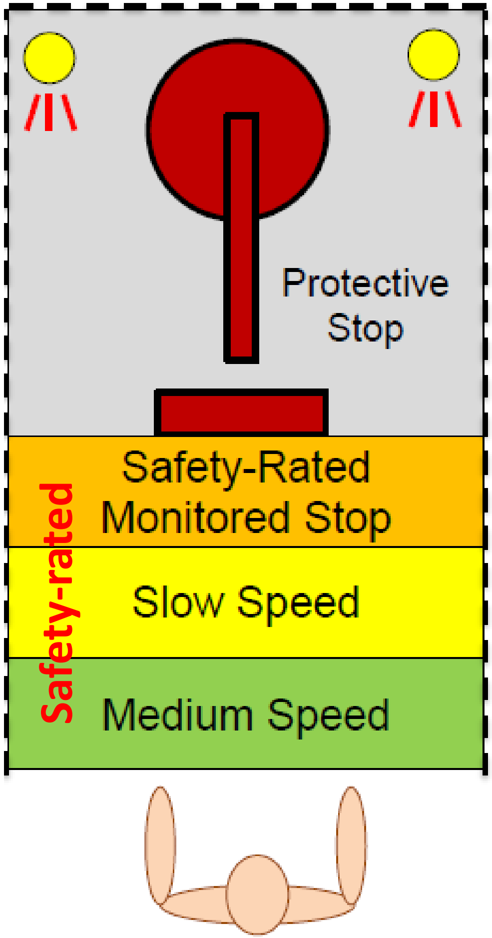
Speed & Separation Monitoring

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



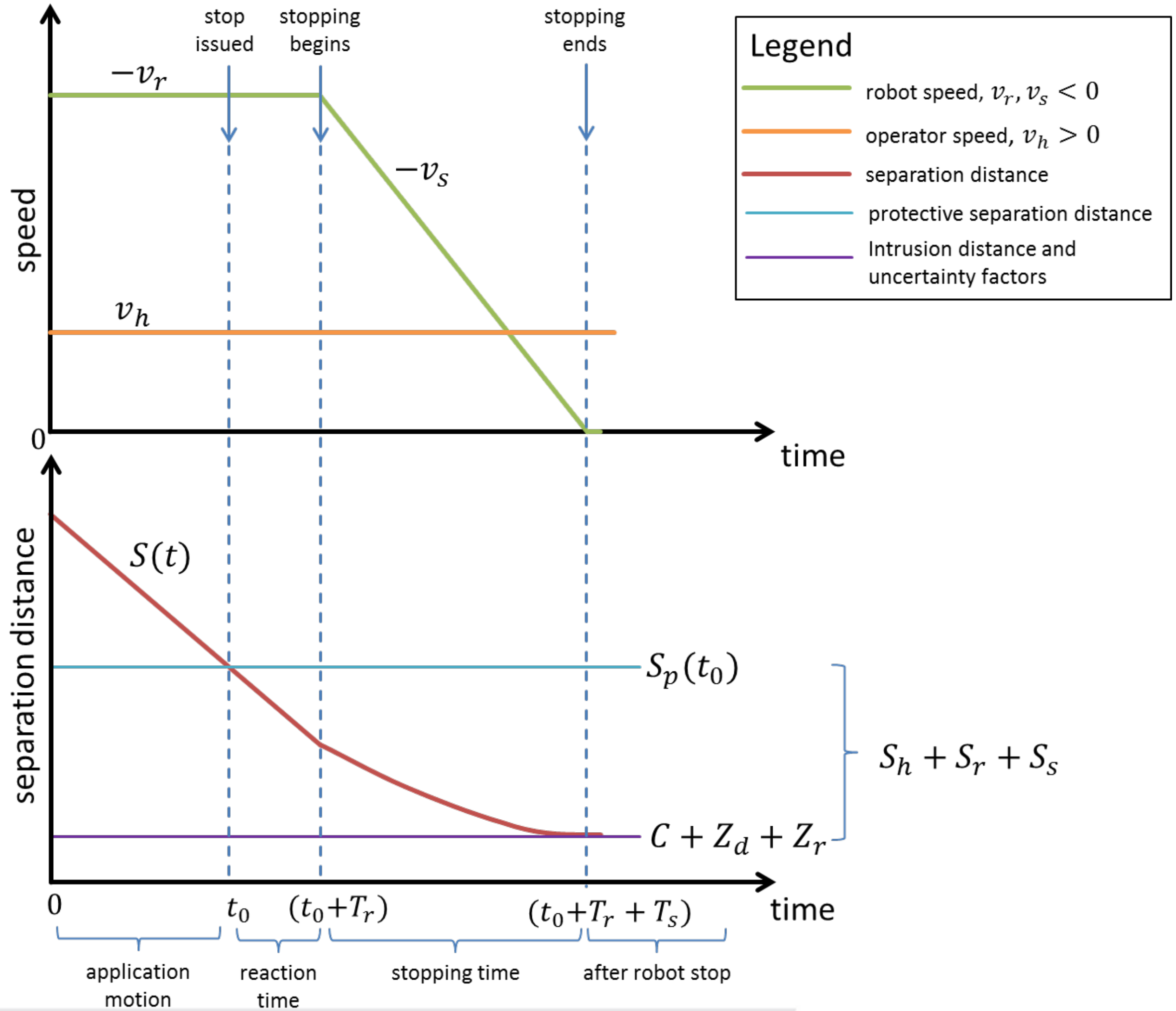
Looks easy, right?

