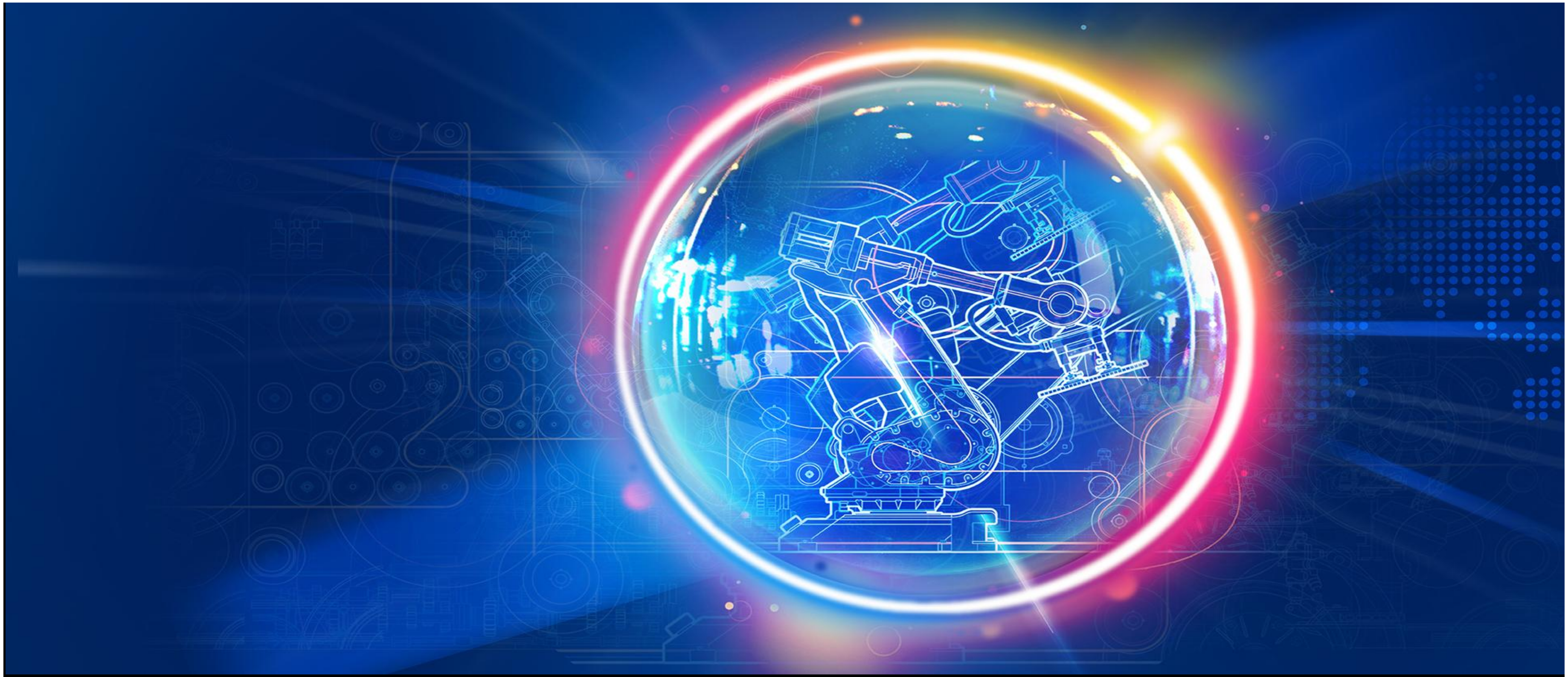

Björn Matthias – 2013-06-19

ABB Robotics Customer Days 2013
Workshop: Safety
→ Status of Standardization

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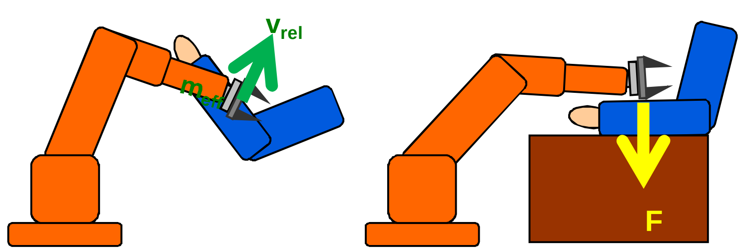
Safety – Status of Standardization
Overview

- Safety Standards for Applications of Industrial Robots
  - ISO 10218-1, ISO 10218-2
  - Related standards and directives
- Safety Functions of Industrial Robot Controller
  - Review of basic safety-related functions
  - Supervision functions
  - Collaborative operation
  - Changes from ISO 10218-1:2006 to :2011
- Present Standardization Projects
  - ISO/TS 15066 – Safety of collaborative robots
  - Biomechanical criteria
- Summary



Safety Standards for Applications of Industrial Robots
ISO 10218-1, ISO 10218-2

ISO 10218-1

- Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots
- Scope
  - Industrial use
  - Controller
  - Manipulator
- Main references
  - ISO 10218-2 – Robot systems and integration


INTERNATIONAL STANDARD

ISO 10218-1

Robots and robotic devices — Safety requirements for industrial robots —

Part 1: Robots

- Common references
  - ISO 13849-1 / IEC 62061 – Safety-related parts of control systems
  - IEC 60204-1 – Electrical equipment (stopping fnc.)
  - ISO 12100 – Risk assessment
  - ISO 13850 – E-stop

ISO 10218-2

- Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration
- Scope
  - Robot (see Part 1)
  - Tooling
  - Work pieces
  - Periphery
  - Safeguarding
- Main references
  - ISO 10218-1 – Robot
  - ISO 11161 – Integrated manufacturing systems
  - ISO 13854 – Minimum gaps to avoid crushing
  - ISO 13855 – Positioning of safeguards
  - ISO 13857 – Safety distances
  - ISO 14120 – Fixed and movable guards


INTERNATIONAL STANDARD

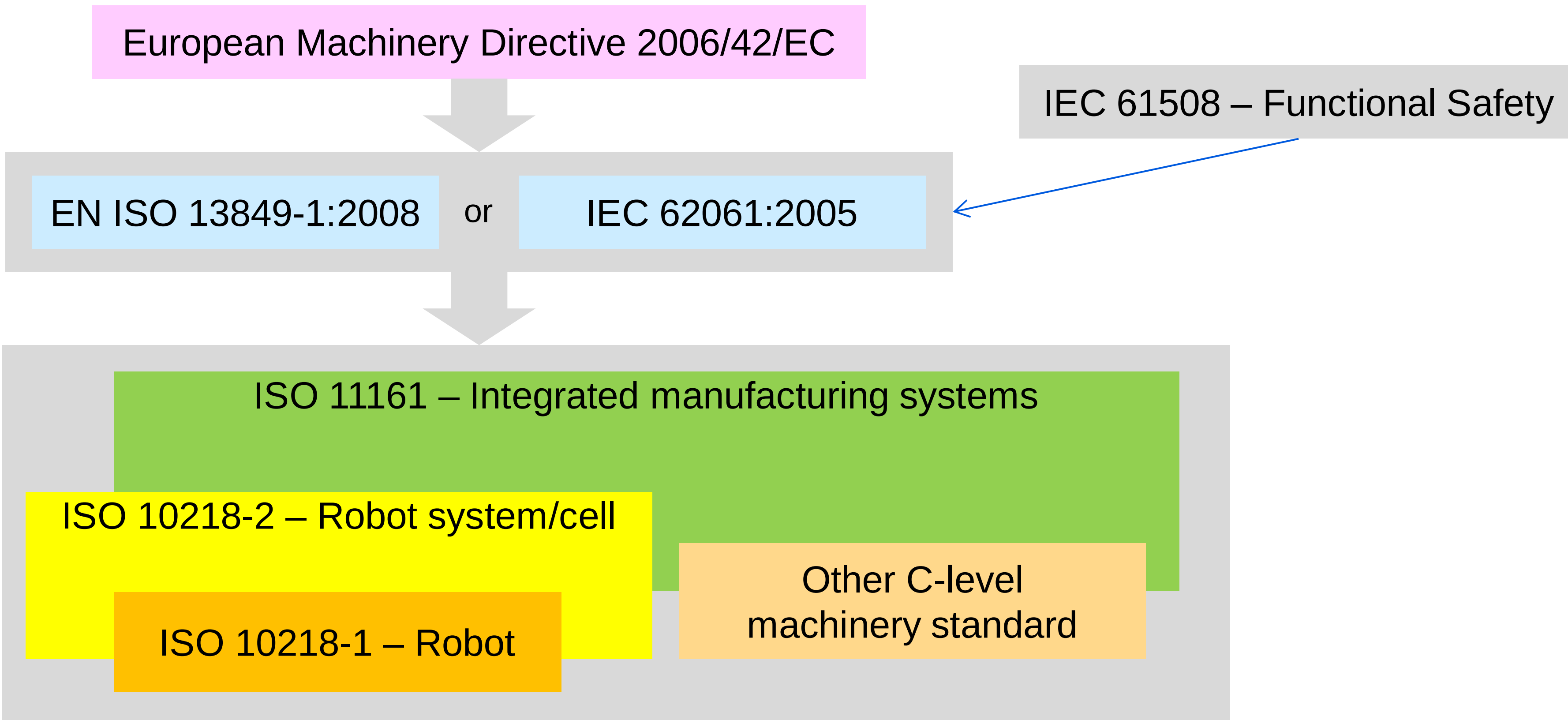
ISO 10218-2

Robots and robotic devices — Safety requirements for industrial robots —

Part 2: Robot systems and integration

Safety Standards for Applications of Industrial Robots
Related Standards and Directives

Example: European Union

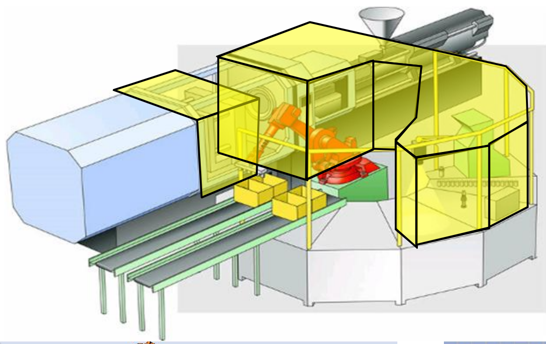


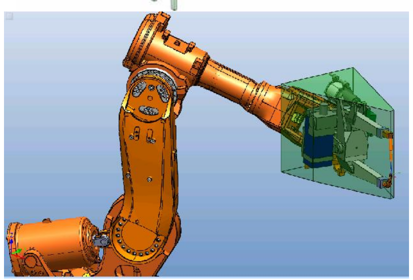
Safety Functions of Industrial Robot Controller
Review of Basic Safety-Related Functions

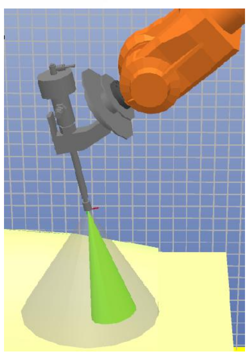
- E-stop
- Protective stop
  - Stop categories (cat. 0, cat. 1, cat. 2 as per IEC 60204-1)
- Operating modes
  - Automatic / manual / manual high-speed
- Pendant controls
  - Enabling
  - Start / restart
  - Hold-to-run
- Limit switches
- Muting functions
  - Enable / limits switches / …

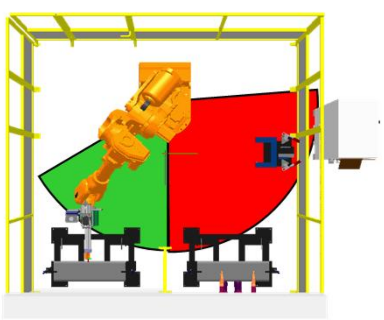
ABB

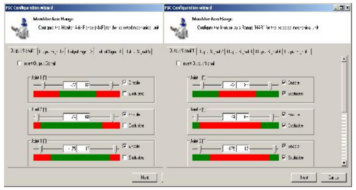
Safety Functions of Industrial Robot Controller
Supervision Functions











