Industrial Robot Safety

Collaborative Robot Applications

Prepared For: manufacturing Safety Alliance of BC

Prepared By : ROBOT safety

October 2024

Disclaimer

- This brief session is intended to provide a high-level overview of the requirements outlined in the applicable industry standards included in the scope of this training course.
- It is incumbent on the participant to reference the current applicable legislation or industry standard for complete requirements.
- Photographs included in this course are for demonstrative purposes only.
- This training does not constitute legal advice, nor can Cobot Safety interpret the Standards. Questions pertaining to the interpretation of legislation or standards must be directed to the appropriate legal authority or organization.

Speaker Introduction

Dave Smith

Work History

Period	Company	Department	Role
1988 - 1991	**Honda of Canada Manufacturing (HCM)**	Weld – Plant 1	Production
1992 - 2001		Weld – Plant 1	Department Safety Specialist
2002 - 2003		Assembly – Plant 2	
2004 - 2020		Safety/Medical	Corporate Equipment and Construction Safety Specialist
2020 -	**Cobot Safety**	Owner, Lead Technical Trainer	

Speaker Introduction

Dave Smith

Professional Development		
Designation / Technical Committee	**Description**	**Since**
CRSP	Canadian Registered Safety Professional	1999
TUV FS Tech	Functional Safety Technician	2017
CSA Z434	Industrial Robot Safety	2000
ISO/ TC299	Robotics and Robotic Devices	2001
CSA Z460	Lockout - Other Methods	2002
CSA Z432	Safeguarding of Machinery	2003
ISO / TC199	Machinery Safety	2005

Agenda

Module		Topics
1	Safety Standards	▪ Industrial Robot Safety Standard (CSA Z434-14) ▪ ISO TS 15066 – Collaborative Robots ▪ Debunking the myth on “Cobots”
2	Collaborative Applications	▪ Introduction to Collaborative Applications ▪ The 4 Methods of Collaborative Operation ▪ Design requirements for Collaborative Applications ▪ Body Model from ISO TS 15066 and Permissible Force Limits by Exposed Body Part ▪ Risk Reduction Measures Intro

Safety Standards

MODULE 1

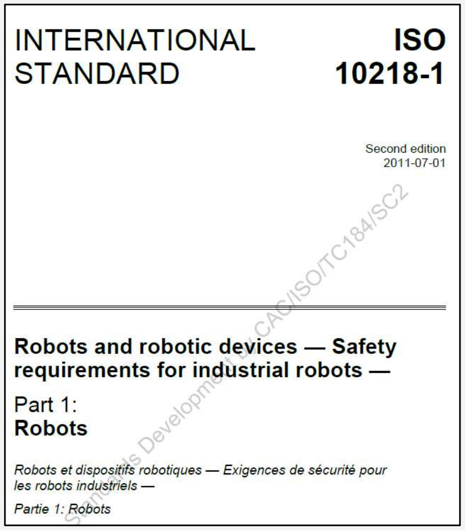
INDUSTRIAL ROBOT STANDARDS

A BRIEF HISTORY

INDUSTRIAL ROBOT STANDARDS

(CURRENT SITUATION)

International
(2011)


INTERNATIONAL STANDARD

ISO 10218-1

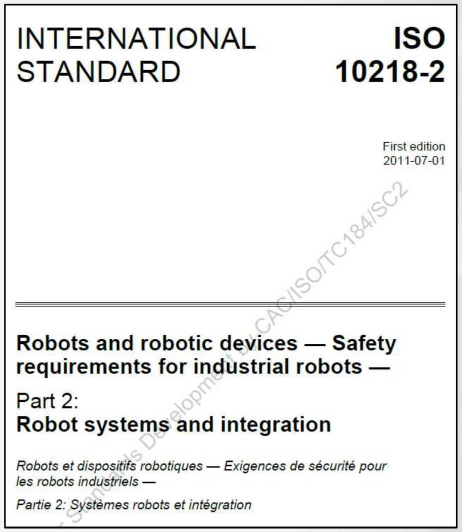
Second edition
2011-07-01

Robots and robotic devices — Safety requirements for industrial robots —

Part 1:
Robots

Robots et dispositifs robotiques — Exigences de sécurité pour les robots industriels —

Partie 1: Robots


INTERNATIONAL STANDARD

ISO 10218-2

First edition
2011-07-01

Robots and robotic devices — Safety requirements for industrial robots —

Part 2:
Robot systems and integration

Robots et dispositifs robotiques — Exigences de sécurité pour les robots industriels —

