Deutsche Gesetzliche Unfallversicherung

BG/BGIA risk assessment recommendations according to machinery directive

Design of workplaces with collaborative robots

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Summary of contents

Preliminary remark

The BG/BGIA recommendations for the risk assessment according to the machinery directive are published by the

– German Institutions for Statutory Accident Insurance

  and

– the Institute for Occupational Safety and Health (BGIA).

Their objective is to provide companies an aid for the accident prevention related part of risk assessment.

These BG/BGIA recommendations were drawn up in collaboration with the

– Expert Committee for Machine Construction, Production Systems and Steel Construction of the Institution for Statutory Accident Insurance and Prevention Metall Nord Süd (Fachausschuss Maschinenbau, Fertigungssysteme, Stahlbau der Berufsgenossenschaft Metall Nord Süd).

1 Introduction

Parts 1 and 2 of the EN ISO 10218 standards define the occupational safety requirements for the “Collaborative Robots” application area in the industrial robot field. These requirements apply to workers’ job tasks that involve direct close contact between the collaborative robot and the workers.

The concept of Collaborative Robots used in this BG/BGIA recommendations includes – apart from the robot itself, the final effector, the tool adapted to the robotic arm with which the robot carries out tasks and the objects moved with it.

This applies, for example, to small robots (used continuously with persons as part of the manufacturing process in near and overlapping workrooms). The present BG/BGIA recommendations can also be useful in the field of Service Robots.

In these workplace applications with collaborative robots there are no longer separating protective safeguards for certain workrooms that can always prevent a collision risk between robot and affected person. In these cases, other suitable protective measures can be implemented to determine the possibility of a collision and constantly minimize it by controlling the robot. Nonetheless, a residual risk still remains.

Risk assessments must be carried out for such working areas that must take into account new occupational safety requirements that apply in case of a collision, thus keeping injury risks within low, tolerable levels should a collision occur.

The collisions covered by the present BG/BGIA recommendations are to be classified as undesired events occurring during working tasks, even though they need not necessarily result in interruption to or cessation of work by the persons concerned. Although wilful and (regarding a work task) essential contacts between a person and a technical work equipment are not meant here, a collision can nonetheless result in an interruption or even in a temporary cessation of the work task with – circumstances permitting – additional professional treatments of the affected person and a reassessment of the workplace.

2 Purpose

These BG/BGIA recommendations 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 user as part of risk assessment in work tasks performed with collaborative robots to ensure accident prevention.

Technological, medical/biomechanical, ergonomic and work organization requirements dealing with occupational safety measures are listed. Depending on risk analysis, further occupational safety requirements must be included.

Particular attention should be paid to the required medical and biomechanical values. These are determined by analogy from the limit values defined for stresses and the resulting strains on the human body at closing edges for all work and traffic areas. Provided they are observed, the strain upon the human body caused by mechanical effects remains at the low level corresponding to the state of the art and good engineering practice. 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.

Moreover, to verify the required limit values for occupational safety, measuring principles that must be technically implemented in measuring devices for the correct measuring of limit values for relevant injury criteria are described. In addition, a procedure for the metrological compilation of the required limit values is described.

Furthermore, these BG/BGIA recommendations offer an example for applying the BG/BGIA recommendations in practice (see Section 8), a template sheet for determining the limit values for several injury criteria to be applied in an isolated instance, guiding values for arranging the collision areas of collaborative robots, and a checklist for applying the BG/BGIA recommendations as part of practical risk assessment.

3 Collision and injury criteria

In the collisions considered herein – those between a collaborative robot and a person – elastic/plastic deformations of certain body regions occur, whereas the colliding robotic structure (partial robot, tool and/or load object areas) 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. If a body part is squeezed or gets stuck for a longer period, a three-dimensional deformation area of the body part remains.

Since partial dynamic collision forces and pressures that determine the injury potential are transferred to the contact area, limit values for the "force" (as clamping/squeezing force or impact force) "pressure/surface pressing" injury criteria are set in the medical/biomechanical requirements of these BG/BGIA recommendations. 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 strain on a certain body part.

