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Institut für Arbeitsschutz der
Deutschen Gesetzlichen Unfallversicherung

**Workshop on 31 August 2007 in Lengfurt – BG Metall Nord Süd**

**“What can, may and should collaborative robots do?”**

# Aspects for working out an acceptable injury risk in workplaces with collaborative robots from the point of view of the institutions for statutory accident insurance and prevention

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# Contents

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# Occupational safety basics – objective

- Machinery directive
- Relevant standards for robots: ISO/FDIS 10218 Parts 1 & 2
  - A hazard analysis must be drawn up!
  - BGZ report 5/2000 (in German) “Gefährdungsbeurteilung” (Hazard assessment) (support of plant hazard assessment by statutory accident insurance carriers: guides, procedural aids, catalogues, safety checks, brochures, etc.)
  - So far, there are not enough instructions for carrying out hazard analyses for workplaces that use collaborative robots.
  - Definition of the task:

    ***Drawing up of guidelines (checklists) for carrying out an hazard analysis for work tasks involving collaborative robots***

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# Main elements of hazards/risks

- **Mechanical hazards (ISO/FDIS 10218 Parts 1 & 2)**
  (clamping/squeezing, shearing off, cutting/severing, grasping, retracting/catching, bumping, coiling, twisting, tilting of the robot)
- **Hazards caused by disregard of ergonomic principles during the arrangement** (general ergonomic arrangement requirements; body postures: required postures, static postures, repetitions, difficult/impossible anatomical postures ➔ usability aspects when arranging the human-machine interfaces)
- **Psychological and mental hazards**
  (misconduct/stress: personal deficits: acceptance/competence conviction; high concentration/performance requirements, unexpected or overly complex processes)
- **Manipulation of the protective/control functions of a collaborative robot**
  *Report: "Manipulation von Schutzeinrichtungen an Maschinen", Februar 2006 (Manipulation of Machine Safeguards, February 2006)*
  - Estimate of manipulation frequency: 25 to 35% are manipulated
  - Accidents can occur in half of them
  - One-fourth of all machine accidents are attributable to manipulation

  What does this mean for workplaces that use collaborative robots?

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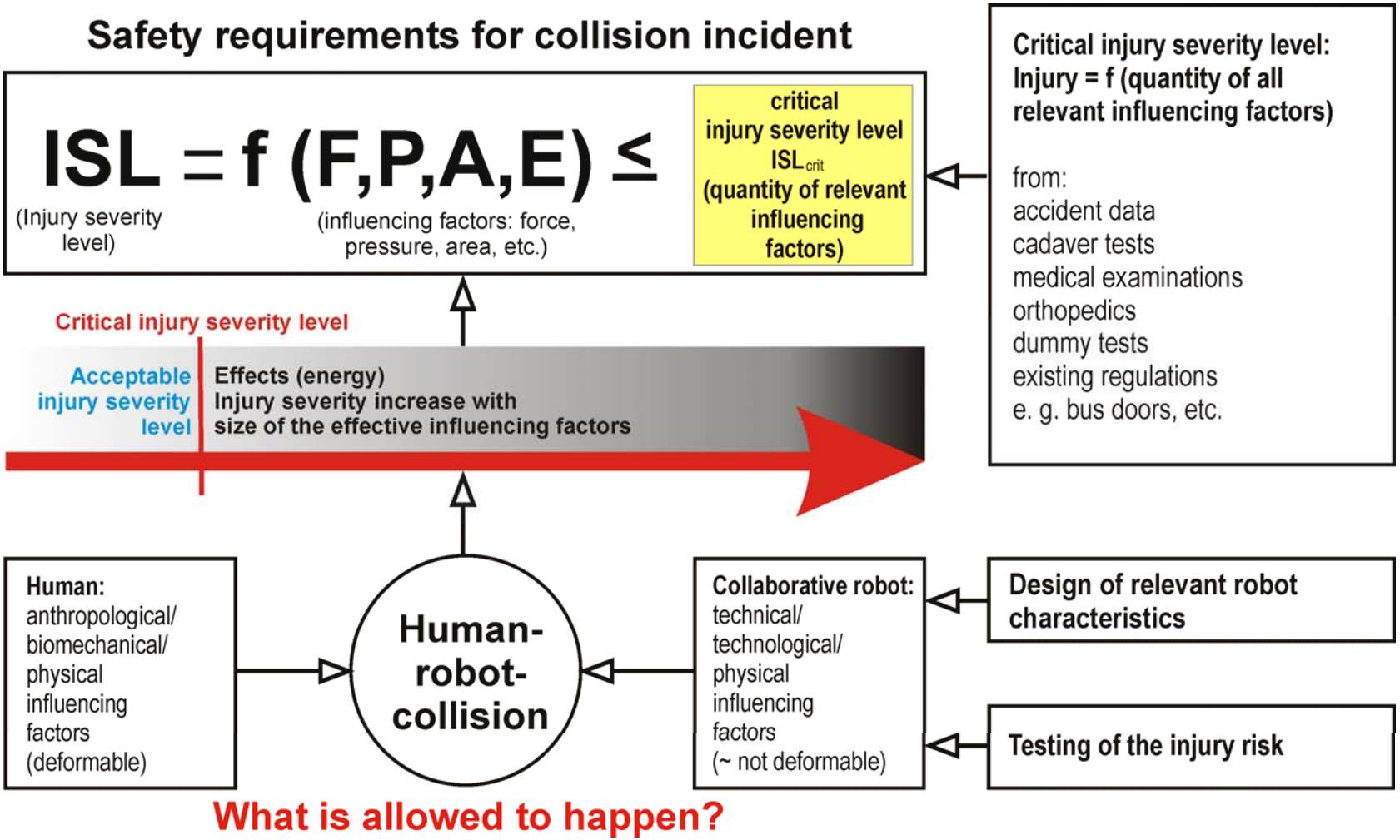
# Critical injury risk in a collision