Partie 2: Systèmes robots et intégration

National
(2012)

ISO Standards
- never speak to the manufacturer and integrator in the same document
- do not include user requirements

RIA / ANSI Standards
- can speak to all stakeholders in one document
- R15.06 combines ISO 10218 Parts 1 and 2 and includes user requirements

INDUSTRIAL ROBOT TECHNICAL SPECIFICATION (ISO/TS 15066)

- development began immediately after ISO 10218 Parts 1 & 2 were published in 2011
- goal was to provide more guidance on collaborative applications
- ISO / TS 15066 published in 2016
- the requirements are being incorporated into the next version of ISO 10218 (2024 – target date)

TECHNICAL SPECIFICATION

ISO/TS 15066

First edition
2016-02-15

Robots and robotic devices — Collaborative robots

INDUSTRIAL ROBOT STANDARDS

(PATH FORWARD)

ISO 10218-1
Manufacturer
2011

ISO 10218-2
Integrator
2011

ISO / TS 15066
Collaborative Robots
2015

ISO / TR 20218-1
End Effectors
2018

ISO / TR 20218-2
Manual Load Stations
2017

ISO 10218-1
Manufacturer
2024

ISO 10218-2
Integrator
2024

ANSI / RIA R15.06-2025
Robotics Industries Association

CSA Z434-2025
Canadian Standards Association

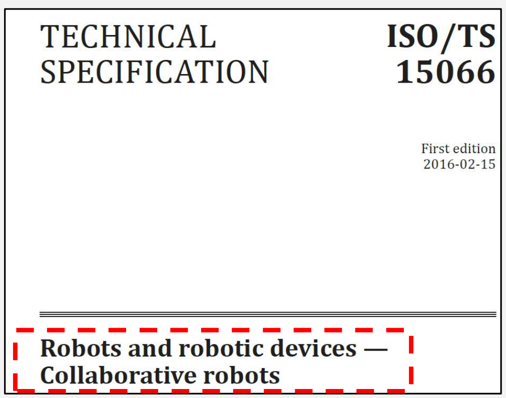
Canada and the USA are currently working on harmonized user requirements for North America

Debunking The Myth

Is there any such thing as a Collaborative Robot or “Cobot”?

“Collaborative Robot”

Robot designed for direct interaction with a human within a defined collaborative workspace


TECHNICAL SPECIFICATION

ISO/TS 15066

First edition
2016-02-15

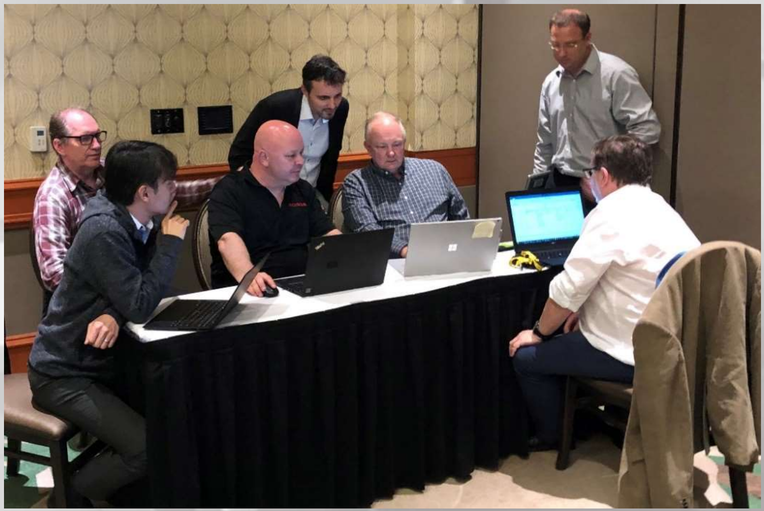
Robots and robotic devices — Collaborative robots

Are both of these robots designed for direct human interaction ?

Debunking The Myth

Conclusion:

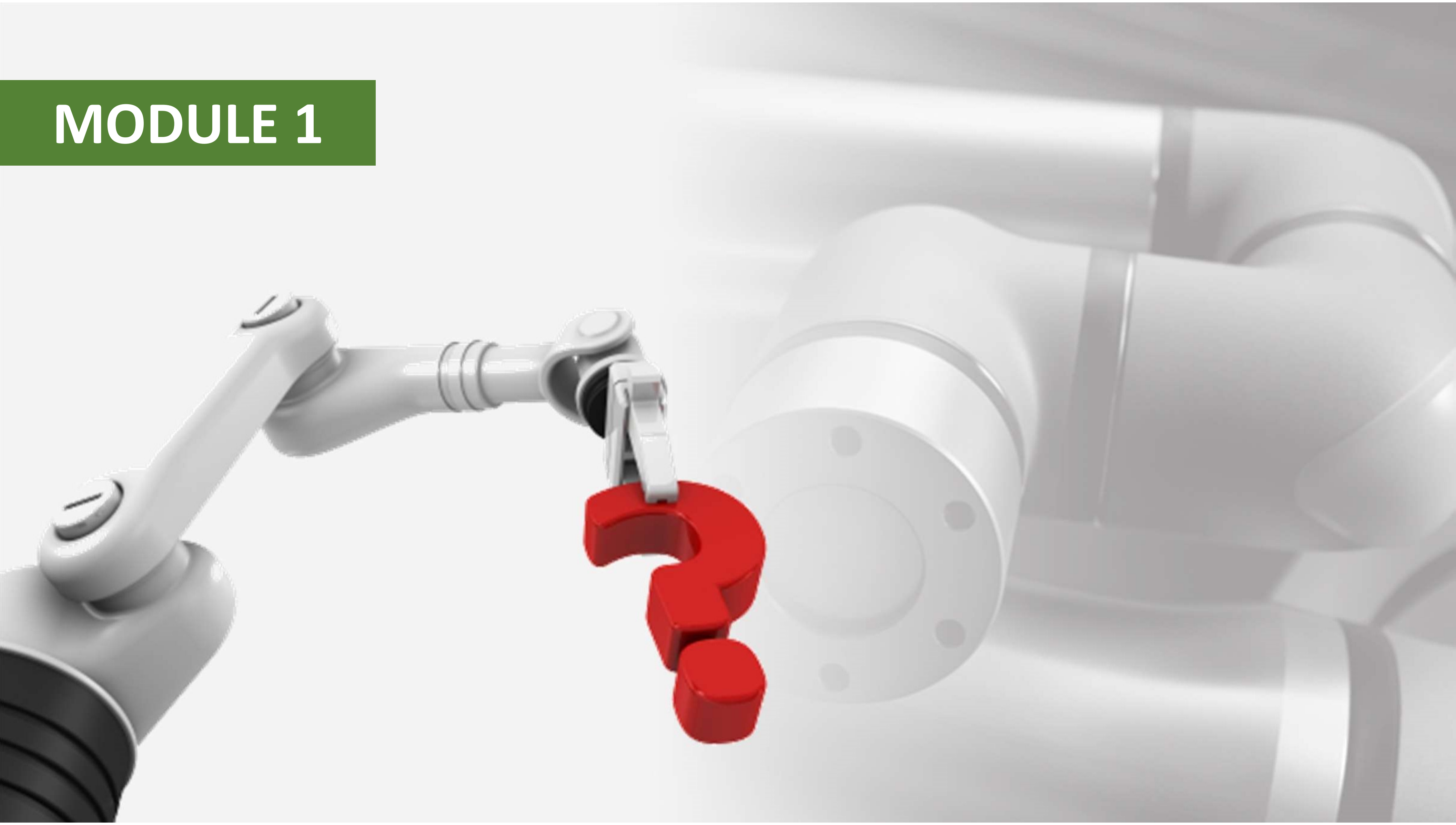
- It is simply a type of industrial robot
- The application is critical, not the robot
- The term "collaborative robot" has been deleted in the next edition (2025)