- Basic supervision of robot motion, i.e. motion executed corresponds to motion commanded
- Supervision of kinematic quantities
  - Position
    - TCPs, elbow, solid model of manipulator, tool
  - Speed
    - TCPs, elbow, …
  - Acceleration, braking
- Possibility: Supervision of dynamic quantities, esp. for collaborative operation
  - Torques
  - Forces
- Possibility: Application-related / user-defined supervision functions

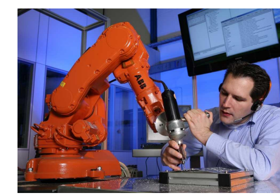
Safety Functions of Industrial Robot Controller
Collaborative Operation (1)

Safety-rated monitored stop
(ISO 10218-1, 5.10.2, ISO/TS 15066)

- Reduce risk by ensuring robot standstill whenever a worker is in collaborative workspace
- Achieved by
  - Supervised standstill - Category 2 stop (IEC 60204-1)
  - Category 0 stop in case of fault (IEC 60204-1)

Hand guiding
(ISO 10218-1, 5.10.3, ISO/TS 15066)

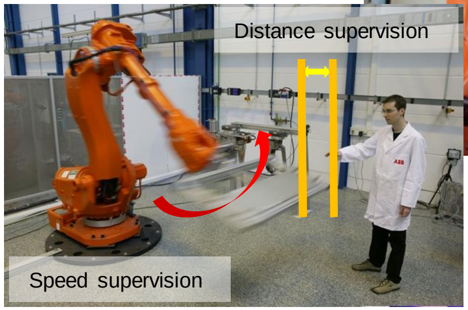
- Reduce risk by providing worker with direct control over robot motion at all times in collaborative workspace
- Achieved by (controls close to end-effector)
  - Emergency stop
  - Enabling device



Safety Functions of Industrial Robot Controller
Collaborative Operation (2)

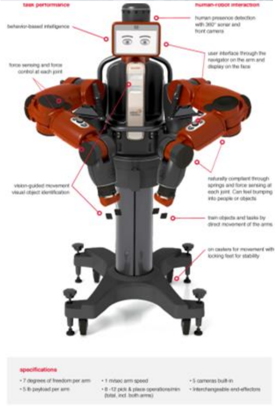
Speed and separation monitoring
(ISO 10218-1, 5.10.4, ISO/TS 15066)

- Reduce risk by maintaining sufficient distance between worker and robot in collaborative workspace
- Achieved by
  - distance supervision, speed supervision
  - protective stop if minimum separation distance or speed limit is violated
  - taking account of the braking distance in minimum separation distance
- Additional requirements on safety-rated periphery
  - for example, safety-rated camera systems



Power and force limiting by inherent design or control
(ISO 10218-1, 5.10.5, ISO/TS 15066)

- Reduce risk by limiting mechanical loading of human-body parts by moving parts of robot, end-effector or work piece
- Achieved by low inertia, suitable geometry and material, control functions, …
- Applications involving transient and/or quasi-static physical contact



Safety Functions of Industrial Robot Controller
Collaborative Operation (3)

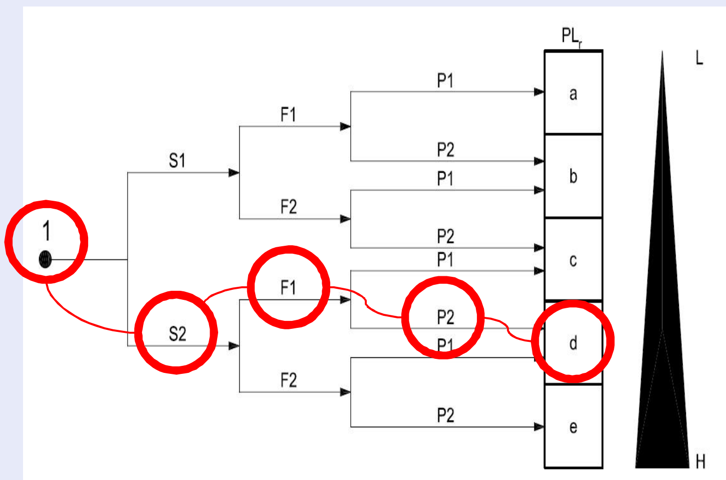
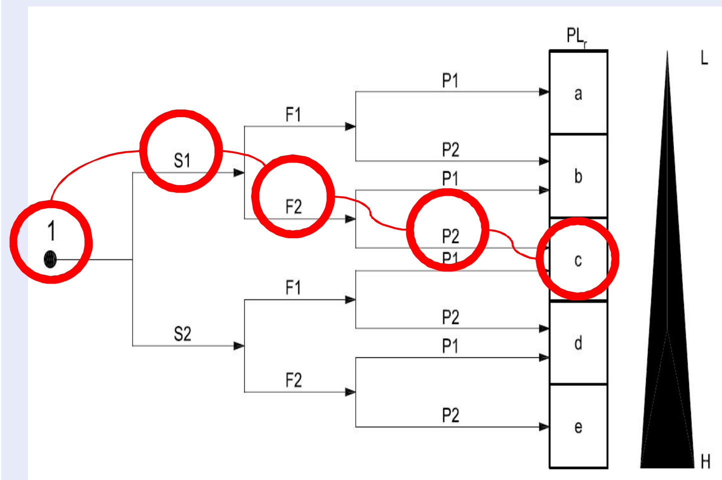
Standard industrial robot	**Special robots for collaborative operation** (following ISO 10218-1, clause 5.10.5)
Injury severity S2 (irreversible)	Injury severity S1 (reversible)
Exposure F1 (rare)	Exposure F2 (frequent)
Avoidability P2 (low)	Avoidability P2 (low)
	
Required safety performance level: PL d	Required safety performance level: PL c

ABB-activities in standardization:
- ISO/TC 184/SC 2/WG 3 "Robots and robotic devices - Industrial safety"
- DIN NA 060-30-02 AA "Roboter und Robotikgeräte"

Present projects in standardization:
- ISO/TS 15066 "Collaborative robots – safety"
- ISO/TS on manual loading stations
- Upcoming 2014: review of ISO 10218-1, -2

Safety Functions of Industrial Robot Controller
Changes from ISO 10218-1:2006 to :2011 (1)

Functionality, Clause	ISO 10218-1:2006	ISO 10218-1:2011	Comments
5.2.1 Power transmission components	--	Fixing systems of fixed guards shall remain attached to machine or guard during service access	
5.4 Safety-related control system performance	• Refers to ISO 13849-1:1999 (EN 954-1) • Usage of safety cat. 3	• Refers to ISO 13849-1:2006 • Usage of PL d and structure cat. 3 • Reference to IEC 62061 as alternative	Now well-aligned with (new) Machinery Directive
5.5 Protective stop	--	Clarification that PS shall have stop cat. 0 or 1	Optional cat. 2 stop is OK as additional function
5.6 (Reduced) Speed Control	• 250 mm/s manual mode (5.6)	• 250 mm/s manual mode (5.6.2) • Reduced speed control (5.6.3), over-speed not possible • Monitored speed limit (5.6.4), exceeding gives PS	New definitions used in collaborative operation
5.7.4 Manual high speed	• Possible to program / teach	• Program verification only • Reset speed to initial speed (max. 250 mm/s) whenever enable-device cycled • Single action to restore higher speed within 5 min. of pause	Hotly contested change! Is e.g. LoadID verification or is it programming?
5.8.3 Enabling device	--	Description provided for switching enabling between left + right hands	Practical relevance?
5.8.5 Initiating automatic operation	Shall not be possible using pendant alone	Shall not be possible using pendant alone	No change, but market requires mode switch on pendant ???

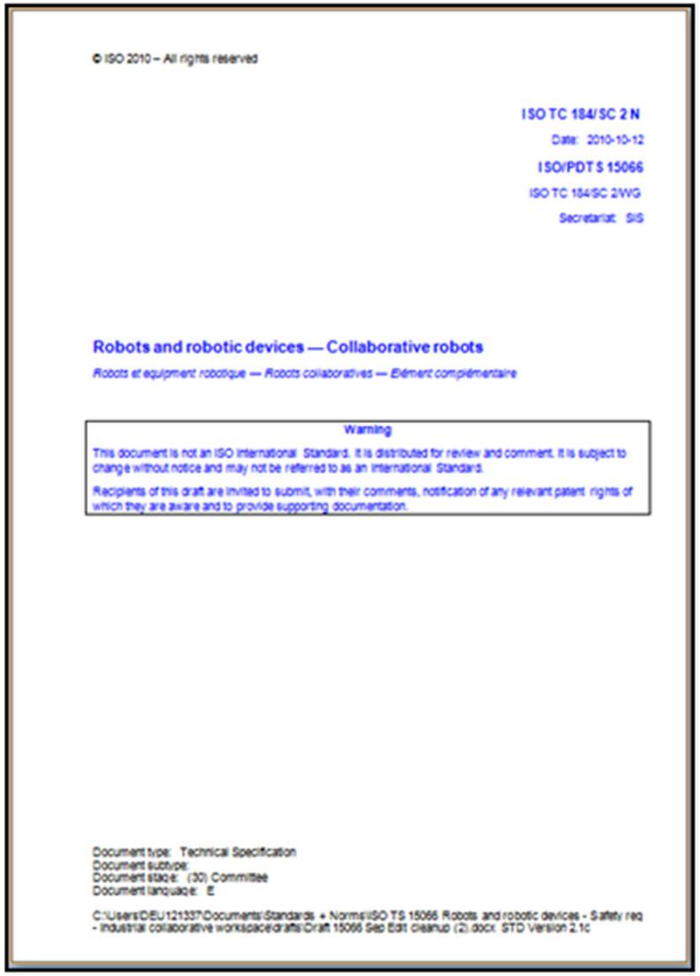
Safety Functions of Industrial Robot Controller
Changes from ISO 10218-1:2006 to :2011 (2)

Functionality, Clause	ISO 10218-1:2006	ISO 10218-1:2011	Comments
5.10.2 (Safety-rated monitored) Stop	Simple stop function	Option of stop cat. 2 safe standstill function	Improved clarity
5.10.3 Hand guiding	Max. speed from risk assessment, but limited to 250 mm/s	Max. speed from risk assessment	Depending on application details, speeds > 250 mm/s are possible
5.10.4 Speed and position / separation monitoring	• Max. speed from risk assessment, but limited to 250 mm/s • Reference to ISO 13855	• Max. speed from risk assessment • Reference to ISO 10218-2 • Reference to ISO/TS 15066 • Reference to ISO 13855	If separation distance is sufficient, speeds >> 250 mm/s are possible, allowing productive applications. Guidance from ISO/TS 15066 not yet available ☹
5.10.5, 5.10.6 Power and force limiting	• Max. dynamic power = 80 W • Max. static force at TCP = 150 N • Limitation by inherent design or by control function(s)	• No numerical values given • Risk assessment to determine values • Reference to ISO 10218-2 • Reference to ISO/TS 15066	Existing solutions using 80 W or 150 N are no longer OK. Transition period of old version expired on 2012-12-31. Guidance from ISO/TS 15066 not yet available ☹
5.12.3 Safety-rated soft axis and space limiting	• Soft limits shall be static. Changes require power-cycle.	• Soft limits shall be static. Changes require restart of safety-related sub-system.	No longer required to reboot the entire controller.
6 Verification and validation	--	New chapter	The V&V methods were given as footnotes in older version. In newer version, methods given in Table F.1
6.2 / 7.2 Instruction handbook		Numerous additional items specified	Improved guidance to achieve conformity to Machinery Directive

Safety Functions of Industrial Robot Controller
Changes from ISO 10218-1:2006 to :2011 (3)