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

$S_p(t_0)$	= **Protective separation distance**
S_h	= The operator’s change in location
S_r	= The robot’s change in location
S_s	= The robot’s stopping distance
C	= The intrusion distance that a part of the body can move toward the hazard zone prior to actuation of the safeguard
$Z_d + Z_r$	= Position uncertainty for both the robot and operator

ISO TS 15066:2016
NOTE: Robot system!

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$



ISO TS 15066:2016
Figure 2

Power and Force Limiting

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

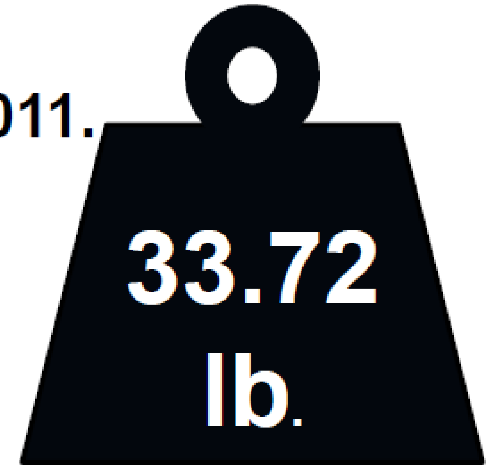
- Robot systems required to be specifically designed for power and force limiting
- Forces that can be exerted are required to be limited *robot, end-effector, workpiece*
- Robot system reacts when contact occurs
  - Contact could be quasi-static (pressure) or transient (dynamic)

Applications

- Small or highly variable applications
- Conditions requiring frequent operator presence

Power and Force Limits?

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



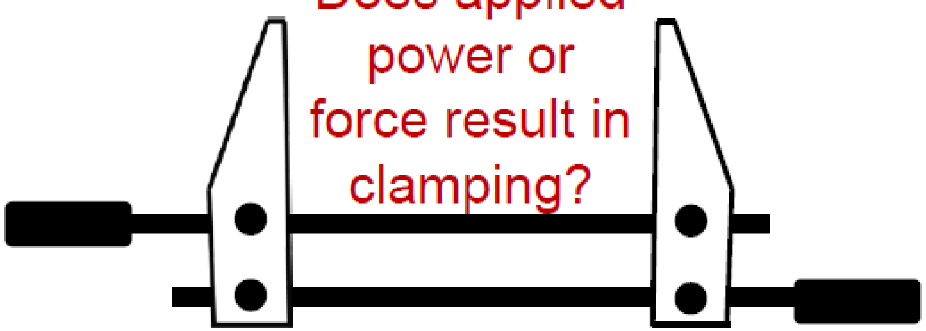
$$1\,W = 1\,N\frac{m}{s} = 1\frac{kg\,m^2}{s^3}$$