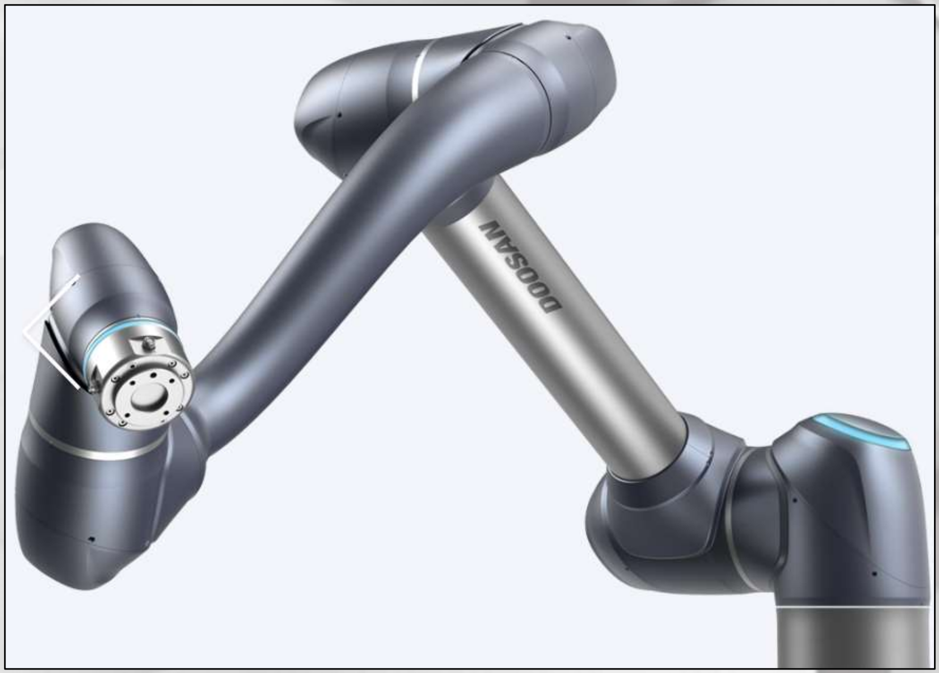
Cobot Safety's Definition of **"Collaborative Robot":**

"An industrial robot with safety features that make it suitable for integration into a collaborative application"

MODULE 1



MODULE 2 Collaborative Applications



Collaborative Application Requirements

Robotic automation designed to work safely alongside human workers in a shared, collaborative workspace

- Used for pre-determined tasks
- Possible when all protective devices are active
- Robots are specifically designed for a collaborative application (meet Part 1 requirements), e.g., smooth and round joints, padded framework, etc.
- Visual indication when the robot is in collaborative mode

Collaborative Robot Applications

	**Hand Guiding** Clause 5.14.4	▪ Hand guiding allows a robot to move through direct input from an operator. ▪ The robot stays in a safety monitored stop until an operator actuates the hand guiding device through an enabling switch.
	**Speed and Separation Monitoring** Clause 5.14.5	▪ The robot is able to move concurrently with the operator as long as they maintain a pre-determined distance apart. Often a safety-rated laser area scanner monitors this application.

Collaborative Robot Applications

	**Power and Force Limiting** Clause 5.14.6	Limitations on power and force require a special robot that has power or force feedback built in. This system lets the robot detect contact with a person.
	**Safety-rated Monitored Stop**	Safety monitored stop pauses a robot's motion while an operator is in the collaborative workspace. The robot maintains power but cannot move.

Collaborative Application Considerations and Requirements

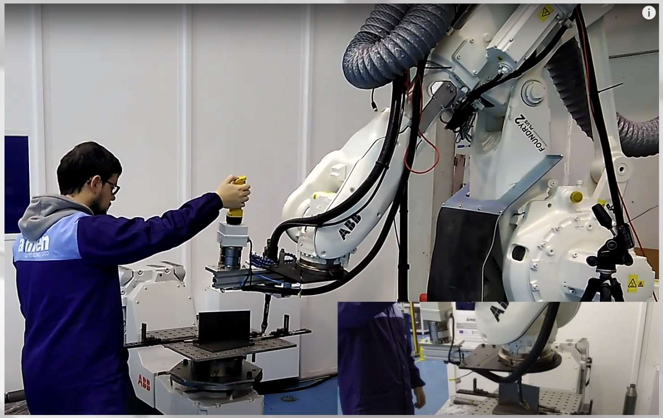
- Physical contact can occur during operation
- Protective measures shall be provided, based on a risk assessment.
- The **risk assessment shall consider** the workspace and all tasks required to be performed within it.

Collaborative Application Requirements

- The collaborative workspace is clearly defined, e.g., floor markings
- Operators are safeguarded by protective devices and robot design (Part 1 requirements are met)
- Safety-rated soft axes and space limiting should be used to reduce the range of motion
- Robot system is installed with **20” clearance** from operating space or other protective measures to stop robot motion
- The change between autonomous and collaborative operations shall not endanger the operator, e.g., install a push button to resume autonomous operation