Functionality, Clause	ISO 10218-1:2006	ISO 10218-1:2011	Comments
Annex A	Hazard list based on ISO 14121-1:1999 (normative ?)	Hazard list based on ISO 12100:2010 (informative)	
Annex B, normative	• Braking distances, angles, times shall be measured • Cat. 0 stop at 33%, 66%, 100% of max. speed, payload, extension • Cat. 1 stop at 33%, 66%, 100% of max. speed, payload, extension	• Braking distances, angles, times can be measured or simulated with validated tool • Cat. 0 stop only for 100% of max. • Cat. 1 stop at 33%, 66%, 100% of max. speed, payload, extension • Computation of intermediate values allowed • Description of measurement procedure must be provided to integrator	
Annex E, informative	Graphical symbol for manual high speed given	No graphical symbol for manual high speed	ISO deemed it is not permissible to “create” symbol from superposition of symbols 0026 and 0096

Present Standardization Activities
ISO/TS 15066 – Safety of Collaborative Robots



ISO TC 184/ SC 2 N
Date: 2010-10-12
ISO/PDTS 15066
ISO TC 184/SC 2/WG
Secretariat: SIS

Robots and robotic devices — Collaborative robots

Robots et equipment robotique — Robots collaboratives — Elément complémentaire

Warning

This document is not an ISO International Standard. It is distributed for review and comment. It is subject to change without notice and may not be referred to as an International Standard.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Document type: Technical Specification
Document subtype:
Document stage: (30) Committee
Document language: E

C:\Users\DEU121337\Documents\Standards + Norms\ISO TS 15066 Robots and robotic devices - Safety req - Industrial collaborative workspace\drafts\Draft 15066 Sep Edit cleanup (2).docx STD Version 2.1c

- Design of collaborative work space
- Design of collaborative operation
  - Minimum separation distance S / maximum robot speed K_R
  - $S = K_H(T_R + T_B) + K_R T_R + B + C + Z_S + Z_R$
  - Static (worst case) or dynamic (continuously computed) limit values
  - Safety-rated sensing capabilities
  - Ergonomics
- Methods of collaborative working
  - Safety-rated monitored stop
  - Hand-guiding
  - Speed and separation monitoring
  - Power and force limiting (biomechanical criteria!)
- Changing between
  - Collaborative / non-collaborative
  - Different methods of collaboration
- Operator controls for different methods, applications
  - Question is subject of debate: What if a robot is purely collaborative? Must it fulfill all of ISO 10218-1, i.e. also have mode selector, auto / manual mode, etc.?

ISO / TS 15066 – clause 5.4.4 “Power and force limiting”

Free impact / dynamic contact

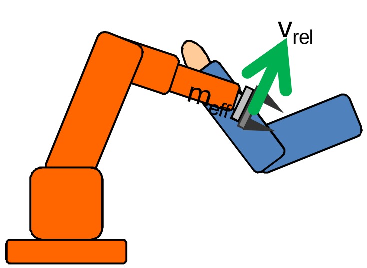
- Accessible parameters in design or control
  - Effective mass (robot pose, payload)
  - Speed (relative)

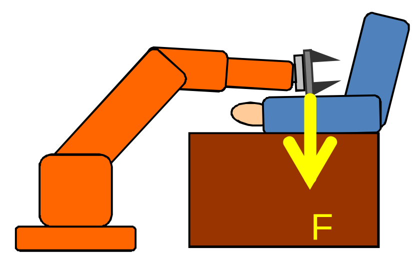
Pain threshold	Minor injury threshold
Highest loading level accepted in design	Highest loading level accepted in risk assessment in case of single failure
Table of values for each body region	Table of values for each body region
May design robot / application to respect lesser loading levels, depending on ergonomic analysis	May design robot / application to respect higher loading levels, depending on risk assessment

Constrained contact / quasi-static contact

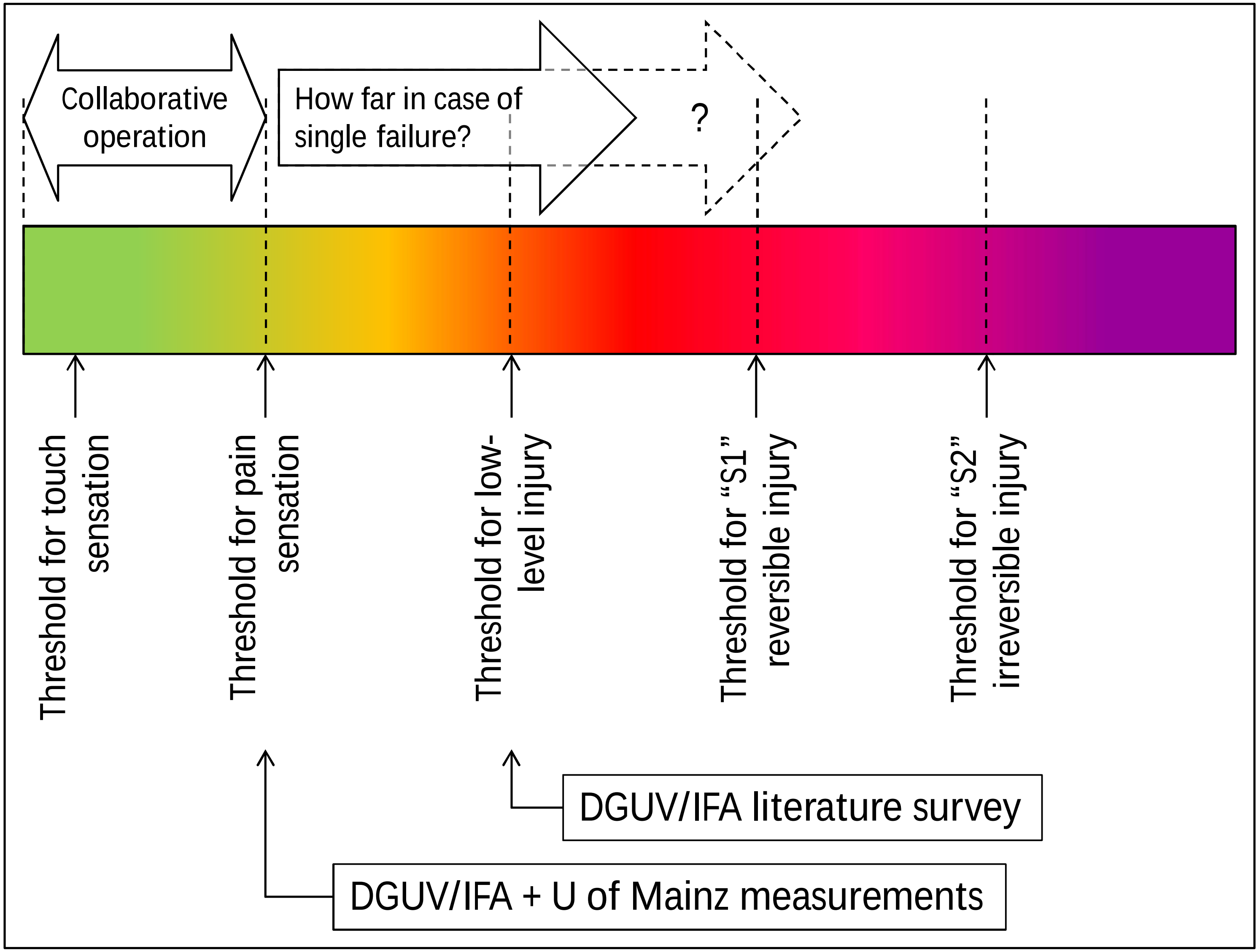
- Accessible parameters in design or control
  - Force (joint torques, pose)

Pain threshold	Minor injury threshold
Highest loading level accepted in design	Highest loading level accepted in risk assessment in case of single failure
Table of values for each body region	Table of values for each body region
May design robot / application to respect lesser loading levels, depending on ergonomic analysis	May design robot / application to respect higher loading levels, depending on risk assessment





Present Standardization Activities
Biomechanical Criteria



Summary

- Presently valid C-type standards for industrial robotics applications are
  - ISO 10218-1:2011 for the robot
  - ISO 10218-2:2011 for the robot system and integration
- Transition period for ISO 10218-1:2006 has expired on 2012-12-31 and a number of important changes have been made in ISO 10218-1:2011
- Collaborative operation is an exciting and promising new area and still the subject of original research in many aspects, especially including determination of applicable biomechanical design criteria
- Progress depends on your input! Please voice your views, hopes and concerns!

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Deutsche Gesetzliche Unfallversicherung
Fachbereich Holz und Metall

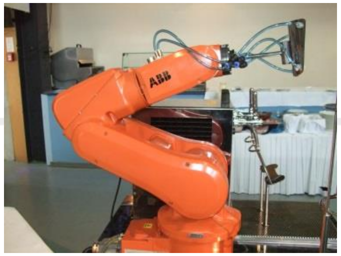

ABB Customer Days 2013

Mainz (Germany), 18-19 June 2013

Research Project: Investigation of change from pressure feeling to pain at the man machine interface of collaborative robots

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Robot safety - Industry

DGUV

Deutsche Norm Januar 2012

DIN EN ISO 10218-1

DIN

Ersatz für DIN EN ISO 10218-1:2009-07

Industrieroboter-Sicherheitsanforderungen-
Teil 1: Roboter (ISO 10218-1:2011);
Deutsche Fassung EN ISO 10218-1:2011

Industrial robots

Deutsche Norm Juni 2012

DIN EN ISO 10218-2

DIN

Industrieroboter-Sicherheitsanforderungen-
Teil 2: Robotersystem und Integration (ISO 10218-2:2011);
Deutsche Fassung EN ISO 10218-2:2011

Industrial robot system and integration

INTERNATIONAL TECHNICAL SPEZIFICATION

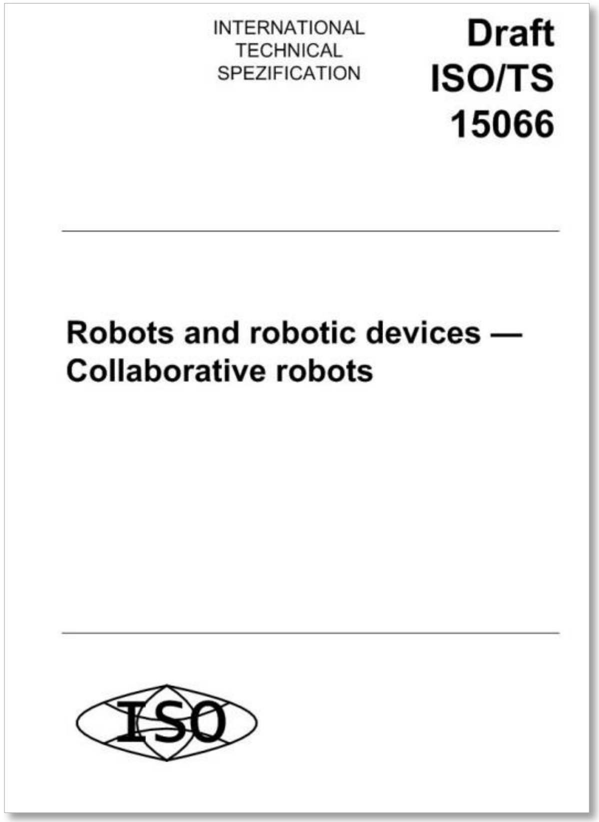
Draft ISO/TS 15066

Robots and robotic devices — Collaborative robots

ISO

Harmonized standards under EC MD

ISO/TS 15066: 4 Concepts


INTERNATIONAL TECHNICAL SPEZIFICATION

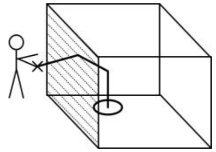
Draft ISO/TS 15066

Robots and robotic devices — Collaborative robots

ISO

Hand guiding

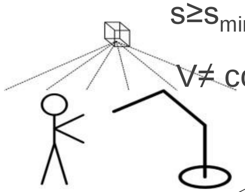
V=f(overtravel, risk)



