# Verification and Validation with Power and Force Limited Robots

YASKAWA

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# What is Verification and Validation?



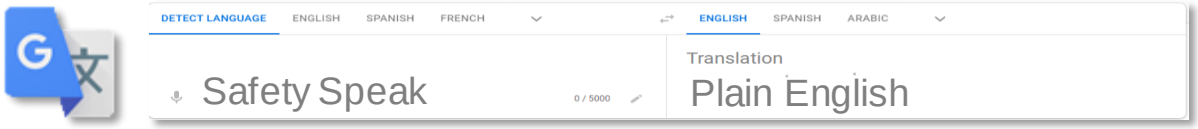
**From ISO 10218-2 2011 or ANSI/RIA 15.06 2012**

**3.15**
**Verification**
Confirmation by examination and provision of objective evidence that requirements have been fulfilled

**3.14**
**Validation**
Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled

Clear as mud

# What is Verification and Validation ?




**Verification is asking the question:**

Did we build the _ _ _ _ _ right?

- In this case the _ _ _ _ _? = Safety System

**Validation is asking the question:**

Did we build the right S**afety System**?

# Are We Required to Do Verification and Validation?

In Short…**Yes**!

- **From ISO 10218-2 2011 or ANSI/RIA 15.06 2012**
  - 6 Verification and validation of safety requirements and protective measures
    - 6.1 General

      The robot system manufacturer or integrator **shall** provide for the verification and validation of design and construction of robot systems including appropriate safeguarding devices

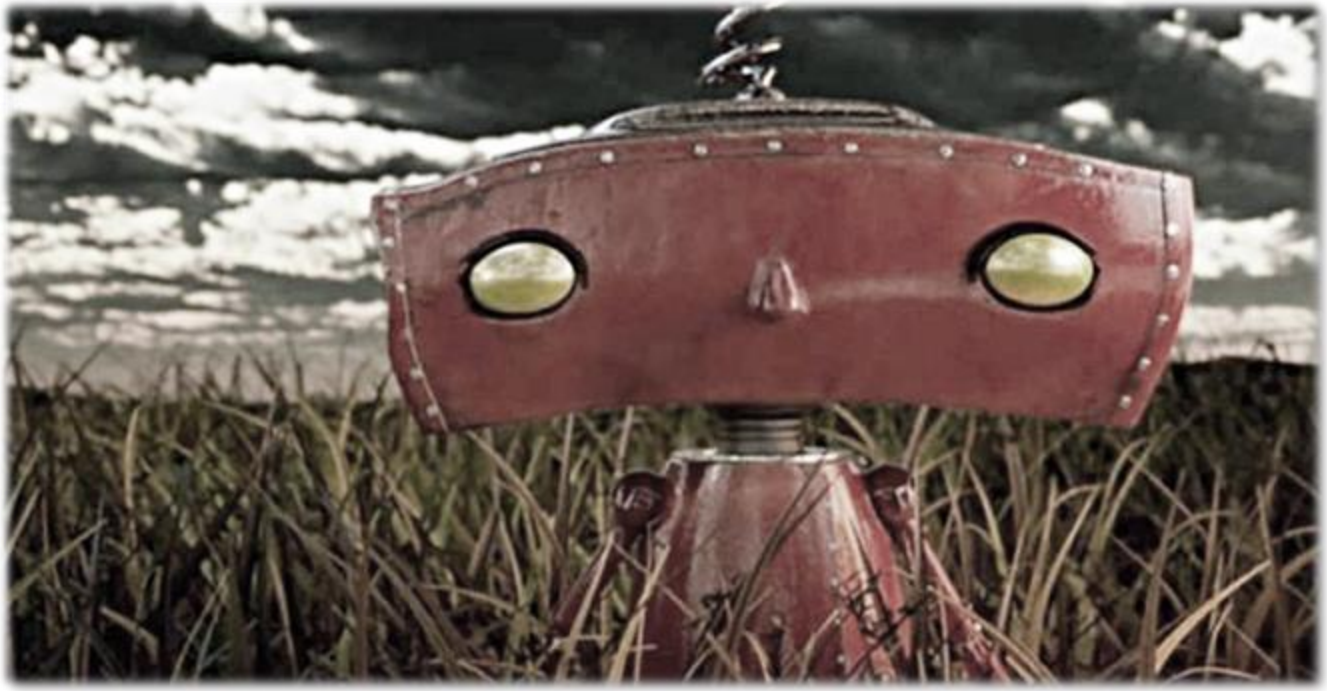
- **ISO TS15066 2016 & RIA TR R15.606-2016**

  For Industrial Robots and Robot Systems Safety Requirements - Collaborative Robots
  - **Verification and validation**

    See ISO 10218-2:2011, Clause 6, for verification and validation requirements.