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# Critical injury risk $IR_{crit}$

**Is this acceptable for us?**

- Determination for all relevant body regions (body model); classification for the purpose of differentiating injury severity
- Determination for all relevant types of strain (impacts, squeezing movements, etc.)
- Oriented towards injury severity scales (e. g. Abbreviated Injury Scale – AIS) and recognized injury classification such as ICD 10
- Formulation of an $IR_{crit}$ in “injury” and “causative influencing factors”
- Results:
  - Derivation of requirements: Set to limit and structural values for all body regions and types of strain
  - Arrangement data for design, control and safety functions (verifiability)

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# Relevant body regions

| MBR | | IR | |
|---|---|---|---|
| 1 | Full body | 1.1 | Total region |
| 2 | Head | 2.1 | Total region |
| | | 2.2 | Skull |
| | | 2.3 | Face |
| | | 2.4 | Eyes |
| | | 2.5 | Ears |
| | | 2.6 | Nose |
| | | 2.7 | Mouth |
| 3 | Neck | 3.1 | Total region |
| | | 3.2 | Larynx |
| | | 3.3 | Frontal region |
| | | 3.4 | Lateral region |
| | | 3.5 | Back region |
| | | 3.6 | Cervical spine |
| 4 | Upper extremities | 4.1 | Total region |
| | | 4.2 | Shoulders |
| | | 4.3 | Shoulder joints |
| | | 4.4 | Upper arms |
| | | 4.5 | Elbow joints |
| | | 4.6 | Lower arms |
| | | 4.7 | Hands |
| | | 4.8 | Hand joint |
| | | 4.9 | Finger |
| | | 4.10 | Finger joints |

| MBR | | IR | |
|---|---|---|---|
| 5 | Trunk | 5.1 | Total region |
| | | 5.2 | Thoracic wall |
| | | 5.3 | Thoracic organs |
| | | 5.4 | Thoracic spine |
| | | 5.5 | Stomach |
| | | 5.6 | Upper back |
| | | 5.7 | Lower back |
| | | 5.8 | Lumbar spine |
| 6 | Lower extremities | 6.1 | Total region |
| | | 6.2 | Pelvis |
| | | 6.3 | Hips |
| | | 6.4 | Hip joints |
| | | 6.5 | Upper thighs |
| | | 6.6 | Knee |
| | | 6.7 | Knee joints |
| | | 6.8 | Lower thighs |
| | | 6.9 | Feet |
| | | 6.10 | Feet joints |
| | | 6.11 | Toes |
| | | 6.12 | Toe joints |

| | |
|---|---|
| MBR | Main body region of body model |
| IR | Individual region of body model |

- Classification into main and individual regions
- Critical demands on
  - main and individual regions
  - types of strains

e. g.:

- ***Trunk***
  ***Impact incident***
  *Maximum force*
  *Maximum surface pressing*
- ***Lower extremities***
  ***Clamping/Squeezing incident***
  *Maximum clamping force*
  *Maximum surface pressing*
- ***Hands***
  ***Shearing incident***
  *Maximum shearing force*
  *Maximum shearing stress*
- *etc.*