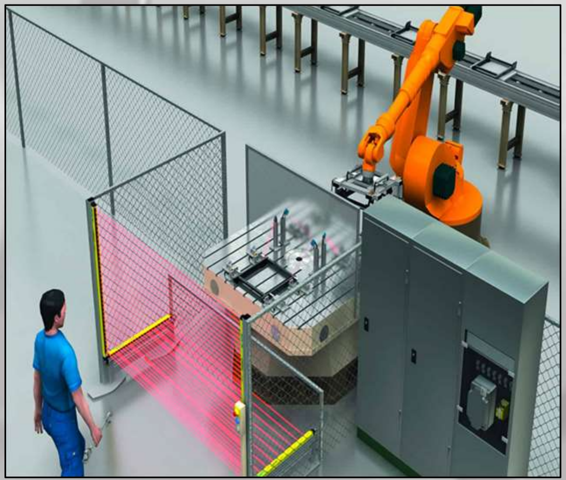
Hand Guiding

- Operator transmits motion commands to the robot via a hand guiding device (**not** lead through teaching)
- Guiding device must be located as close to the end effector
- Must include emergency stop and enabling device capabilities
- Does not apply to power and force limiting robot operation
- Speed must be safety rated and monitored



Safety-Rated Monitored Stop

- Collaborative workspace to be established using ISO 13855 – *Positioning of safeguards with respect to the approach speeds of parts of the human body*
- The robot can operate non-collaboratively if there is no operator in the collaborative workspace
- The operator may enter when the robot system motion has stopped and the safety-rated monitored-standstill is active
- The robot system motion can continue when the operator has exited the collaborative workspace



Safety-rated Monitored Stop
Truth Table

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

Collaborative workspace to be established using ISO 13855:2010, *"Positioning of safeguards with respect to the approach speeds of parts of the human body"*

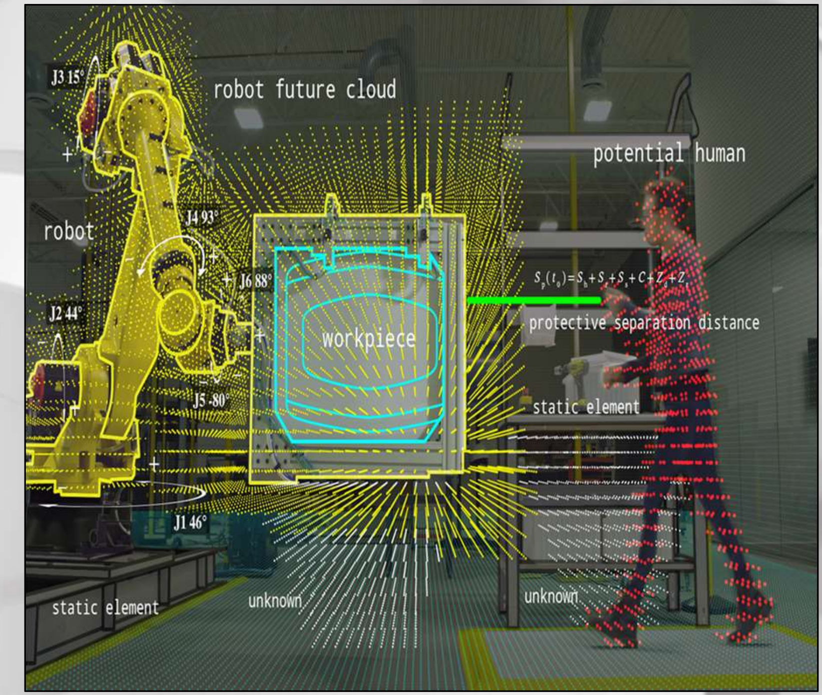
Speed & Separation Monitoring

- The operator and robot system may move at the same time in the collaborative workspace
- Risk reduction is achieved by maintaining the protective separation distance between the operator(s) and the robot at all times
- Can be used with any robot
- Benefits include fewer limitations on end effector design as well as robot speed and payload, closer, more flexible collaboration than safety-rated monitored stop

Speed & Separation Monitoring

- Speed and separation monitoring relies on knowing where people and robots are in the collaborative workspace
- Continuous monitoring of the workspace is required
- The protective separation distance must always be maintained based on the following formula

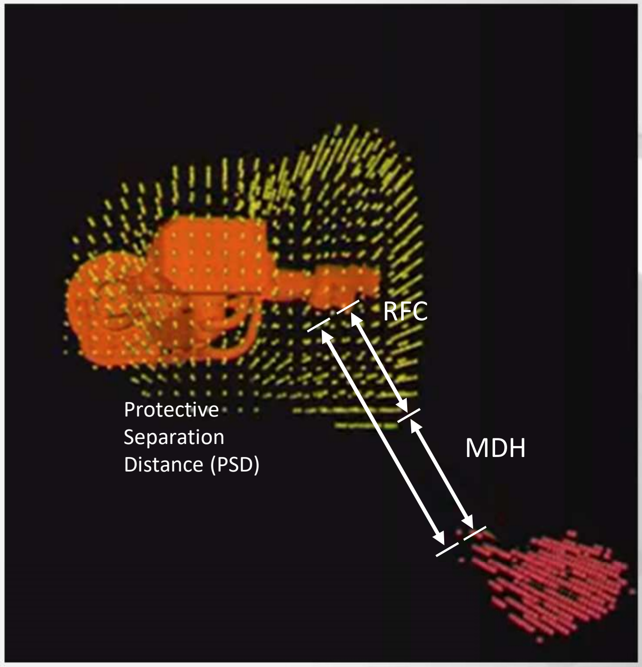
$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$