# Let's Get Into the Weeds for a Moment

Touch on TS15066, PFL, and Risk Assessments as it relates to Verification and Validation.

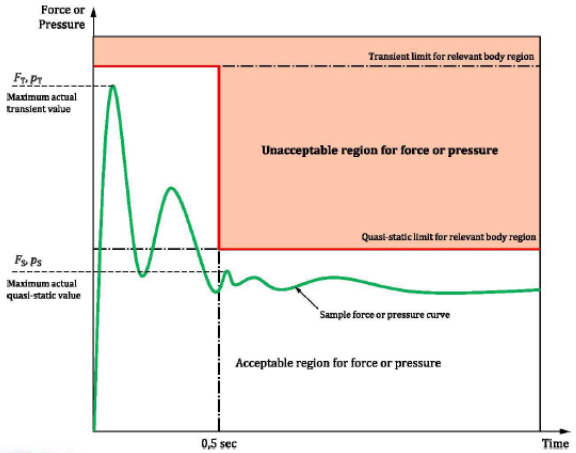


# ISO TS15066 2016 & RIA TR R15.606-2016

**Important concepts:**

## Transient Contact

- Contact between an operator and part of a robot system, where the operator body part is not clamped and can recoil or retract from the moving part of the robot system. Duration is <=.5s



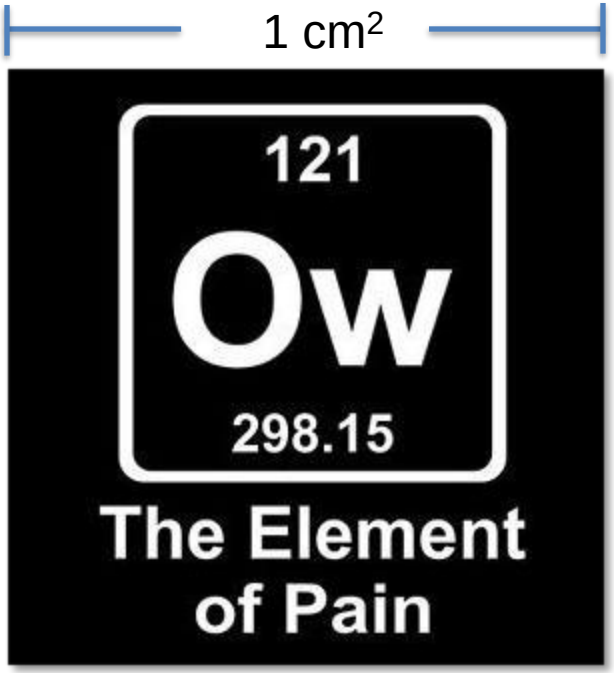

## Quasi-Static Contact

– Contact between an operator and part of a robot system, where the operator body part can be clamped between a moving part of a robot system and another fixed or moving part of the robot cell. Duration is >.5s

# ISO TS15066 2016 & RIA TR R15.606-2016

Important Concept - **Pain is the precursor to injury**

The rationale for creating biomechanical limits was established in conjunction with ISO TC 184 WG3 and testing conducted by the University of Mainz (Germany). Testing was conducted using 100 healthy adult test subjects on 29 specific body areas, and for each of the body areas, pressure and force limits for quasi-static contact were established evaluating onset of pain thresholds.

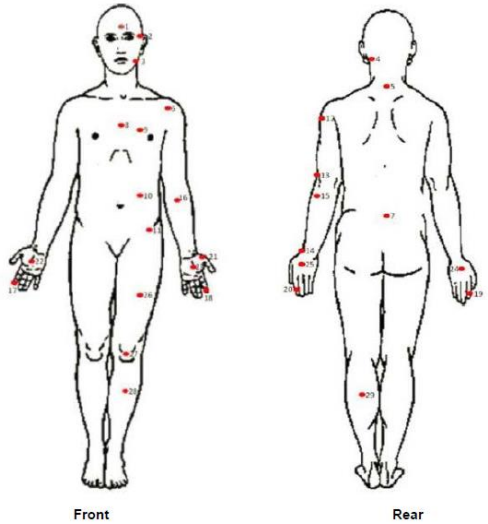


# ISO TS15066 2016 & RIA TR R15.606-2016

## PFL Safety Concept

- "The robot system shall be designed to adequately reduce risks to an operator by not exceeding the applicable threshold limit values for quasi-static and transient contacts, as defined by the risk assessment." (ISO TS15066)

