Paper No. 6045:

Requirements for hazard analyses referring to mechanical exposure in workplace applications with collaborative robots

Hans Jürgen Ottersbach, Michael Huelke
Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA)
Department "Accident Prevention and Product Safety",
Alte Heerstr. 111, D-53757 Sankt Augustin, FRGermany, http://www.dguv.de/ifa
Tel. +49 (0)2241 231 2680, FAX: +49 (0)2241 231 2234, E-Mail: hans-juergen.ottersbach@dguv.de

Key-words:
collaborative robot, collision risk, injury severity, injury criteria, limit values, body model, medical/biomedical requirements, test methods, work place arrangement

ABSTRACT

Collaborative Robots – a new field of industrial robots - work hand in hand with people carrying out work tasks in effective manner and high efficiency. Traditional safety guards for protecting people involved cannot be used any longer. The occupational safety and health requirements shall be ensured with respective arrangement of the work place application including alternative sensor systems and other safety measurements. Nonetheless a residual collision risk remains for respective collaborative work places and operating modes. Some and more global requirements are given in the new and revised standards for industrial robots but especially not enough medical/biomechanical requirements are available as base of risk assessment work to delimit the mechanical effects to people under collision risk. In cooperation with the Expert Committee for Machine Construction, Production Systems and Steel Construction the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) developed technological, medical/biomechanical, ergonomic and work organization requirements for the arrangement of collaborative work place applications and published them in BG/IFA recommendations. The document contains a simple body model with main and individual body regions, limit values for different injury criteria, methods for testing of the application of the injury criteria and a check list for the course of action within risk assessment work in practice. Due to these recommendations, workplaces with collaborative robots can be arranged so that the mechanical effects acting on persons that may occur as a result of collision do not exceed a tolerable extent. They can be designed in a way to ensure the required occupational safety for people in question.

1 Introduction

Collaborative industrial robots are complex machines that work hand in hand with people. In a joint working process, robots support and take the load off workers when for example, a robot lifts and positions a heavy workpiece while a person welds lightweight iron hooks. During this work activity, the person is very close to several robotic elements – for example, robot arm or tool – so the robot and person may touch one another. A similar situation takes place with mobile service surroundings in close proximity to people. Until now, guards were needed when using robots so the persons that were within the robot's working range could be safely protected against the mechanical effects of fast-moving robot parts. When the industrial robot standards were revised and updated, the new application field of collaborative robots was added as a supplement.

When collaborative robots are used, guards are no longer installed in certain working or collaboration rooms, so a robot-human collision risk cannot be entirely ruled out. Thus, technical protective measures other than guards must be taken to continuously determine the collision risk and minimize it as part of the robot control system – but a residual risk still exists. When a workplace that includes a collaborative robot is being planned, the user must carry out a risk assessment based on a legal framework such as machinery directive and industrial robot standards that should also include an evaluation of injury risks caused by robot-human collisions. In the standards that apply to industrial robots, however, there are not enough occupational safety requirements for evaluating these injury risks.

2 Activities

Acting on an initiative of the Expert Committee for Machine Construction, Production Systems and Steel Construction, the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) compiled in a development project the technological, medical/biomechanical, ergonomic and work schedule requirements made to such workplaces. They supplement and specify the requirements of the standards and have been summarized in BG/IFA recommendations. Due to these recommendations the IFA performs a lot of consulting work for robot manufacturer and application-processes in company's practice and standardisation groups.

3 Acceptable stress level and stress model

A collaborative work process carries a collision risk between the robot and concerned people. In case of a collision in the collaborative room - during the working tasks were carried out - those stressing effects are allowed which causes only small and tolerable injury severity. According to that, tolerable severe injuries are only skin and underlying tissue strains that do not penetrate the skin and tissue deeply and do not cause bleeding wounds. Fractures or other injuries of the musculoskeletal system must be ruled out.