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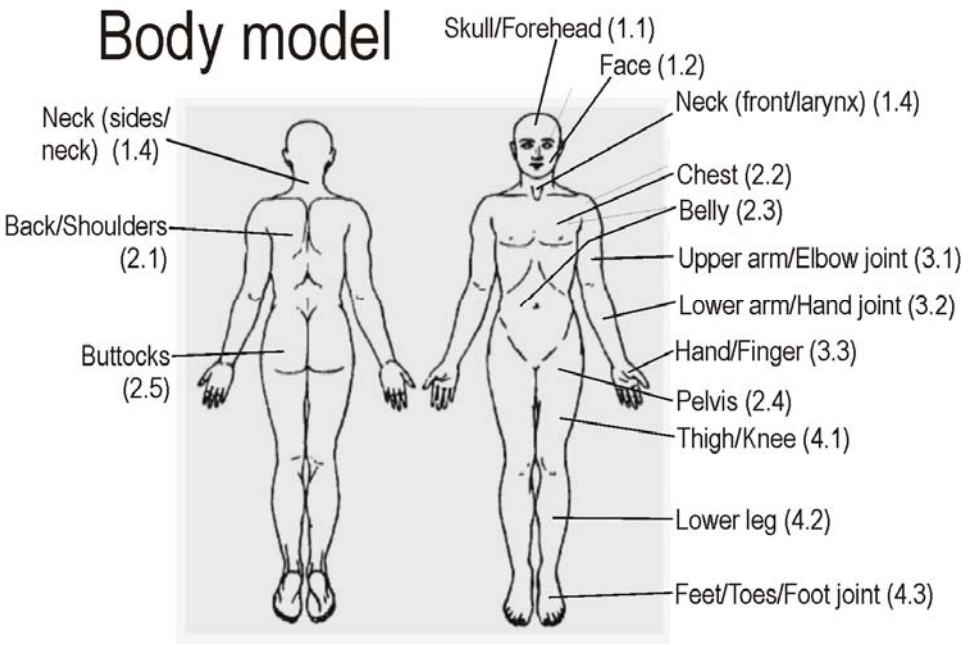
# Simple body model with injury criteria/structural criteria




## *Injury criteria*

- Impact force
- Squeezing/clamping force
- Pressure/surface pressing

## *Structural criteria*

- Softness/Compression capability, etc.

## *General requirements*

- No irreversible injuries; no inner injuries, no strongly bleeding wounds, no bone fractures

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# Physical ability aspects

- Specification of general health fitness for purposes of a minimum requirement
  - Criteria oriented towards the activity profile/risk profile (e. g. limited vision, restricted movement of extremities, hospital status, etc.)
- Check of physical ability
  - For example by following an investigation of an occupational medicine principle: “G25 – Driving, Controlling and Supervisory Activities” (distant/close visual acuity, spatial vision, color vision, visual field, hearing)
  - Investigation of illness status (no chronic/acute illnesses that lower relevant physical ability, specification of follow-up visit (every three years, for example), measures, recommendations if ability is limited, etc.)
  - Reaction time, perception, controls, confidence in own supervisory/competence ability

***Description of the task: Working out requirement criteria for determining physical ability (occupational physician/plant physician)***

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# Testing of the requirements (injury risk)

- Example (using hazard analysis as model ):
  - In a collision room, fingers and hands all the way to the lower arm region may be clamped or squeezed.
  - Hazard analysis → $IR_{crit}$ → Set (limit values)
  - Smallest of maximum clamping forces $CSF_{max}$ for body regions: fingers, hands and lower arms applies.
  - Requirement value is $CSF_{max}$ = 100 N
  - Additional requirements must be considered.
- Testing of occupational safety requirement values:
  - Simulation of the collision
  - Testing of the forces with a clamping/squeezing force-measuring instrument (e. g. with a measuring instrument for bus hatches and car windows activated by external forces)
- ***Evaluation***