Speed and position monitoring

$s \geq s_{min}$

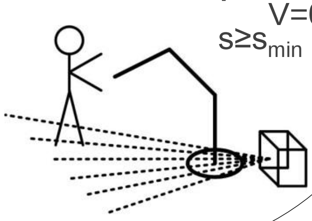
$V \neq const$



Safety-rated monitored stop

$V=0$

$s \geq s_{min}$



Power and force limiting

$F \leq F_{max}$

$p \leq p_{max}$

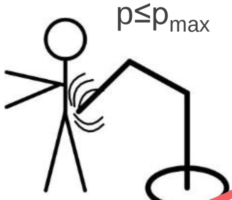
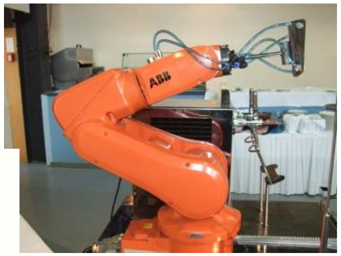


Bild: BGHM/UMB

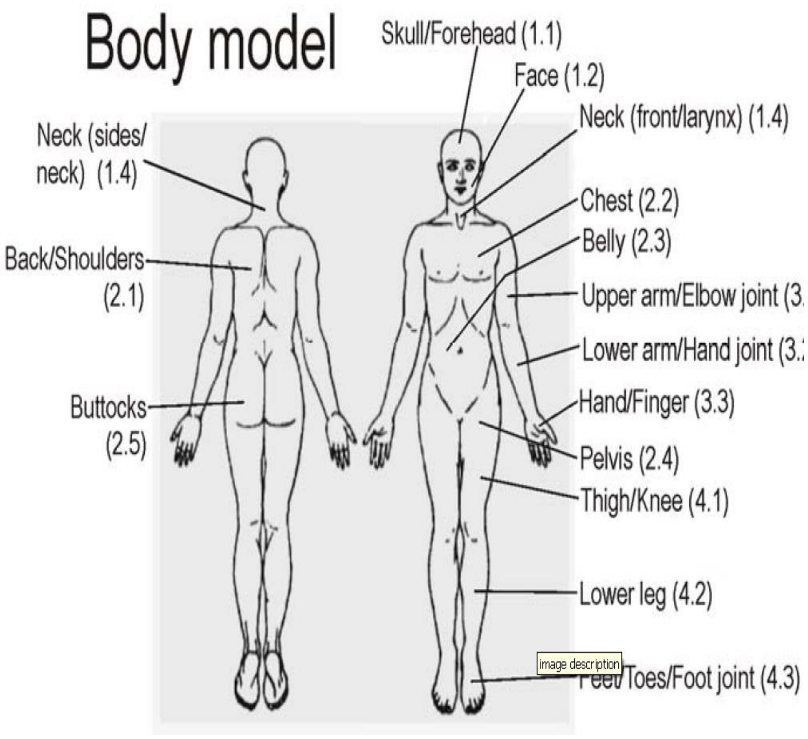
Power and force limiting - Risk assessment



Among others:

- Intended Use and foreseeable misuse
- Consider always robot system consisting of robot and environment, e.g. tools, fixtures, jigs …
- Required space
- Qualification, physiological and mental suitability of personnel
- Ergonomic aspects, e.g. posture
- Access of third persons
- Frequency and severity of potential contact (Force and/or pressure)

Literature study



- No specifically robot related thresholds found
- Further research necessary

Main body regions of the body model	Individual body regions	Limit values			CC [N/mm]
		CSF [N]	IMF [N]	PSP [N/cm]	
1. Head with neck	1.1 Skull/Forehead	130	175	30	150
	1.2 Face	65	90	20	75
	1.3 Neck (sides/neck)	145	190	50	50
	1.4 Neck (front/larynx)	35	35	10	10
2. Trunk	2.1 Back/Shoulders	210	250	70	35
	2.2 Chest	140	210	45	25
	2.3 Belly	110	160	35	10
	2.4 Pelvis	180	250	75	25
	2.5 Buttocks	210	250	80	15
3. Upper extremities	3.1 Upper Arm/Elbow joint	150	190	50	30
	3.2 Lower arm/Hand joint	160	220	50	40
	3.3 Hand/Finger	135	180	60	75
4. Lower extremities	4.1 Thigh/Knee	220	250	80	50
	4.2 Lower leg	140	170	45	60
	4.3 Feet/Toes/Joint	125	160	45	75

Sorce: IFA

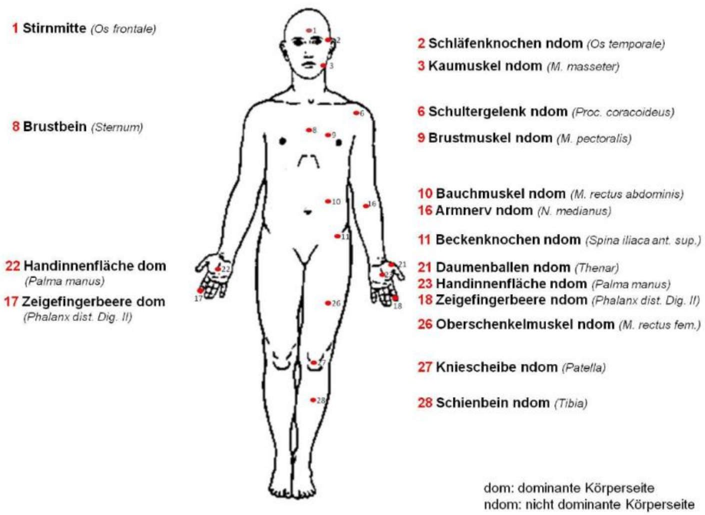
Research project: Algometer

Bild: IFA

Bild: BGHM

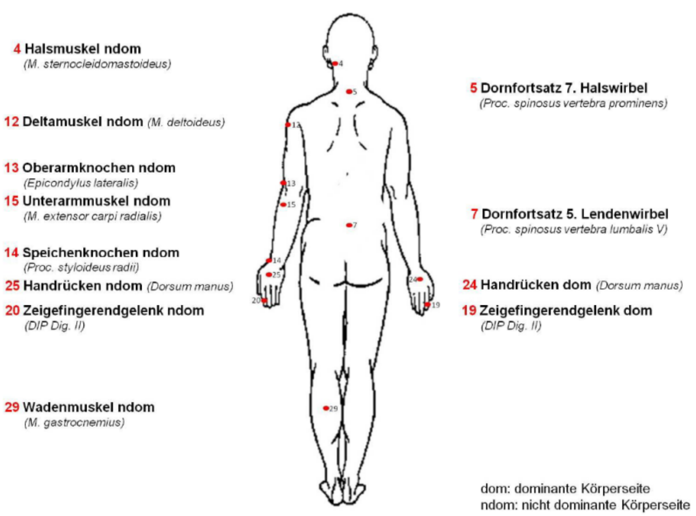
- Algometer developed at IFA (Institute for Occupational Safety and Health)
- Specifically designed probe according to feedback from robot user
- Algometer stops when pressure feeling changes to pain
- The investigations are below AIS 1 and S1.(no bloody wounds or fracture)

Contact positions for study



Pre study: Finalized April 2012

- 10 Test person
- Definition of 29 contact points
- Test machine modified and optimized
- Modified probe for measurement of force and pressure
- Training operation of test machine
- Training treatment of test persons