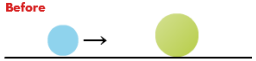
- The limit values for the relevant contact events on the exposed body regions shall be [analyzed] for the most stringent limits. These "worst case" threshold limit values for the transient and quasi-static events shall be used in determining the proper level of risk reduction. Design or measures shall be implemented so that the effects of the identified contacts remain below these threshold limit values



# ISO TS15066 2016 & RIA TR R15.606-2016

## Calculating Theoretical Limits during Verification

**Before**



**After**

**Calculate the Robots Effective Mass** (BETA 3 Arm)

$$M_R = \frac{M}{2} + M_L$$

Where:
**$M_L$**=is the effective payload of the robot system, including the end of arm tooling and the part.
**M** = The total mass of the moving parts of the robot.

Step #1

$$\mu = \left[\frac{1}{M_H} + \frac{1}{M_R}\right]^{-1} \quad or \quad \frac{M_H * M_R}{M_H + M_R}$$

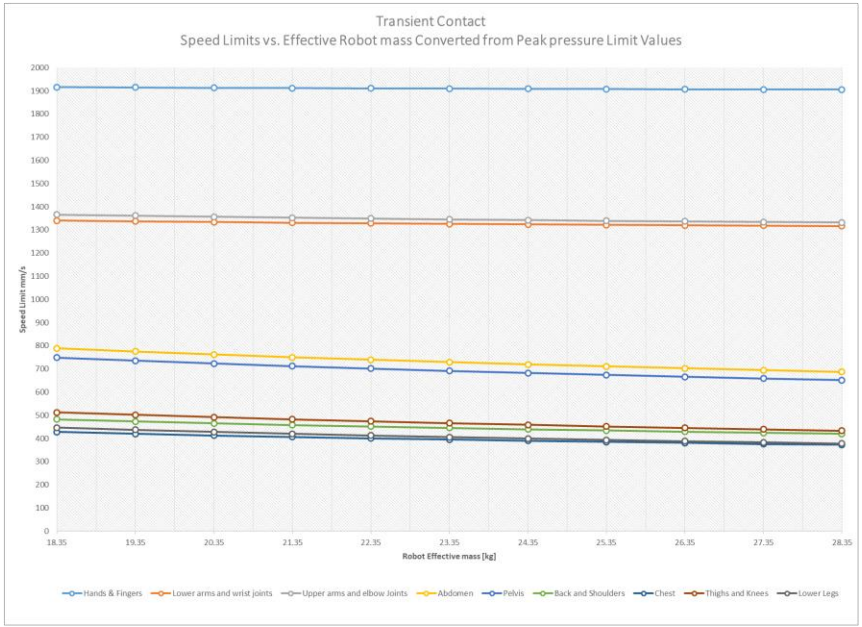
Where:
**$\mu$** =is the reduced mass of the two body system
**MH** = Is the effective mass of the human body region. (See table A3)

Step #2

| Body region | Maximum Allowable Pressure ps [N/cm2] |
|---|---|
| Hands and fingers | 200 |
| Lower arms and wrist joints | 180 |
| Upper arms and elbow Joints | 190 |
| Abdomen | 140 |
| Pelvis | 210 |
| Back and Shoulders | 160 |
| Chest | 120 |
| Thighs and knees | 220 |
| Lower legs | 210 |

$$Vrel, max = \left(\frac{2 * Pmax * A}{\sqrt{k * \mu}}\right) = \frac{m}{s} * 1000 = \frac{mm}{s}$$

Step #3



# ISO TS15066 2016 & RIA TR R15.606-2016

## Effect of area on speed using pain / force data

| Body region | Transient contact Speed limit [mm/sec] as a function of robot effective mass (MR) **from 18-28kg** based on maximum pressure value (Pmax) with an area (A) of 1 cm2 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** |
| Hands and fingers | 1916 | 1915 | 1913 | 1912 | 1911 | 1910 | 1909 | 1908 | 1907 | 1906 | 1905 |
| Lower arms and wrist joints | 1340 | 1337 | 1334 | 1331 | 1329 | 1326 | 1324 | 1322 | 1320 | 1319 | 1317 |
| Upper arms and elbow Joints | 1366 | 1361 | 1357 | 1353 | 1349 | 1346 | 1342 | 1340 | 1337 | 1334 | 1332 |
| Abdomen | 789 | 775 | 762 | 750 | 739 | 729 | 720 | 711 | 703 | 695 | 687 |
| Pelvis | 749 | 736 | 723 | 712 | 702 | 692 | 683 | 674 | 666 | 659 | 652 |
| Back and Shoulders | 482 | 474 | 466 | 458 | 452 | 445 | 440 | 434 | 429 | 424 | 420 |
| Chest | 428 | 420 | 413 | 407 | 401 | 395 | 390 | 385 | 381 | 377 | 373 |
| Thighs and knees | 512 | 502 | 492 | 483 | 474 | 466 | 459 | 452 | 446 | 440 | 434 |
| Lower legs | 447 | 437 | 429 | 421 | 413 | 406 | 400 | 394 | 388 | 383 | 378 |