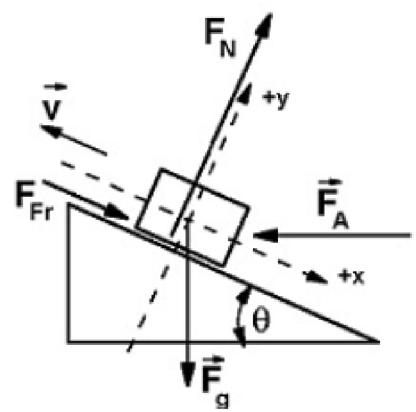
Watts applied to *mechanical power*, not *motor ratings*

$$F = ma$$

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

Does applied power or force result in clamping?





Power and Force Limiting

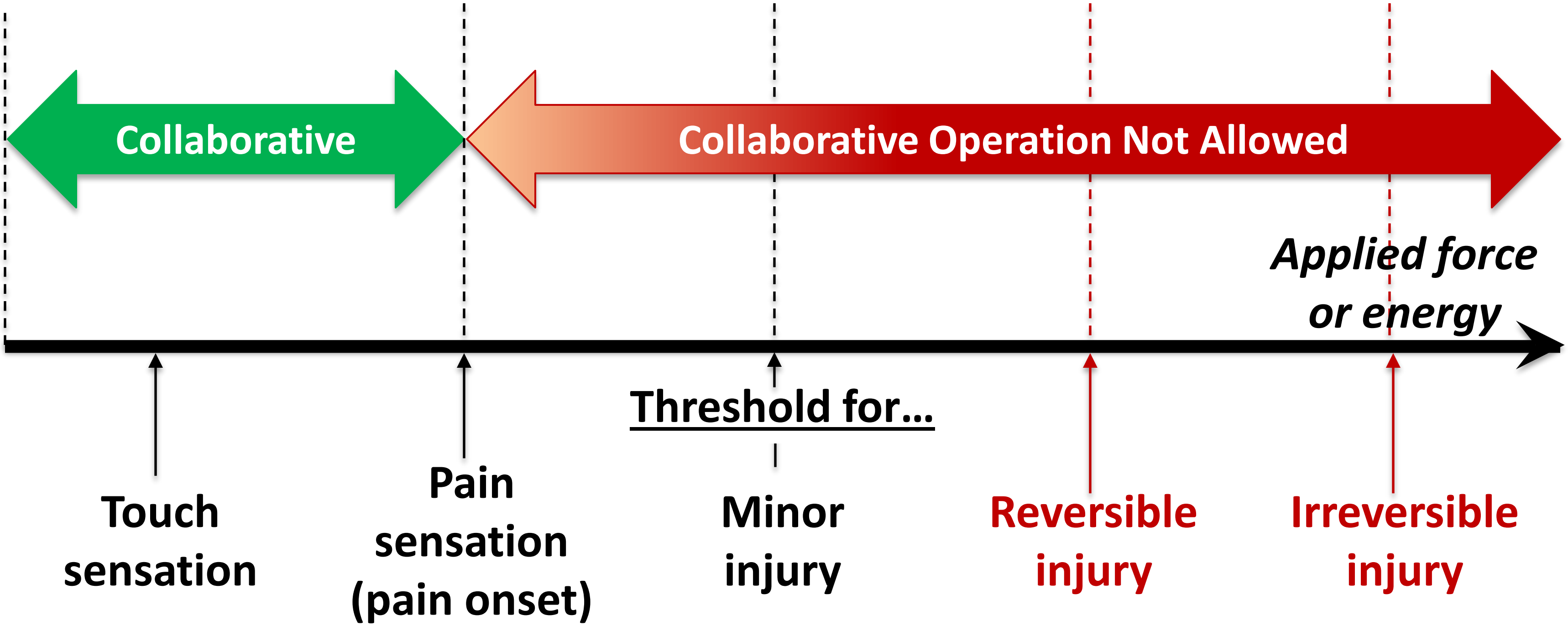
Risk reduction for potential contact, where there will be no harm to the operator:

- Identify conditions for such contact to occur
- Evaluate risk potential for such contacts
- Design robot system & collaborative workspace so contact is infrequent and avoidable
- Consider operator body regions, origin of contact event, probability or frequency, type (quasi-static or transient), forces, speeds…

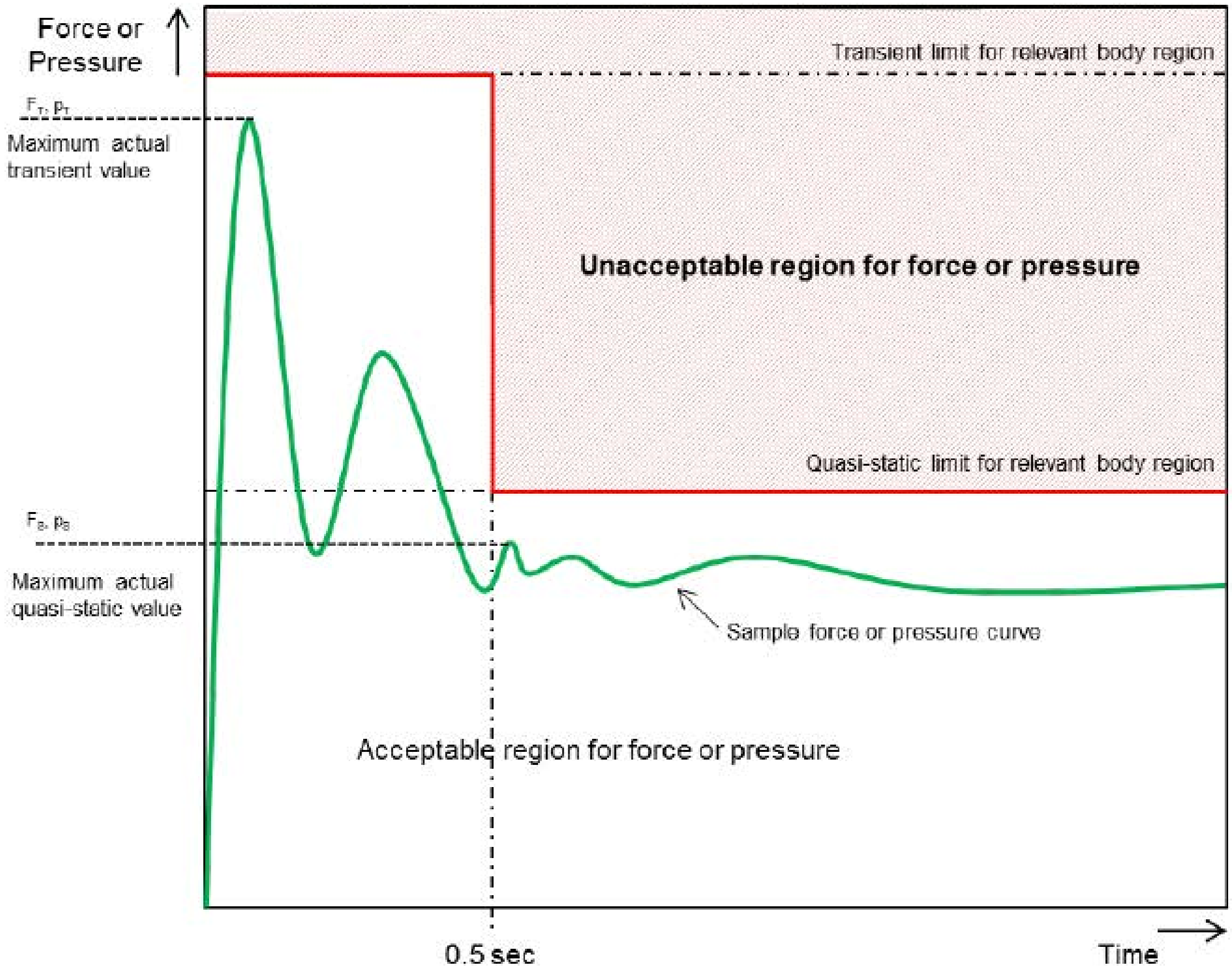
Contact to head, throat & neck to be prevented