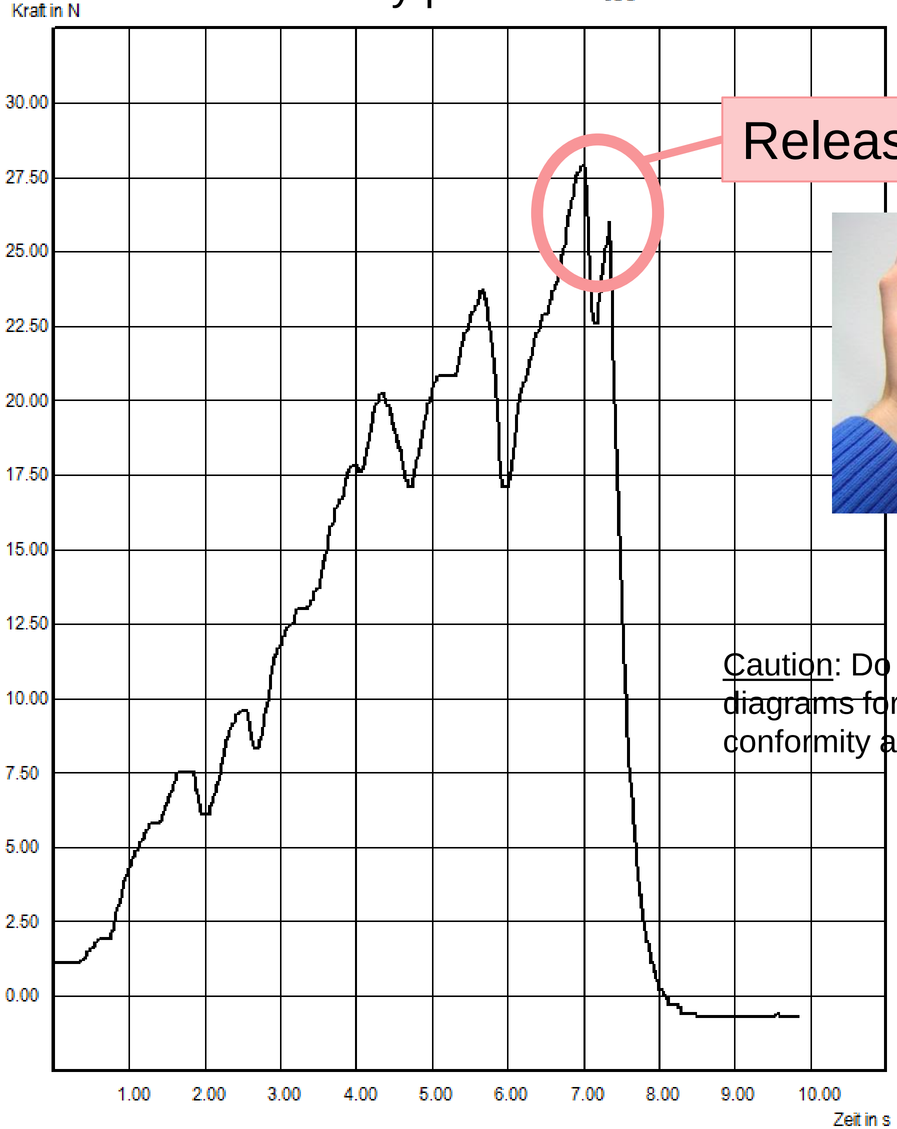


Main study: Start June 2012, ends 2014

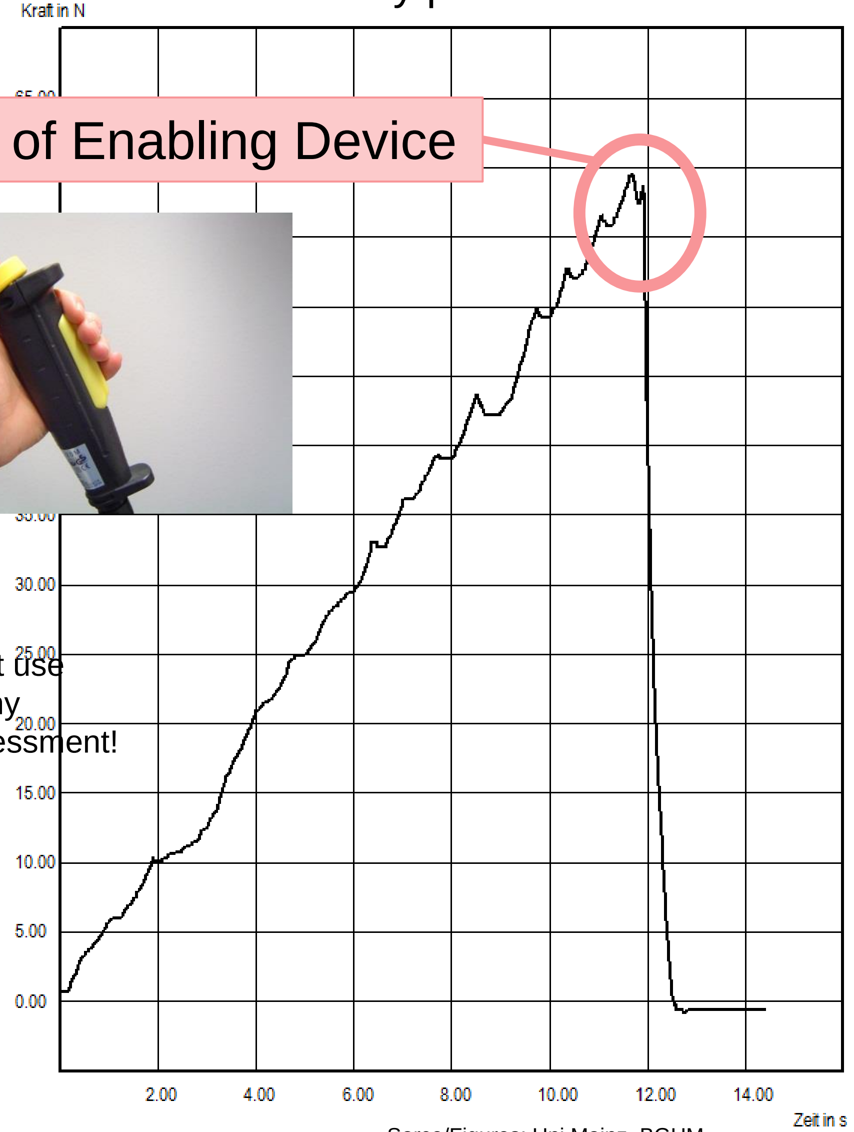
- 100 Test person
- Of which 30 metal worker (male and female)
- 3 cycles each test person
- 1 day for medical examination

Measurement of force

Body part X



Body part Y



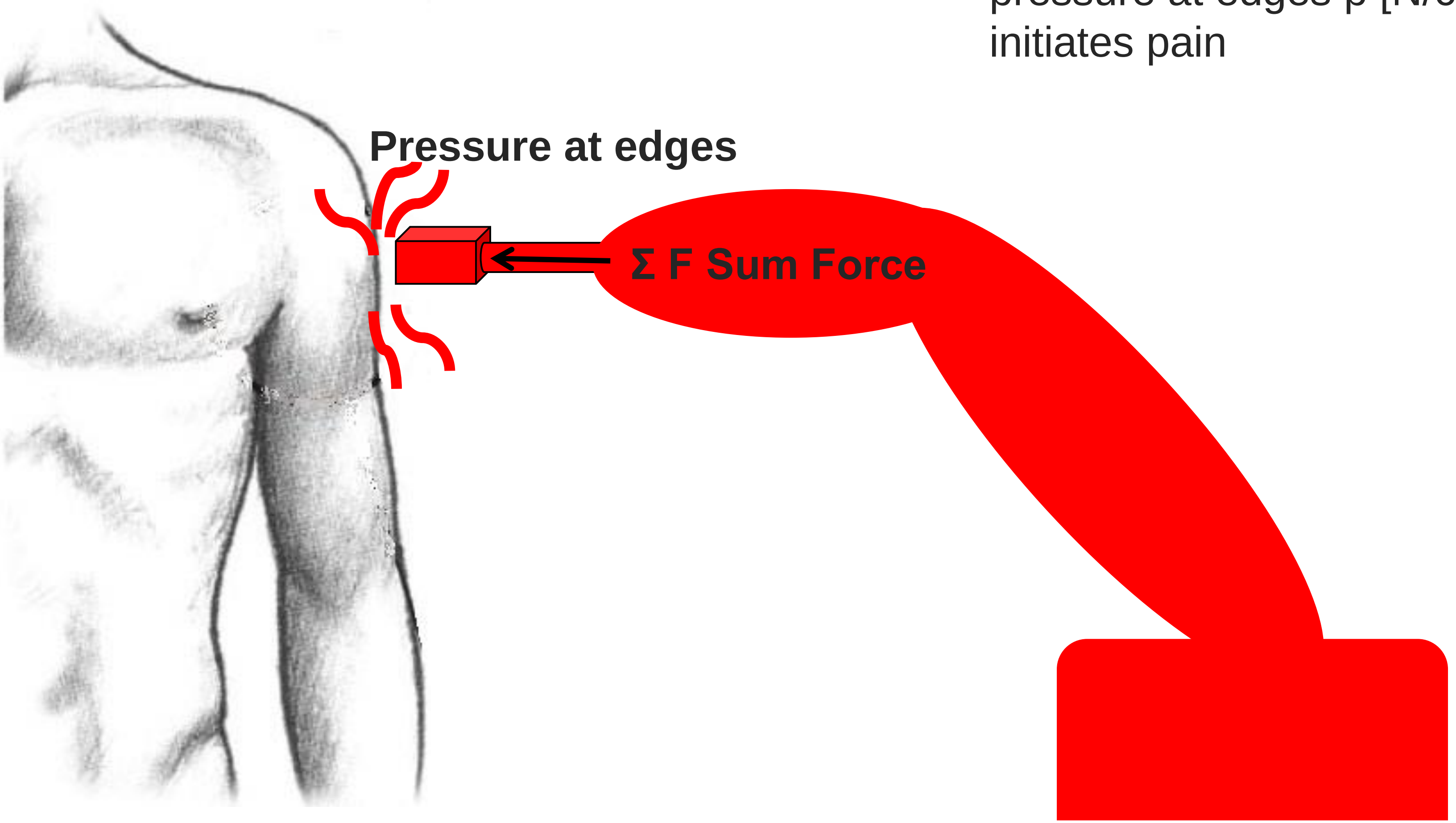
Release of Enabling Device

Caution: Do not use diagrams for any conformity assessment!

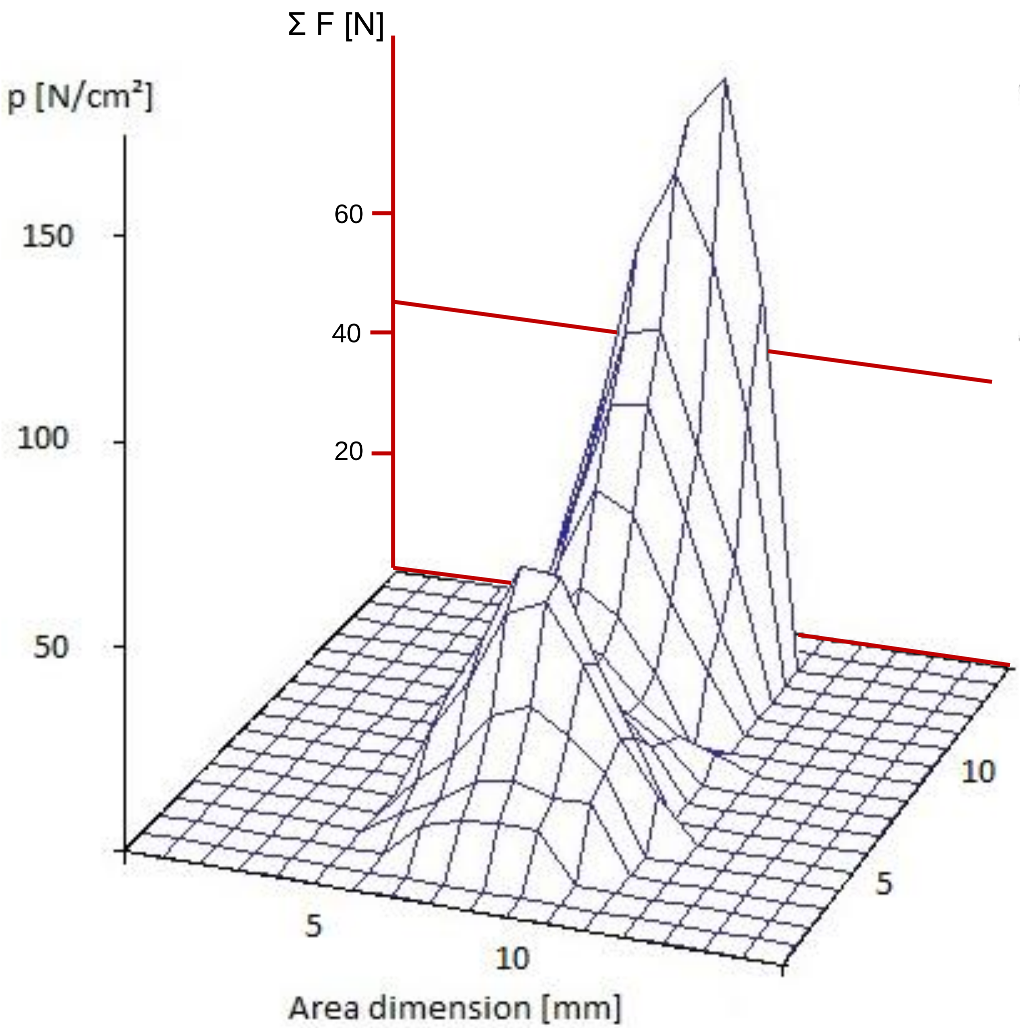
Sorce/Figures: Uni Mainz, BGHM

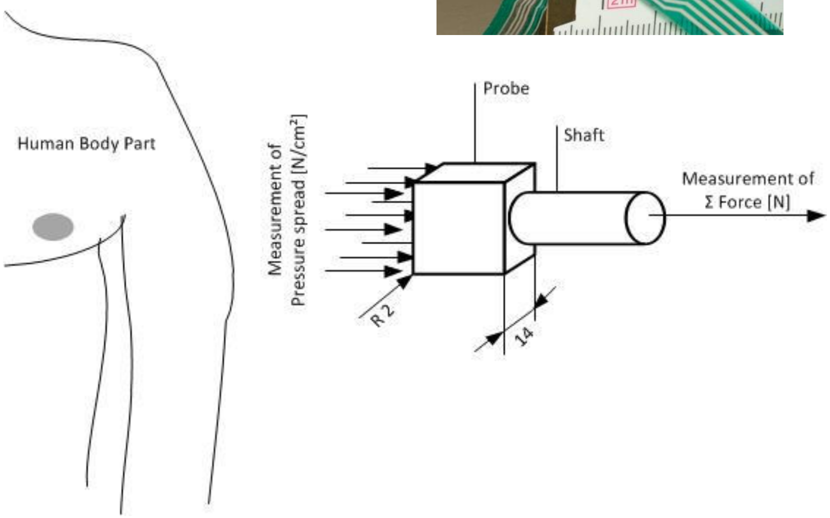
Pressure p and force F

– Aside Force in particular pressure at edges p [N/cm²] initiates pain



Pressure spread and Σ force (example)



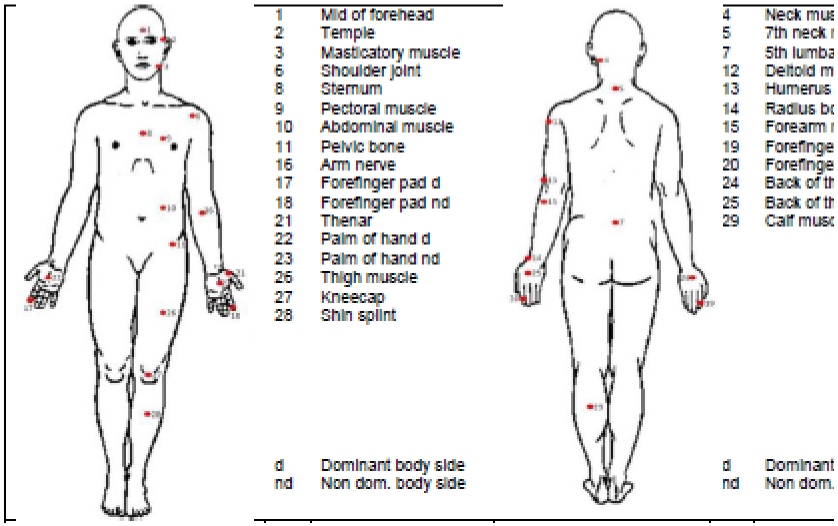


Test conditions:

- Cubic test probe with edge length of 14 mm and rounded edges of 2 mm radius (see figure 1).
- Quasi static increase of contact on human body part by 2 N/s (point 2 and 3) and 5 N/s (all other points).
- Resolution of surface pressure measurement system of at least 1 mm²

Results of interim report

DGUV

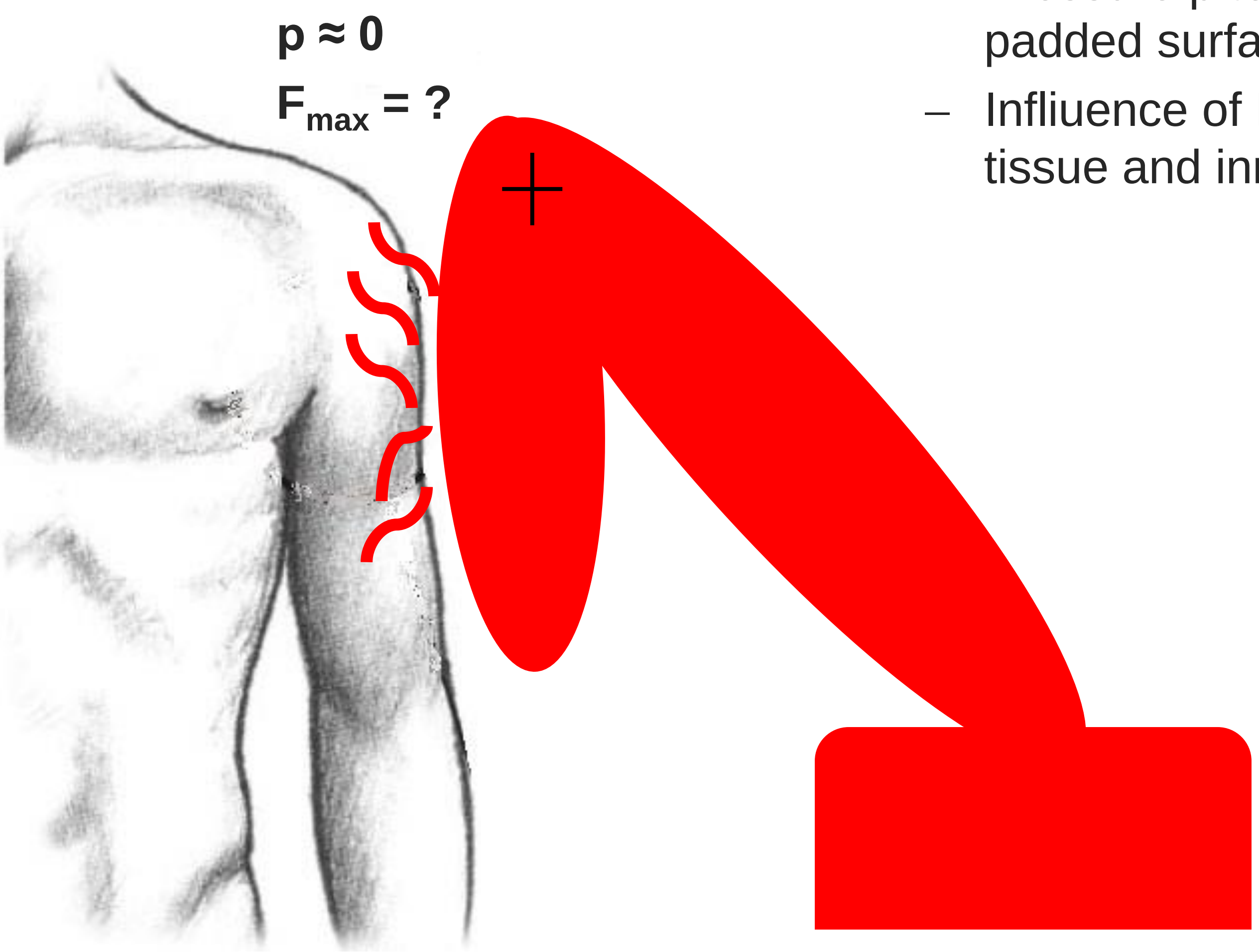


Measurement localization		Force [N]				Peak pressure [N/cm²]			
	Description	N	Q1	Median	Q3	N	Q1	Median	Q3
1	Mid of forehead	36	30	45	52	36	92	114	134
2	Temple	36	17	24	27	35	50	85	154
3	Masticatory muscle	35	13	18	21	32	46	100	197
4	Neck muscle	35	15	18	25	33	51	108	153
5	7th neck muscle	36	27	39	48	36	103	149	194
6	Shoulder joint	36	19	27	37	36	87	99	156
7	5th lumbar vertebra	36	50	64	72	36	109	133	190
8	Sternum	36	31	42	53	36	82	99	118
9	Pectoral muscle	25	25	30	46	25	63	89	161
10	Abdominal muscle	35	21	29	38	34	73	119	247
11	Pelvic bone	36	32	42	54	36	130	181	197
12	Deltoid muscle	36	33	45	57	35	108	137	181
13	Humerus	36	38	44	57	36	142	178	251
14	Radius bone	36	32	38	50	36	116	158	193
15	Forearm muscle	36	29	34	42	36	90	134	162
16	Arm nerve	36	36	44	60	35	106	122	175
17	Forefinger pad d	36	51	63	83	36	117	163	230
18	Forefinger pad nd	36	50	61	80	36	124	159	215
19	Forefinger end joint d	36	38	47	67	36	160	208	269
20	Forefinger end joint nd	36	35	46	61	36	125	[illegible]	219
21	Thenar	36	[illegible]	[illegible]					
22									

Preliminary data !

Please do not use for any conformity assessment !

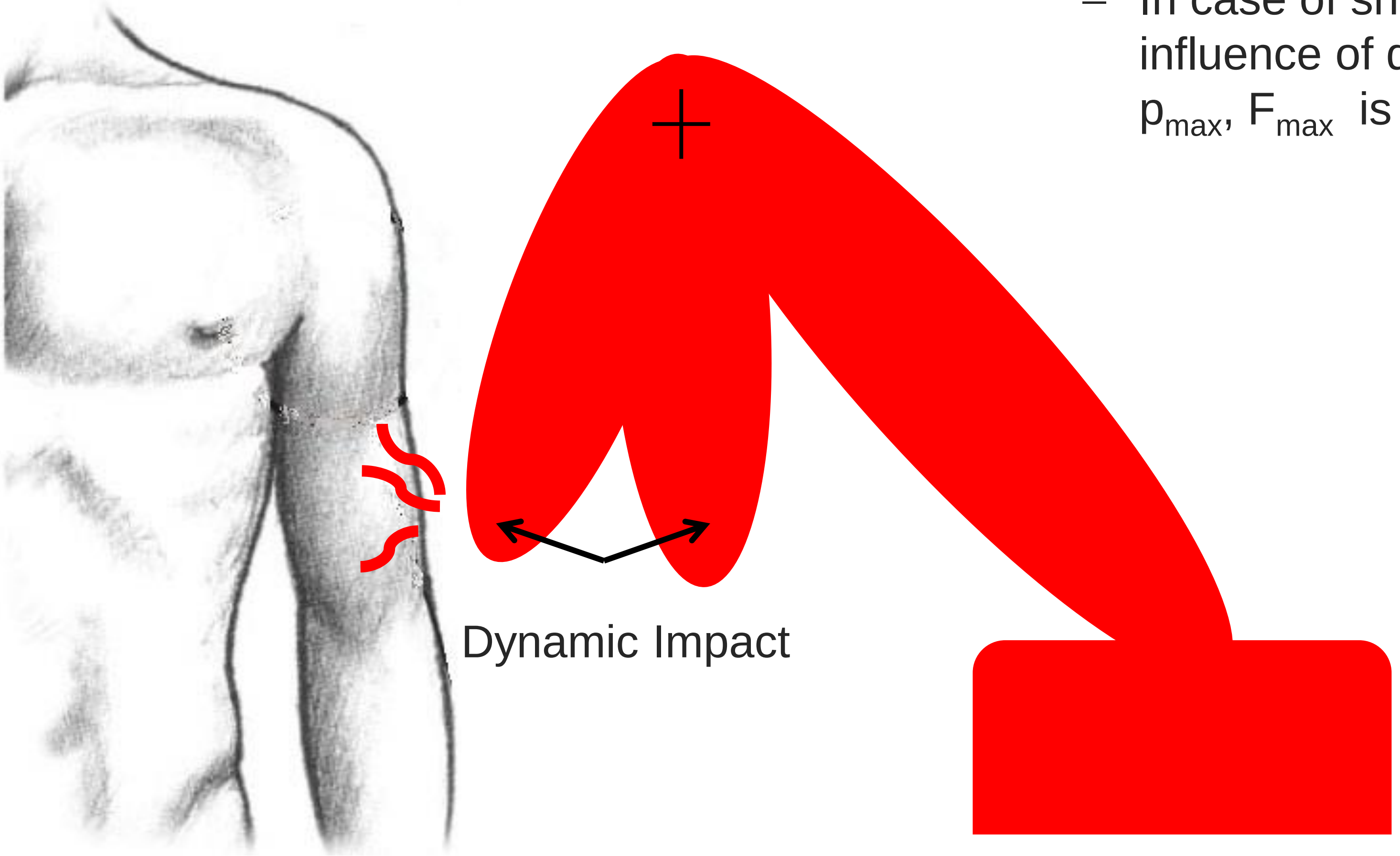
Further research



- Pressure p tends to zero in case of flat padded surfaces
- Infliuence of Force F on deep muscular tissue and inner organs

Further research

p_{max}, F_{max} = f (duration) = ?



- In case of short impact the influence of duration time on p_{max}, F_{max} is not known

Summary

- Interim Report of University of Mainz will be published July 2013
- Preparation of new annex for ISO TS 15066 accordingly
- Provide final research report in 2014. Revise15066 accordingly
- Development of measurement devices for force and pressure by IFA
- Provide further research
- Traditional robots cannot be replaced by robots with force and pressure limiting
- Example- Application needed for certification of collaborative robots
- First certificates issued by Berufsgenossenschaft

Summary

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Internationale Robotik-Experten zu Besuch an der Universitätsmedizin

Internationale Robotik-Experten informieren sich im Institut für Arbeits-, Sozial- und Umweltmedizin

Am 11. Juni 2012 besuchte das Komitee „Robots and robotic devices" der International Organization for Standardization (ISO) das Institut für Arbeits-, Sozial- und Umweltmedizin (Leiter: Univ.-Prof. Dr. med. Dipl.-Ing. Stephan Letzel). Aufgabe der zirka 30 Experten aus Amerika, Asien und Europa ist es, international verbindliche Normen zu beschließen, die den sicheren Umgang mit Robotern regeln. Seit einigen

und in Kooperation mit dem Institut für Arbeitsschutz der DGUV, der Berufsgenossenschaft Holz Metall sowie dem Institut für Medizinische Biometrie, Epidemiologie und Informatik (IMBEI) an gesunden Probanden, wie hoch die Druckschmerzschwellen an 29 für die Praxis bedeutsamen Körperpartien sind. Das Projekt ist auf drei Jahre angelegt, als wissenschaftliche Mitarbeiter sind Dr. Britta Geißler und

Bei praktischen Demonstrationen konnten die Robotik-Experten Messungen selbst erleben und ihre individuellen Schmerzschwellen erfahren. In seiner Dankesrede zeigte sich der Vorsitzende Jeff Fryman, USA, beeindruckt von den in Mainz durchgeführten Forschungen. [Prof. Axel Muttray]

Report in Newspaper:

Meeting of ISO TC 184 SC 2 Industrial Robots at University of Mainz in June 2012

Summary

From the 100 test persons have been tested:

41 test persons tested

(of which 21 metal worker)

36 evaluated

Translation and publication of final report is planned

E-mail response of a tested metal worker:

"… I find that all functioned well. Your staff was very friendly, the tests functioned without trouble. And also the environment was fine. I enjoyed stay in your house.
P.S. 2-3 of my friends are interested as well. Should I connect them to you?"