| Body region | Transient contact Speed limit [mm/sec] as a function of robot effective mass (MR) **from 18-28kg** based on maximum pressure value (Pmax) with an area (A) of 1 mm2 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** |
| Hands and fingers | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Lower arms and wrist joints | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Upper arms and elbow Joints | 14 | 14 | 14 | 14 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Abdomen | 8 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Pelvis | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Back and Shoulders | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 |
| Chest | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Thighs and knees | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 |
| Lower legs | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

1 $cm^2$ Contact Surface Area

Speed

1 $mm^2$ Contact Surface Area

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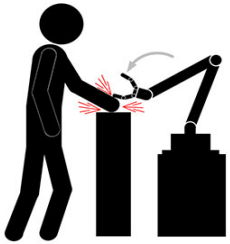
# PFL Application: Things to Consider

Evaluate the contact events including reasonably foreseeable misuse.

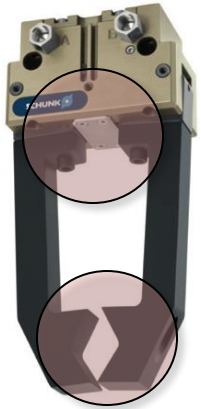
- Robot – Operator (All potential body areas)
- EAOT – Operator (- - -)
- Part being handled by the Robot – Operator (- - - )
- Are the contact events Quasi-Static or Transient?

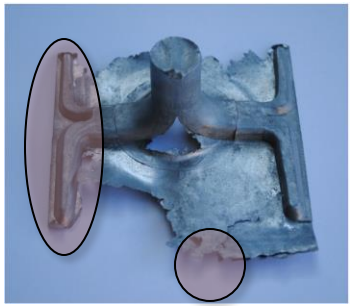


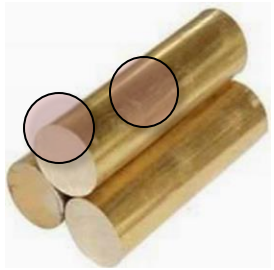

# PFL Application: Things to Consider

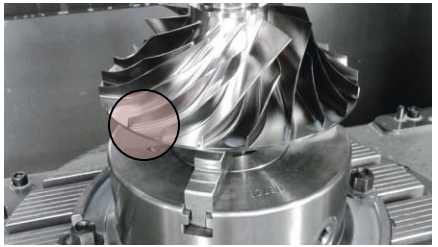
Evaluate the contact events with respect to the Pain/Force Limits:

- What are the surface areas involved in the contact events?
- Evaluate the contact events against the pain /force limits of the body model. (Verification and Validation)









# Additional Items to Consider in the Risk Assessment

A risk assessment shall consider the entire collaborative task and workspace including as a minimum:

- Robot characteristics (e.g. load, speed, force, power)
- End effector hazards
- Layout (e.g. separation distance between the robot and the operator)
- Operator location with respect to the robot arm
- Fixture design and related hazards
- Design and location of any manually controlled guiding device
- Application specific hazards
- Limitations caused by operator PPE
- Environmental conditions (e.g. chemicals, RF, or radiation)
- Performance criteria of the associated safety functions.


**Objects with sharp, pointed, shearing or cutting edges, such as needles, shears, or knives, and parts which could cause injury shall not be present in the contact area.**

# Risk Assessments Involving PFL Solutions

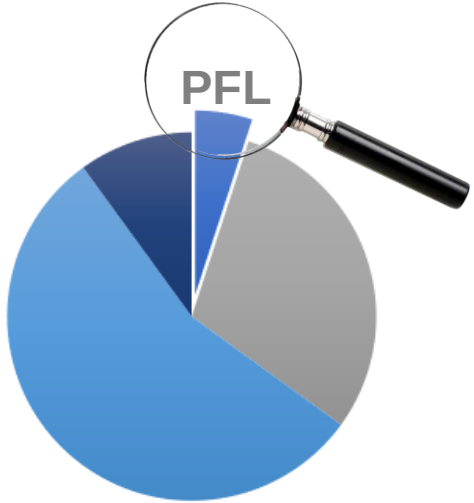
## Verification and Validation - Narrowing the focus

| | Task | Hazard Category | Hazard | Cause/Failure Mode | Severity | Probability | Risk Level | Reduce Risk | Control System | Severity | Probability | Risk Level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | normal operation | struck by/impact | robot | No Perimeter Guarding, PFL, FSU | Serious | Likely | High | other devices | PFL & FSU | Minor | Likely | Low |
| 2 | normal operation | pinch points | between robot/conveyor | No Perimeter Guarding, PFL, FSU | Serious | Likely | High | other devices | PFL & FSU | Minor | Likely | Low |