ISO TS 15066:2016
Clause 5.5.4.3

TS 15066: Onset of Pain Study

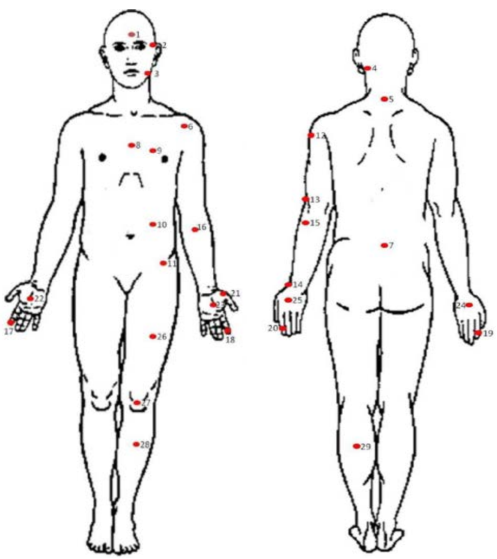


Onset of Pain Study



ISO TS 15066:2016 figure 3
Study by University of Mainz

Body Regions Tested



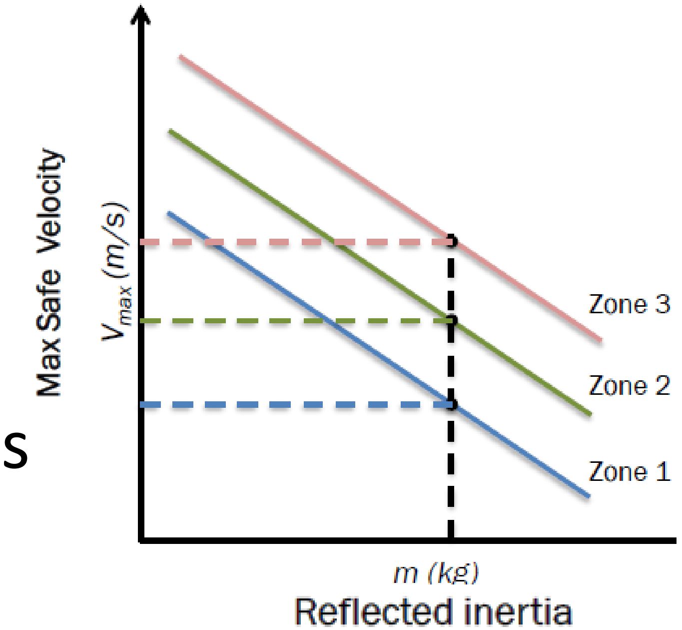
Body Region	Specific Body Area	
Skull and forehead	**1**	**Middle of forehead**
	2	**Temple**
Face	**3**	**Masticatory muscle**
Neck	4 to 5	*multiple*
Back and shoulders	6 to 7	*multiple*
Chest	8 to 9	*multiple*
Abdomen	10	Abdominal muscle
Pelvis	11	Pelvic bone
Upper arms & elbow joints	12 to 16	*multiple*
Lower arms and wrist joints	14 and 15	*multiple*
Hands and fingers	17 to 25	*multiple*
Thighs and knees	26 to 27	*multiple*
Lower legs	28 to 29	*multiple*