The combination of both injury criteria is shown in Figure 1. In this risk analysis example, a collision is assessed as a clamping/squeezing event on the hand-finger system on which it is assumed that the acting limit values are a maximum external total force of 135 N and a maximum partial pressure of 50 N/cm² in the collision surface area.

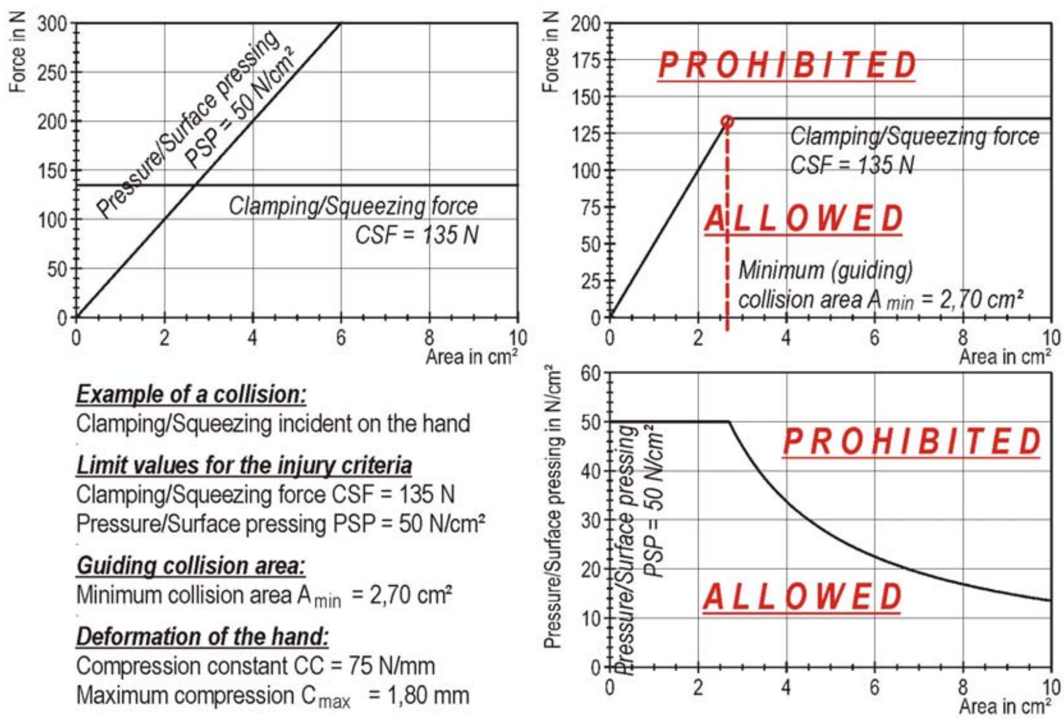

Figure 1: Exemplary representation of the injury criteria concept for assumed limit values of the "hand and finger" individual body part

In the left force/surface diagram, the limit value for the pressure has been given as a linear function and the limit value for the force as a constant. The limit value for the force 135 N limits surface pressing of 50 N/cm² with higher forces starting at 135 N, thereby generating the characteristic bent line of the upper right force/surface diagram.

The characteristic line divides the permitted surface pressing from the non-permitted ones. The bent spot is found at a surface area of 2.7 cm², which corresponds to the quotient from the limit values for force and pressure. As a result of this, for collision areas of 2.7 cm² and higher, pressures in the range of 50 N/cm² occur with homogeneous surface pressings. With collision areas below 2.7 cm², the external total force must be reduced in order not to exceed the limit value of 50 N/cm². In the lower right diagram, the course of the pressure (surface pressing) related to the collision surface is shown.