Speed & Separation Monitoring

Key Considerations

- Robot stopping time
- Robot stopping distance
- Robot performance
- Reducing the PSD allows for closer collaboration



MDH = *minimum distance to the hazard*

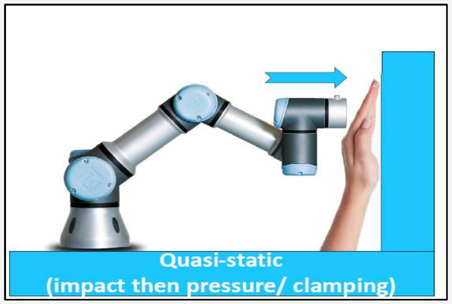
Power & Force Limiting

- Physical contact between the robot and operator can occur
- Contact may be intended or unintended
- Contact situations can be :
  - Quasi-static (pinching or clamping)
  - Transient (dynamic)
- Contact can occur due to:
  - Intended contact situations
  - Unintended contact caused by operator
  - Unintended contact due to a technical failure

Power & Force Limiting

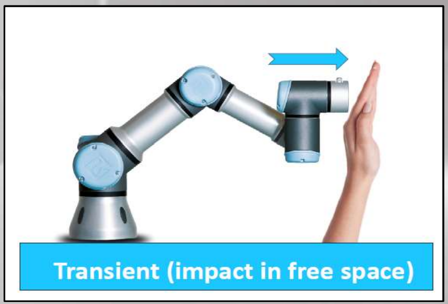
QUASI-STATIC CONTACT

- Clamping or crushing of a body part
- Pressure or force is exerted on the trapped body part for a longer period



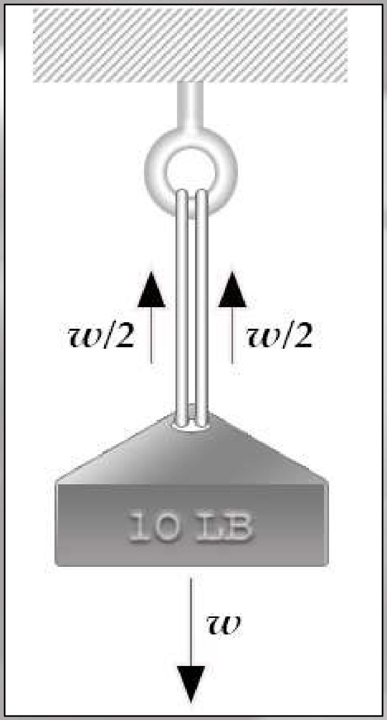
TRANSIENT CONTACT

- Also referred to as "dynamic impact"
- Body can recoil or retract and avoid being pinched or crushed
- Pressure or force is exerted on the trapped body part for a shorter period



Power & Force Limiting

- A table was created in ISO TS 15066 to assist in determining the maximum force values that are permitted in a collaborative application
- Conducted in Germany at the University of Mainz the values are based on pain thresholds, not the onset of injury
- The results are based on a single study
- Testing was conducted on 100 healthy adult subjects (small sample size)
- Transient contact derived by multiplying quasi-static values by 2



CONTACT FORCE: HOW MUCH IS TOO MUCH ?