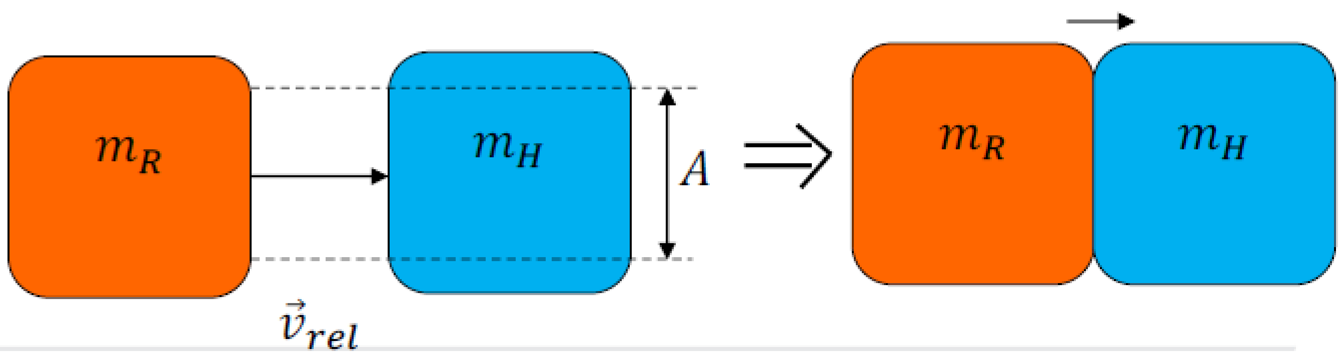
ISO TS 15066:2016, Figure A.1
Study by University of Mainz

Modeling Contact

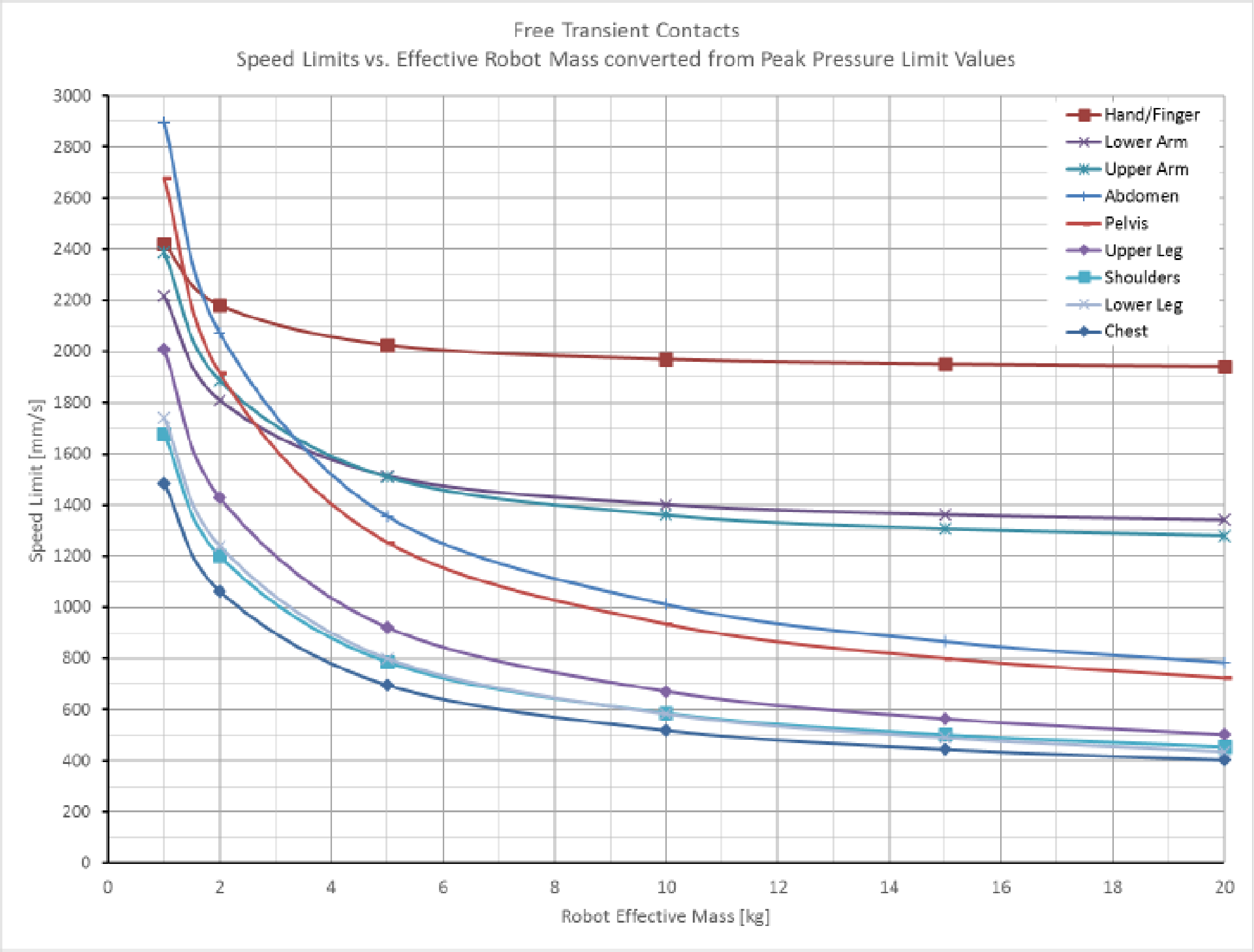
Research by Haddidin et. al. suggests that transfer energy between a robot & human can be affected by changes in velocity.