The limit value for the pressure (surface pressing) inhibits local overloads through excessive pressures caused by collision surfaces that are too small. The limit value for the maximum external collision force inhibits overloads of the body surroundings with larger collision surfaces in which excessive forces could occur under constant pressure if there were no limits.

The limit values for the force and pressure injury criteria that apply to the corresponding collision occurrence – determined as part of risk analysis – must be observed for all body areas under a collision risk, and acceptable test engineering proof is required for this. Creative measures implemented within the scope of sensory analysis, robot control and constructive arrangement of colliding robot parts allow compliance with limit values and therefore of a tolerable injury severity area.

If a dynamic force impulse with a subsequent clear reduction of the acting force all the way to the Zero level occurs during a collision, the limit values for the “impact force” injury criterion must be observed as occupational safety requirements. If, however, the force increases to a certain holding level without a significant initial dynamic exaggerated force increase, then the limit values for the “clamping/squeezing force” injury criterion must be observed. The limit values for both injury criteria, namely “clamping/squeezing force” and “impact force”, must be used if during the entire course of the force progression dynamic force impulses and holding levels are reached.

A favorable arrangement of the colliding surfaces of robot parts can decrease the spread of partial pressures in the collision surface. If a uniform and extensive strain occurs, the marginal force/marginal pressure quotient can be used to roughly approximate the estimate of a minimally required contact area measurement. With contact surfaces whose size is above this minimum value, it is possible to comply with the limit values for the pressure, as a reduction of the external strain force encourages this. This estimate serves as a guiding value for the constructive assessment and arrangement of affected robot regions.

Depending on injury criterion, deformation constants are given for all individual body regions for estimating the deformation paths until the critical force values are reached through colliding robot parts. These data are based on the assumption (sufficient upon initial approximation) of linear deformation behavior of body regions. The limit values for the injury criteria and the deformation constants are given for the individual parts of a detailed body model.

Figure 2 shows an example of a collision between a robot part and a contact area on the upper arm. To emphasize the speed/path behavior, a system of coordinates has been drawn on the point of contact, the upper arm. The diagram shows the course of the speed with the time when the collision was detected and the subsequent reversion of movement of the colliding robot part depending on the approach to the arm and its deformation behavior.