Ensuring safety in A Hybrid Human-Robot Assistance System
Carsten Thomas | Institute of Production Systems

Welding of Tubular and Framework Constructions

- custom-made assemblies, individual construction
- small batch sizes (< 10 pieces)
- high quality requirements
- heavy-weights

Process Steps

- Handling of Single Parts and Pre-Assemblies
- Positioning and Fixation of Parts
- Readjustment of Parts
- Spot and Ground Welding

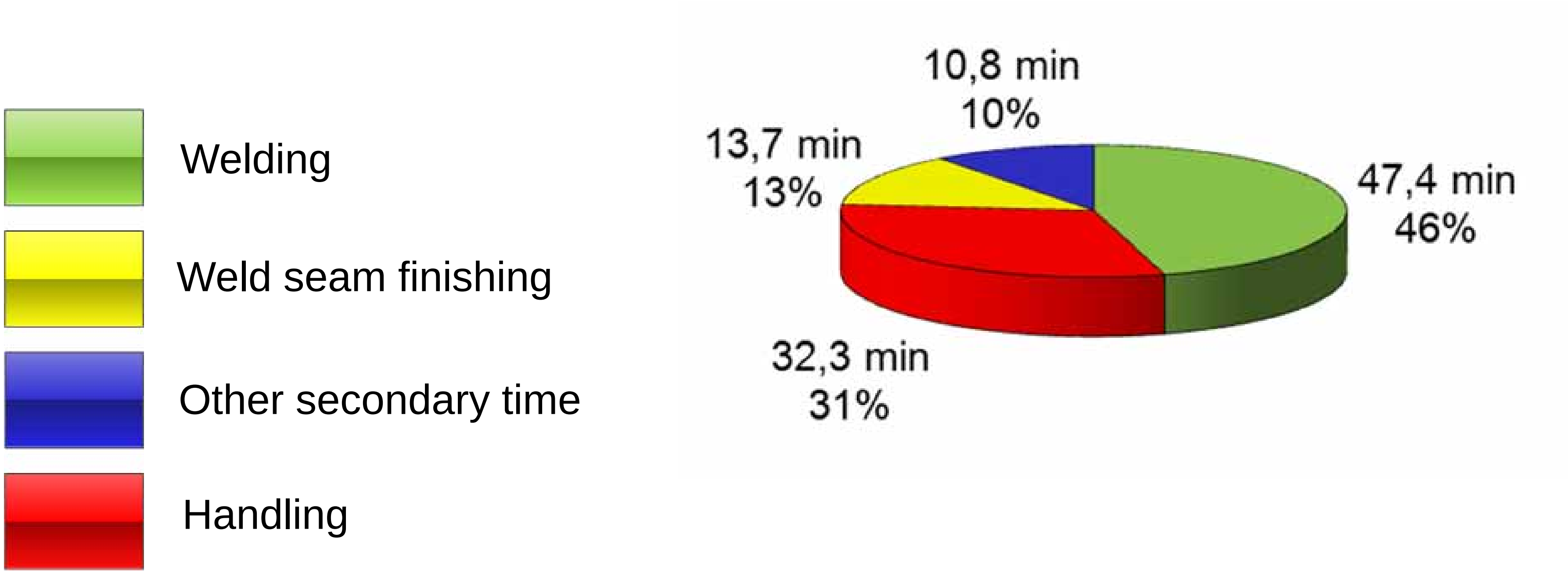
Problems

- labour-intensive tasks with a high amount of manual handling operations
- static body postures of the employees, e. g. when welding overhead or with a bended and twisted back
- working posture during operation is defined by the product geometry

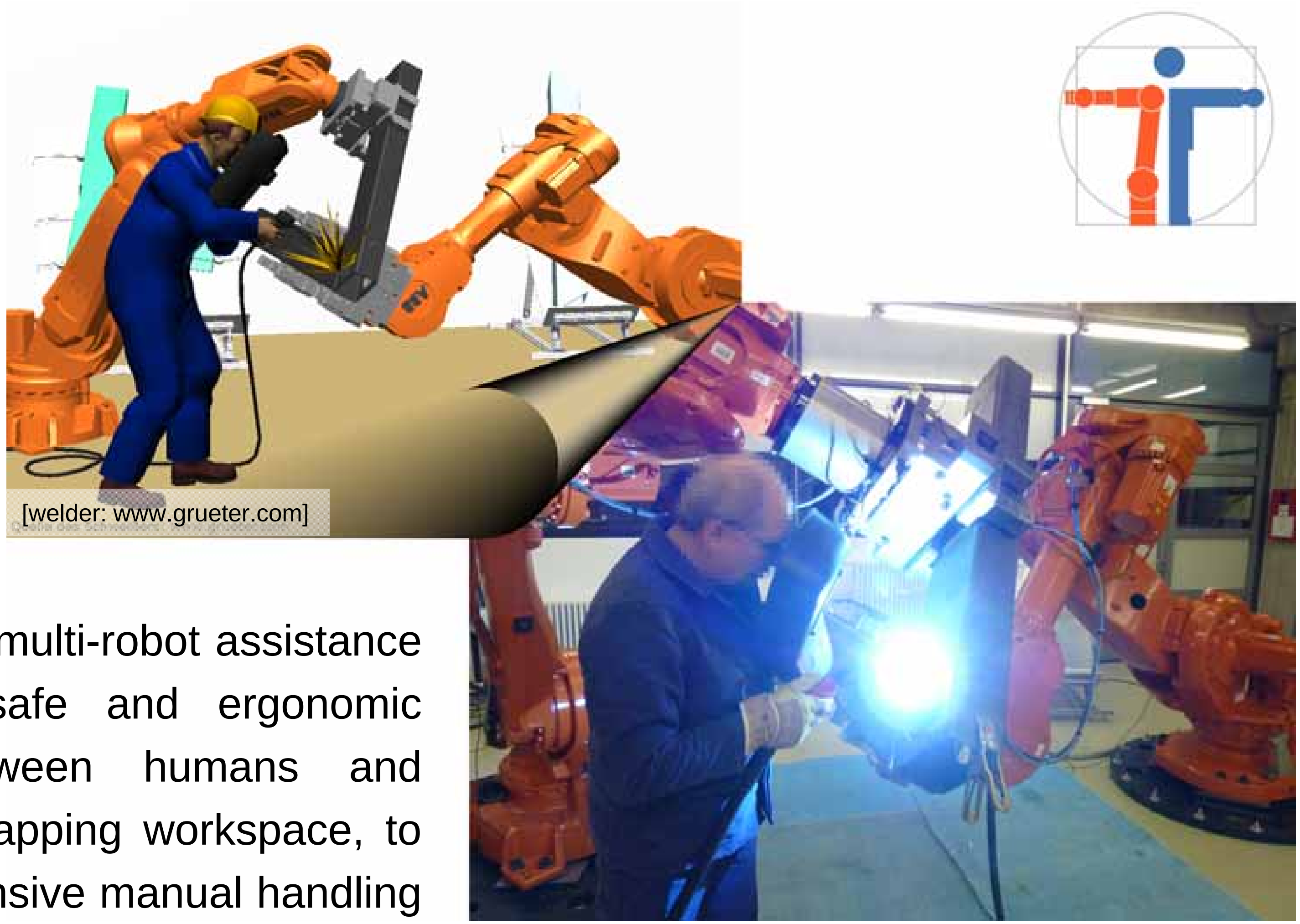
Actual Welding in the Industry

Institut für Produktionssysteme

Analysis of the Process Times



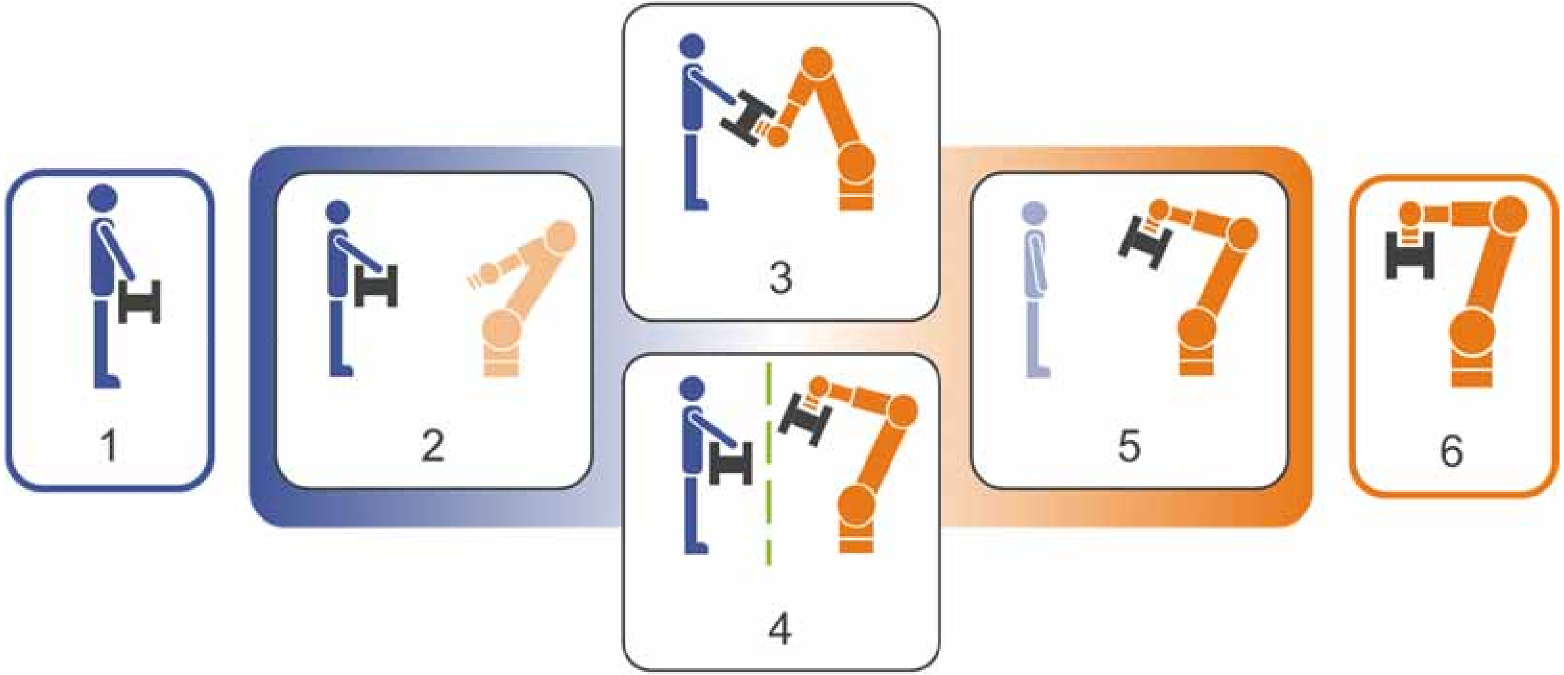
Research Approach



[welder: www.grueter.com]

Development of a multi-robot assistance system with a safe and ergonomic collaboration between humans and robots in an overlapping workspace, to reduce labour-intensive manual handling of heavy parts in welding processes.