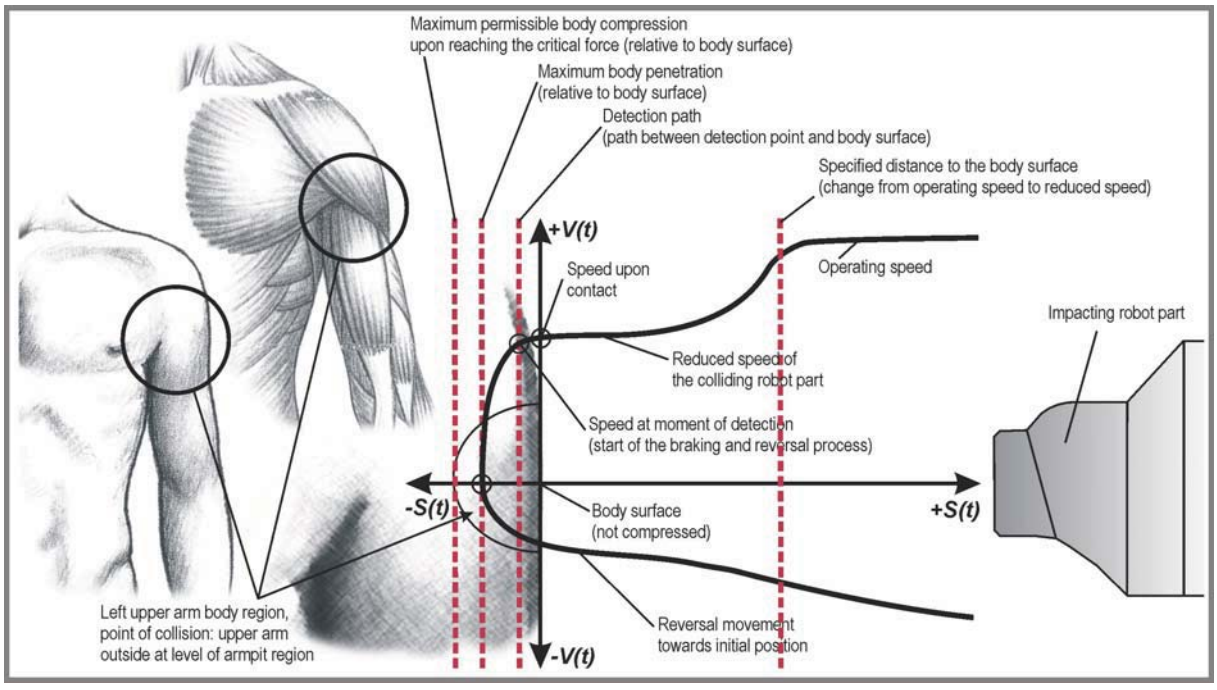
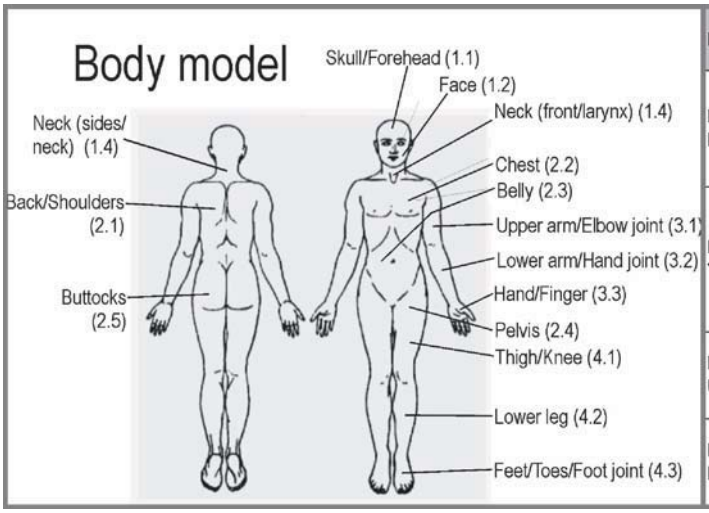


Figure 1: Kinematic process of a collision between a specific robot part and a human body; effected individual body region is the upper arm region – outside

Figure 1 shows a collision process between a specific robot part and the upper arm of a human. The determination of reduced speed, the appropriate detection of the starting collision process, the optimized arrangement of the shape of the colliding robot part and a controlled reversal movement which leads to minor penetration of the body point allows a contact between human and robot without generating of unacceptable injury severities.

4 Body model

The prEN ISO 10218 Part 2 requires a risk assessment work with provision of different body regions. The stress behavior of individual body regions differs considerably. A stress model which includes extensive and exact human-robot-collision has to apply to a useful body model.