The residual Risk Level is “Low” if the following:

- The contact events identified in the Risk Assessment have been Validated to be at or below the permissible force and pressure values stated in ISO TS15066 2016 & RIA TR R15.606-2016.

**Remember the requirement to provide confirmation by examination and provision of objective evidence per ISO 10218-2 2011 or ANSI/RIA 15.06 2012.**



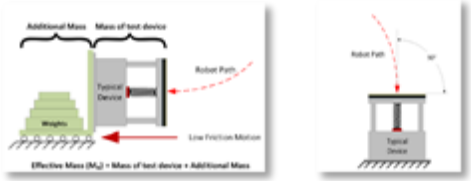

**Risk Assessment**

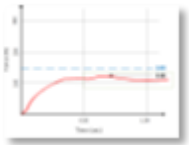
# Is There Guidance for This?

**Yes!** RIA TR R15.806-2018. This document helps to answer the "**How**" question.

**Important concept** – "A robot with PFL functionality is not to be considered safe "out of the box" as the PFL robot is a component within a collaborative application".

- How to use a PFMD – (Pressure and Force Measurement Device) to test design limits in PFL applications.
- Tests for Transient and Quasi-static contact.
- Measurement Procedures
- Measurement Analysis





# What Standards Should I Be Using?

**ANSI/RIA 15.06 2012 (is ISO 10218-1 & 2)**

- **RIA TR R15.306-2014 - Task-based Risk Assessment Methodology (*ANSI B11:0 & B11:19)**
- RIA TR R15.406-2014 – Safeguarding (Going to retire in 2021) **Use ISO 13857:2019 & ANSI B11:19 2019 instead.**
- RIA TR R15.506-2014 - Applicability of ANSI/RIA R15.06-2012 for Existing Industrial Robot Applications
- **RIA TR R15.606-2016 (is ISO TS15066) Robots and robotic devices - Collaborative robots**
- **RIA TR R15.806-2018 Testing Methods for Power & Force Limited Collaborative Applications**

**ISO Documents Class Hierarchy**

**ISO 12100 (2010)** Safety of machinery — General principles for design — Risk assessment and risk reduction

**ISO 13849-1** Safety-related parts of control systems.
- *General principles for design.*

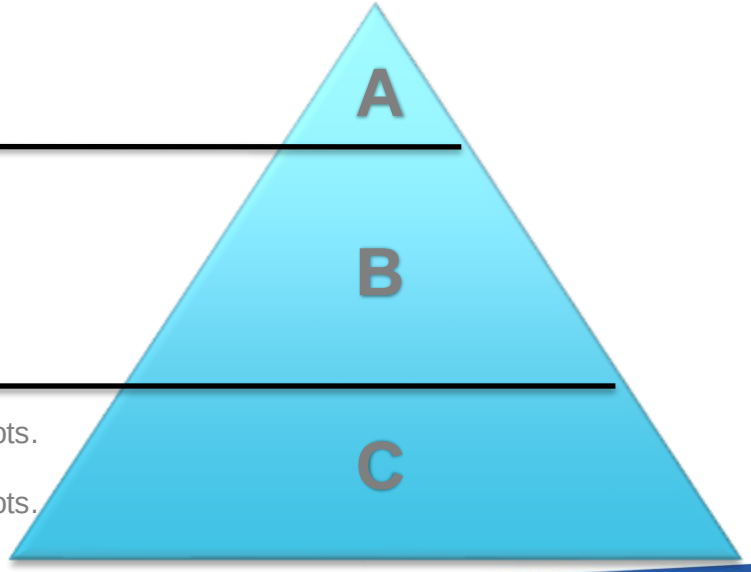
**ISO 13849-2** Safety-related parts of control systems.
- *Validation.*

**IEC 60204-1** Safety of machinery. Electrical equipment of machines.
- Part 1: General requirements.

**ISO 10218-1** Robots and robotic devices. Safety requirements for industrial robots.
- Robots

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

**ISO TS 15066** - Robots and robotic devices — Collaborative robots

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# Questions?