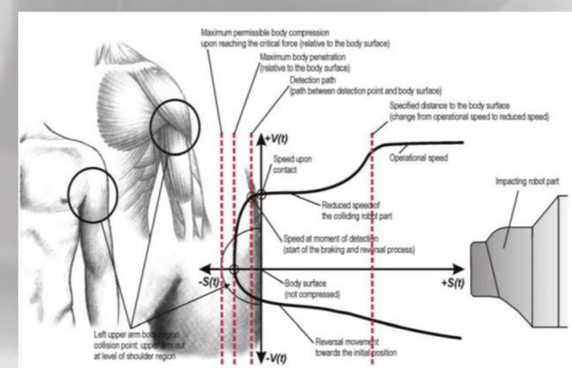
Power & Force Limiting

Table A1, ISO/TS 15066

Table A.1 — Body model descriptions

Body region		Specific body area	Front/Rear
Skull and forehead	1	Middle of forehead	Front
	2	Temple	Front
Face	3	Masticatory muscle	Front
Neck	4	Neck muscle	Rear
	5	Seventh neck vertebra	Rear
Back and shoulders	6	Shoulder joint	Front
	7	Fifth lumbar vertebra	Rear
Chest	8	Sternum	Front
	9	Pectoral muscle	Front
Abdomen	10	Abdominal muscle	Front
Pelvis	11	Pelvic bone	Front
Upper arms and elbow joints	12	Deltoid muscle	Rear
	13	Humerus	Rear
Lower arms and wrist joints	14	Radial bone	Rear
	15	Forearm muscle	Rear
	16	Arm nerve	Front
Hands and fingers	17	Forefinger pad D [a]	Front
	18	Forefinger pad ND [a]	Front
	19	Forefinger end joint D [a]	Rear
	20	Forefinger end joint ND [a]	Rear
	21	Thenar eminence	Front
	22	Palm D [a]	Front
	23	Palm ND [a]	Front
	24	Back of the hand D [a]	Rear
	25	Back of the hand ND [a]	Rear

Body regions are broken down further into specific body areas



Power & Force Limiting

Table A.2 — Biomechanical limits

Body region	Specific body area		Quasi-static contact		Transient contact	
			Maximum permissible pressure [a] p_s N/cm²	Maximum permissible force [b] N	Maximum permissible pressure multiplier [c] P_T	Maximum permissible force multiplier [c] F_T
Skull and forehead [d]	*1*	*Middle of forehead*	*130*	*130*	*not applicable*	*not applicable*
	2	*Temple*	*110*		*not applicable*	
Face [d]	*3*	*Masticatory muscle*	*110*	*65*	*not applicable*	*not applicable*
Neck	4	Neck muscle	140	150	2	2
	5	Seventh neck muscle	210		2	
Back and shoulders	6	Shoulder joint	160	210	2	2
	7	Fifth lumbar vertebra	210		2	2
Chest	8	Sternum	120	140	2	2
	9	Pectoral muscle	170		2	
Abdomen	10	Abdominal muscle	140	110	2	2
Pelvis	11	Pelvic bone	210	180	2	2
Upper arms and elbow joints	12	Deltoid muscle	190	150	2	2
	13	Humerus	220		2	
Lower arms and wrist joints	14	Radial bone	190	160	2	2
	15	Forearm muscle	180		2	
	16	Arm nerve	180		2	

Clause 5.5.5.3 states:

"Contact exposure to sensitive body regions, including the ***skull, forehead, larynx, eyes, ears or face*** *SHALL be prevented whenever reasonably practicable"*

This is why there is no such thing as collaborative speed. Limits are based solely on biomechanical force applied to the affected body part, not a specified speed limitation

Introduction

Universal Robots e-Series robots are equipped with a range of built-in safety functions as well as safety I/O, digital and analog control signals to or from the electrical interface, to connect to other machines and additional protective devices. Each safety function and I/O is constructed according to EN ISO13849-1:2008 (see chapter 8 for certifications) with Performance Level d (PLd) using a category 3 architecture.

All UR Safety Functions are PL=d Category 3

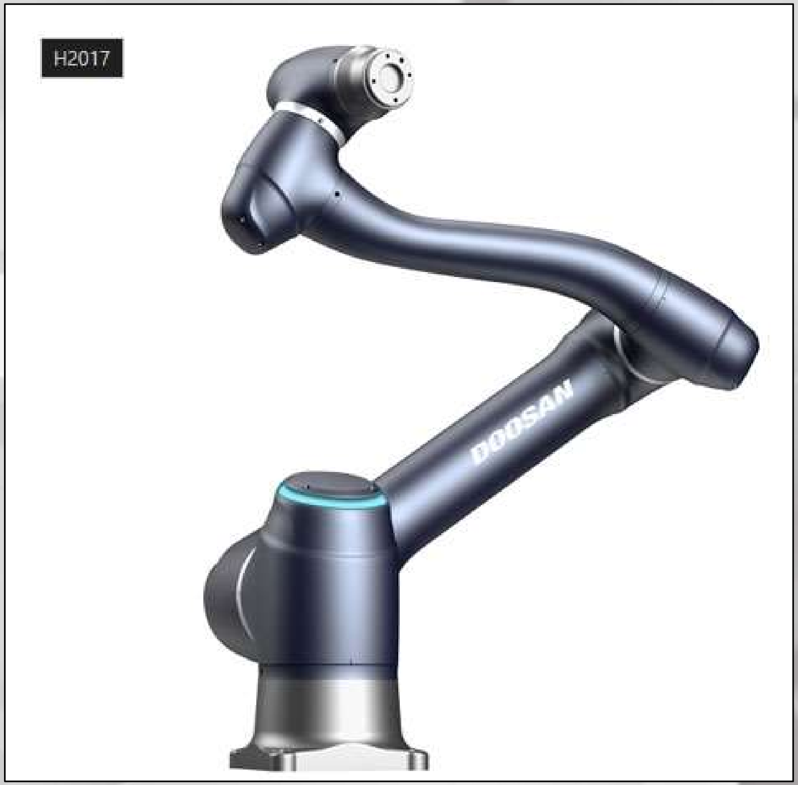
- Robot selection is absolutely ***critical*** in PFL applications
- Not all robot … ake them suitable for i … including those marke …
- Compliance … hen purchasing a … poration