Main body regions	Body region code	Individual body regions
Main region 1 : Head with neck	1.1	Skull/Forehead
	1.2	Face
	1.3	Neck (sides/neck)
	1.4	Neck (front/larynx)
Main region 2 : Trunk	2.1	Back/Shoulders
	2.2	Chest
	2.3	Belly
	2.4	Pelvis
	2.5	Buttocks
Main region 3 : Upper extremities	3.1	Upper arm/Elbow joint
	3.2	Lower arm/Hand joint
	3.3	Hand/Finger
Main region 4 : Lower extremities	4.1	Thigh/Knee
	4.2	Lower leg
	4.3	Feet/Toes/Joint

Figure 2: Body model with main and individual body regions for simple use in companies practice

A simple body model, illustrated in figure 2, with four main regions and fifteen individual body regions was created so all anthropometric points of the body surface can be allocated in the body model. The distribution and the description of the body regions shall allow clear decisions which body regions are affected with collision risks due to the specific work place application. In risk analyses all individual body regions under collision risk must be assigned and documented due to determined collaborative work space and adopted body positions of effected people.

5 Injury criteria and guiding limit values

In a human-robot-collision elastic/plastic deformations of certain body regions occur, whereas the colliding robotic structure (robot parts, tool, load object) is by and large not deformed. Thus, a three-dimensional contact area whose size and shape dynamically changes during the collision occurs on the body. Since partial dynamic collision forces and pressures that determine the injury potential are transferred to the contact area, limit values for these injury criteria “force” (as clamping/squeezing force or impact force) and “pressure/surface pressing” are set as medical/biomechanical requirements. Injury severity can be depicted by limit values of connected injury criteria.

Main body regions	Body region code	Individual body regions	CSF	IMF	PSP	CC
			[N]	[N]	[N/cm²]	[N/mm]
Main region 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
Main region 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
Main region 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
Main region 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

Figure 3: Limit values of the injury criteria “clamping/squeezing force”, “Impact force” and “pressure/surface pressing” relevant to main and individual body regions

The limit values given for the forces indicate the maximum permissible external acting total force on the collision area. To limit the pressure load acting during the collision phase, the maximum permissible partial pressure on the collision area is indicated. Therefore, observance of the limit values for both injury criteria ensures that the degree of injury stays within a tolerable range in the localized stress on a certain body part.

The orientating limit values (Figure 3) were established based on injury data from external mechanical strains that the IFA compiled from bibliographical references and databases. They have to be validated in the next years through extensive research work in cooperation with German medical universities.

6 BG/IFA recommendations

All results of the development project are summarized in BG/IFA recommendations which list occupational safety requirements for work tasks with collaborative robots that supplement or specify the requirements of parts 1 and 2 of the EN ISO 10218 standards. They are recommended to the users as part of risk assessment in work tasks performed with collaborative robots to ensure entirely accident prevention. Technological, medical/biomechanical, ergonomic and work organization requirements dealing with occupational safety measures are listed. Moreover, to verify the required limit values, measuring principles are described that must be technically implemented in measuring devices for the correct measuring of limit values for relevant injury criteria. Furthermore, these BG/IFA recommendations offer guiding values for arranging the collision areas of collaborative robots and a checklist for applying the recommendations as part of practical risk assessment.

7 Conclusion

The results of the project have been summarized in BG/IFA recommendations for arranging workplaces with collaborative robots. It contains extensive aids for applying occupational safety measures in practice, as part of risk assessments. A team of experts made of robot manufacturers, users and research organizations collaborated in working out the contents. Due to these recommendations, workplaces with collaborative robots can be set up so the mechanical effects acting on persons that may occur (in spite of being safeguarded) as a result of a collision do not exceed a tolerable extent. These workplaces can be designed in a way to ensure the required occupational safety for the person in question. The objective of protection for tasks involving collaborative robots is attained however only if the requirements of EN ISO 10218 Parts 1 and 2 are supplemented/implemented by all the requirements formulated in the present recommendations. The BG/IFA recommendations can be downloaded:

http://www.dguv.de/ifa/de/pra/kollaborierende_roboter/index.jsp (in German)

http://www.dguv.de/ifa/en/pra/kollaborierende_roboter/index.jsp (in English)