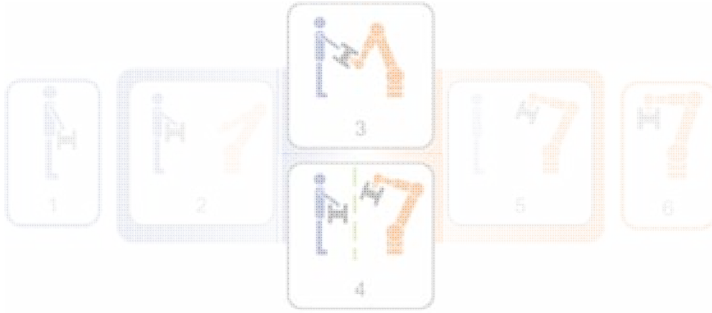
Modes of Human-Robot-Collaboration



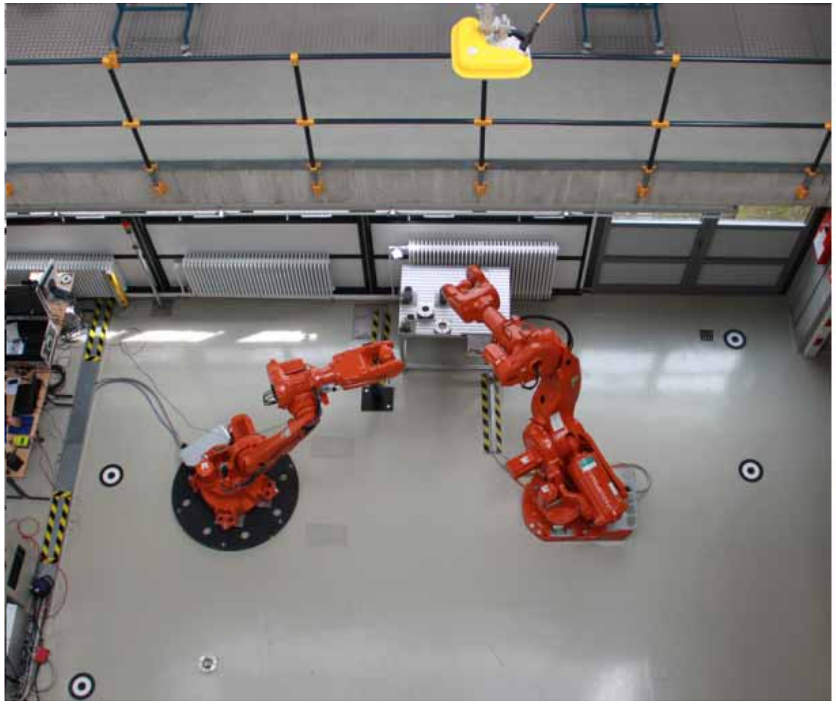
Human	Mode	Robot
manual assembly	1	---
active	2	not active, safe stand still
direct cooperation with robot(s)	3	direct cooperation with human(s)
active, but separate working range	4	active, but separate working range
not active	5	active
---	6	automated assembly

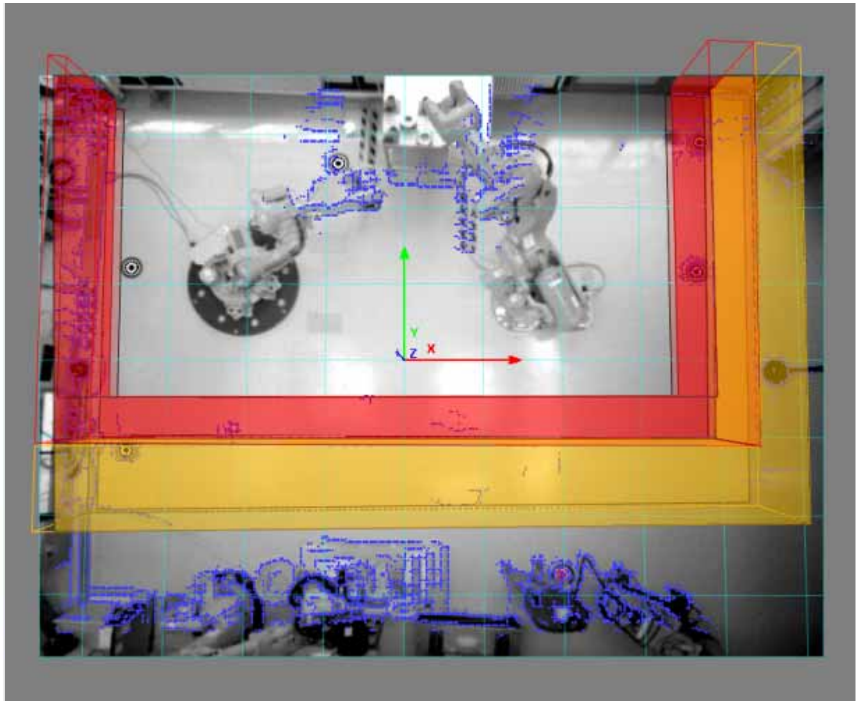
Real Demonstrator and view of the SafetyEyes

- Camera-based sensor system SafetyEye
- Safety robot controller ABB SafeMove



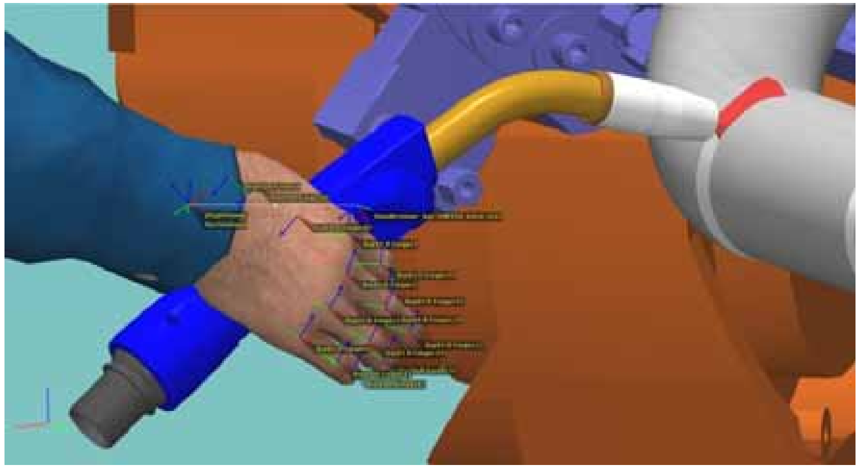
→ Flexible layout of the robot cell
→ Safety configuration adaptable for each mode

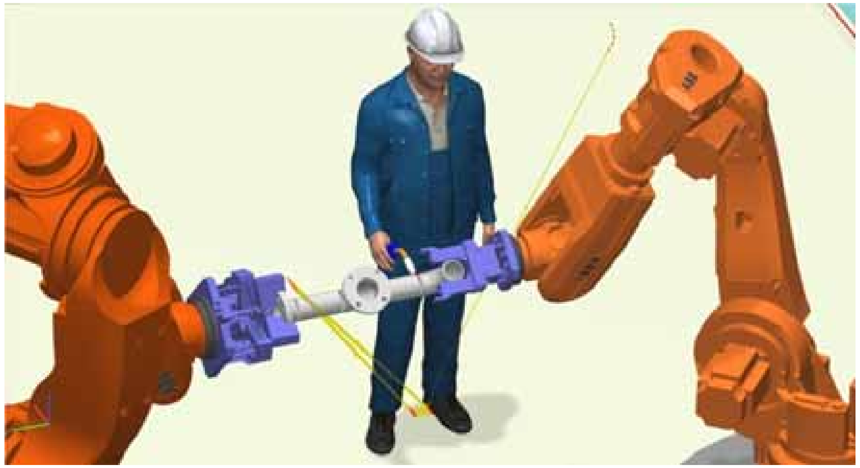




Offline Simulation of a Robot Assistance System

- simulating a direct collaboration between humans and robots requires a Digital Human Model (DHM) to perform collision analysis and evaluate ergonomic conditions in advance
- implementing a fully operational human kinematic, based on a skeleton model covered by a wire frame overlay and a database of different variation of body sizes
- main tasks of the implemented DHM: collision avoidance during the path planning and evaluation of the ergonomic conditions





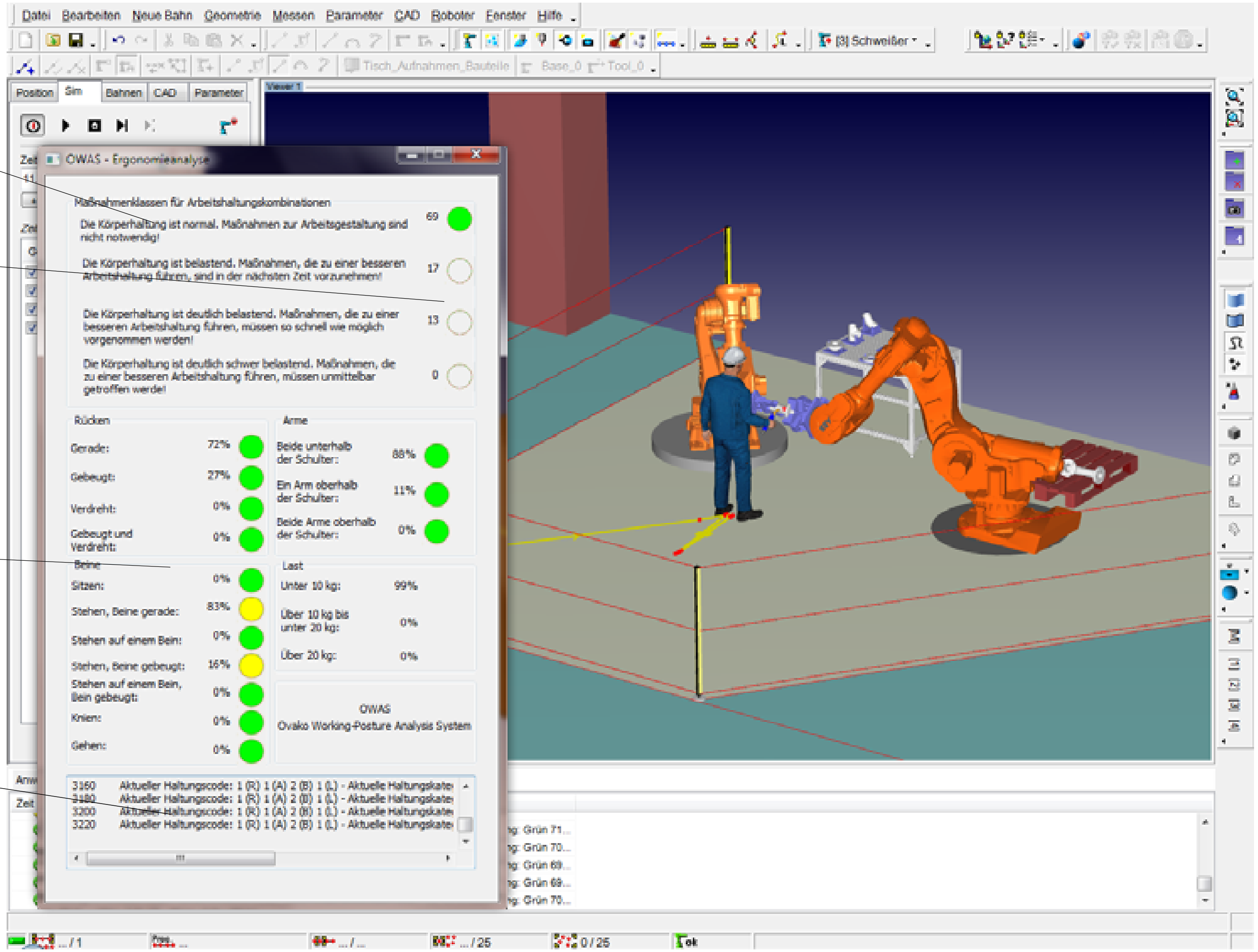
Combinated Human-Robot Simulation and using Ergonomic Assessment Procedure OWAS

Description for OWAS-Categories

Analysis of current posture combination

Detailed evaluation for back, arms, legs and load

Current posture code



Comparison

Hybrid Productions System *rorarob*

Institut für Produktionssysteme

Contact

Acknowledments

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carat robotic innovation

TU Dortmund University

Institute of Production Systems | www.IPS.DO

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