Safety Function	Tolerance	Performance Level	Category
Emergency Stop	–	d	3
Safeguard Stop	–	d	3
Joint Position Limit	5 °	d	3
Joint Speed Limit	1.15 °/s	d	3
Safety Planes	40 mm	d	3
Tool Orientation	3 °	d	3
Speed Limit	50 mm/s	d	3
Force Limit	25 N	d	3
Momentum Limit	3 kg m/s	d	3
Power Limit	10 W	d	3
Stopping Time Limit	50 ms	d	3
Stopping Distance Limit	40 mm	d	3
Safe Home	1.7 °	d	3

Power & Force Limiting

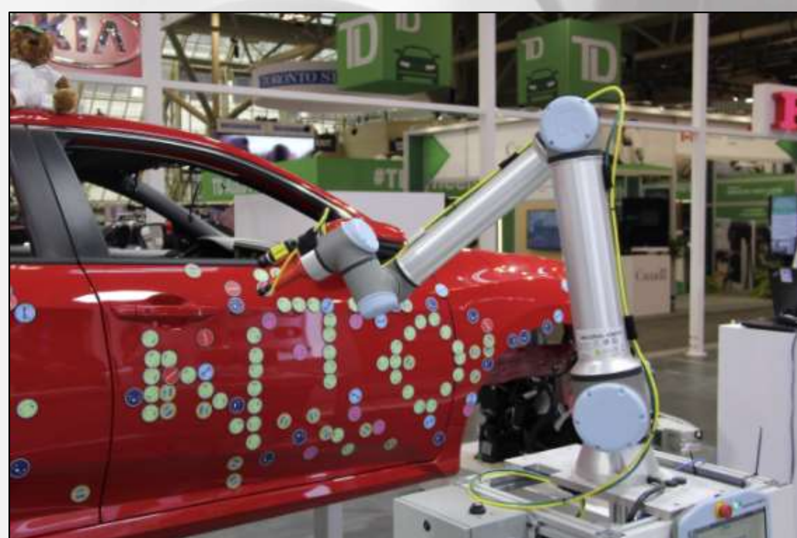
- The Doosan H2017 is compliant with the requirements in ISO 10218-1
  (as per manufacturer's declaration)

- Key safety requirements include collision sensitivity based on 6 torque sensors and a gravity compensation algorithm
- All safety features (e.g., speed and force monitoring) are Pld Cat3.



Power & Force Limiting

2020 International Auto Show – Honda
This interactive display enabled small children to place magnetic stickers directly onto the end effector



MODULE 2

REFERENCE MATERIALS

Provided by :

Universal Robots

Veo Robotics

Inxpect

Fanuc Robotics

BIBLIOGRAPHY

Reference documents :

ISO/TS15066-2016 *Robots and robotic devices – Collaborative robots*

ISO *10218-1 Robots and robotic devices – Safety requirements for industrial robots Part 1 : Robots*

ISO *10218-2 Robots and robotic devices – Safety requirements for industrial robots Part 2 : Robot Systems and Integration*

ISO 13849-1:2006 *Safety of Machinery – Safety related parts of the control systems – Part 1 : General principles for design*

ISO 13850 *Safety of Machinery – Emergency Stop – Principles for design*

ISO 13855 *Safety of Machinery – Positioning of safeguards with respect to the approach speeds of parts of the human body*

ISO 13857 *Safety of Machinery – Safety distances to prevent hazard zones being reached by the upper and lower limbs*