Transfer energy can be modeled as a perfectly inelastic collision.





Transient Contact Speed Limits



ISO TS 15066:2016
Figure A.4

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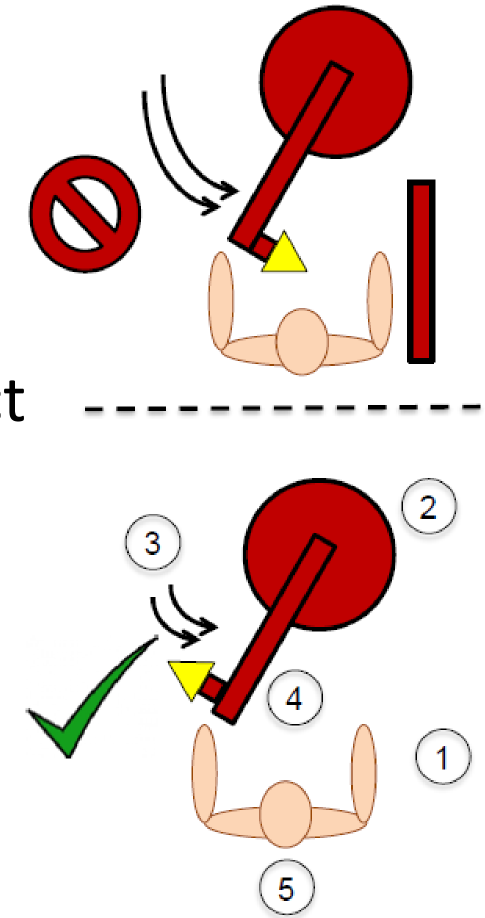
TS 15066: P&F Limiting example

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 posture such that contact surface area is increased
5. Avoid sensitive body areas (head & neck)
   – Insufficient to say "do not bend over" or "keep away"



The APPLICATION is key!

Summary

Collaborative robotics is NEW!

- It is a paradigm shift where previously we separated the robot system from people.
- Allows more interaction & sometimes contact between the robot system and people.
  - **Some** applications might not require "traditional safeguarding".

How did this happen?

- Improvements in safety controls and added safety-related functions and features in robots
- Requires risk assessment and very careful consideration.
- **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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