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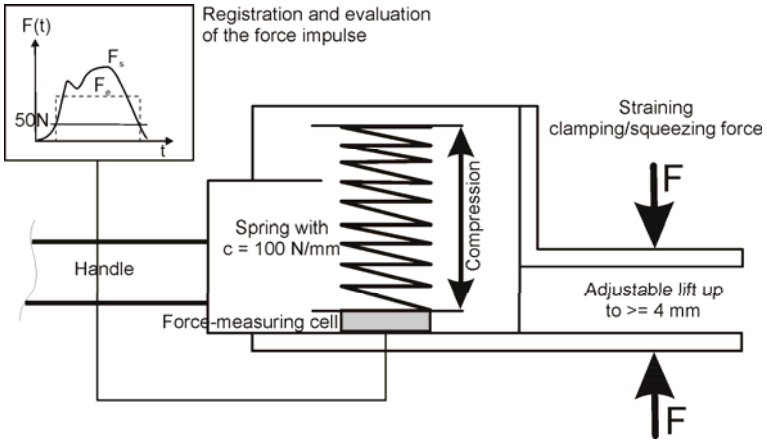
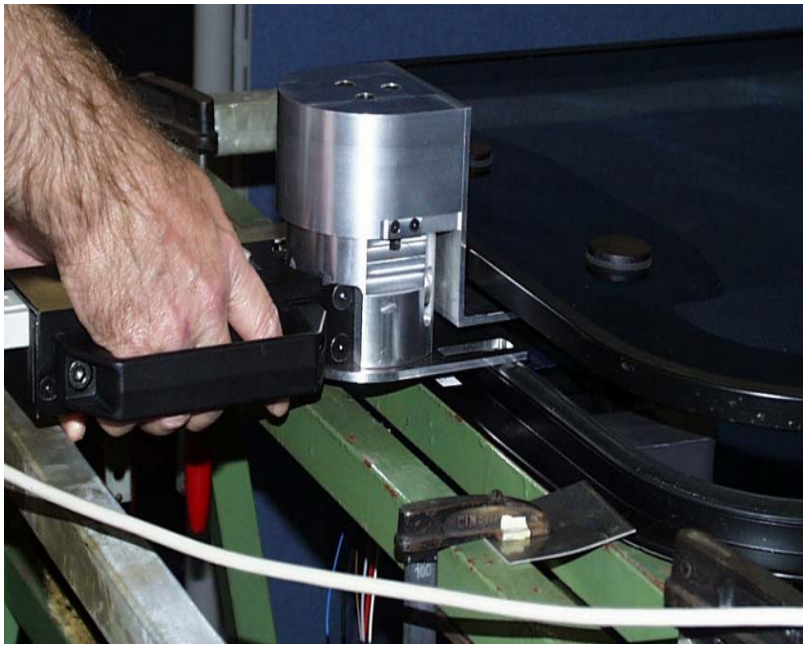
# Closing force measuring instrument for hatches/windows




- The clamping force is mechanical picked up by a lateral fork construction.
- In this way, forces can be measured in gap widths of up to 4 mm (window panes/hatches).

- Spring stiffness of 100 N/mm (roughly reproduces hand deformability)
- Recording of force impulse
- Calculation of peak force
- Calculation of clamping/squeezing force after 5 s, for example
- ***Evaluation***



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# Testing of the requirements (injury risk)

- Example (based on hazard analysis):
  - In a collision room, the head-neck region may be impacted.
  - Hazard analysis → $IR_{crit}$ → Set (limit values)
  - The lowest of maximum impact forces for individual regions $F_{max}$ = 120 N applies.
  - Further ergonomic and general requirements must be considered.
- Testing of occupational safety requirement values:
  - Simulation of impact collision with *biofidel testing bodies* (specific mechanical deformation properties of head-neck region, specific total inertia behavior of the body, reproducibility!)
  - Measurement of force/pressure on point of contact; measurement of internal accelarations
  - Application of biomechanical injury criteria (e. g. in neck region with the NIC (neck criteria), peak acceleration values, other kinematical quantities such as rotational accelerations, angles, etc.)
- ***Evaluation***

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# Summary and outlook

- The hazard analysis is essential for ensuring occupational safety during activities performed with collaborative robots.
- The drawing up of practical instructions with a clear, structured guide would be useful for creating the same, extensive requirement level.
- Recording and evaluation of hazards/risks that include interdisciplinary structure, physical ability and suitable differentiated measures
- Currently, there are several pending tasks that need to be researched:
  - Development of a body region model
  - Determination of injury severity (body regions and types of stresses)
  - Establishment of critical injury severities $IR_{crit}$
    (sets to requirement values: limit, guiding and arrangement values)
  - Physical ability test (health check, standard reaction and perception times)
  - Testing process for verifying occupational safety requirements
- ***Use of a team for processing the topics***
  ***(with the help of the German Occupational Physician Association)***