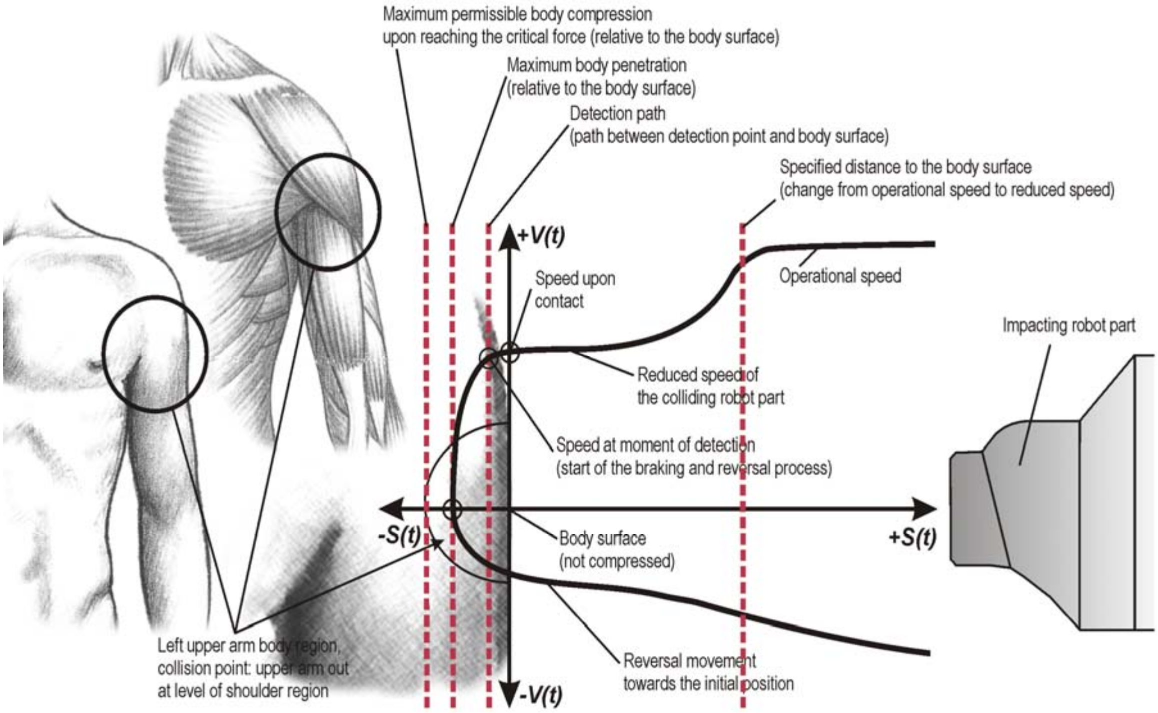

Figure 2: Example of a collision between a robot part and the upper arm with the speed/path course of the colliding robot part

Four border marks have been marked on path axis. In the path area before contact, the work speed has been regulated down to a reduced speed. When the speed is reduced, the distance to the body surface is indicated by the right marking.

If a collision occurs with decreasing distance (caused by a defect in the robot's controls, for example), the contact between upper arm and robot is detected by the force sensor in the robot's arm. So detection can be determined owing to a monitored force threshold, a certain deformation path is needed at the upper arm contact point, shown by the first path marking to the left of the zero point of the path axis.

At that point in time, the impacting robot part has slightly deformed the upper arm contact area with heretofore uniform reduced speed. When detection occurs, the braking and reversal process of the impacting robot is triggered, although its speed of execution depends on the robot's control and electromechanical movement behavior.

Until the speed is fully reduced to zero, the impacting robot part keeps deforming the upper arm. The second path marking to the left of the zero point shows the path at the point of speed reversal. Afterwards, the impacting robot part starts reversing itself with a programmed speed course until a safe basic position is reached. The third path marking to the left of the zero point of the path axis represents the sector of maximum permissible body deformation, which can be estimated as quotient from the permissible external straining force and the compression constant of the affected body area.

In this example, the tolerable injury severity on this body spot is reached by keeping the speed of the robot part near the upper arm reasonably reduced, by sensibly adjusting the contact detection with the available force sensory system, by the robot’s sufficiently available braking and reversal behavior and a relatively flat collision surface of the impacting robot part.

4 Course of action during application of the BG/BGIA recommendations

The course of action taken when applying these BG/BGIA recommendations in practice can be verified with a checklist, where the criteria, key words and aids to be followed are listed so a risk assessment can be drawn up for operating a collaborating robot. Both the operator and the robot manufacturer should make extensive information available for this purpose.

All elements, information, data, measurements, stipulations and results that must be performed and/or tested according to these BG/BGIA recommendations as part of the occupational safety partial risk assessment must be summed up and listed in an appropriate document. The order of the items and sub-items of the checklist (see page 34 of the enclosure) can be assumed to be the appropriate structure of such a document, which must be inserted into the total risk assessment for application in the workplace with a collaborative robot operation.

5 Requirements

The following sections list the technological, medical/biomechanical, ergonomic and work organization requirements for arranging work tasks with collaborative robots.

5.1 Technological requirements

a) In workplaces that use collaborative robots, the probability of a collision between a human being and a collaborative robot must be minimized with suitable measures, such as limiting the potential collision space.

b) If there is danger of a possible collision between a human being and a collaborative robot, no sharp, pointed, shearing or cutting edges and construction parts or rough surfaces may be present in the collision area.

c) In case of a possible collision, only extensive touching areas may occur. For this purpose, suitable housings, covers or separating planes can be used. The distance between two points of the external lines of the collision area lying opposite each other should be at least 5 mm, see Figure 3.

d) Possible collision areas must be made recognizable (black/yellow).

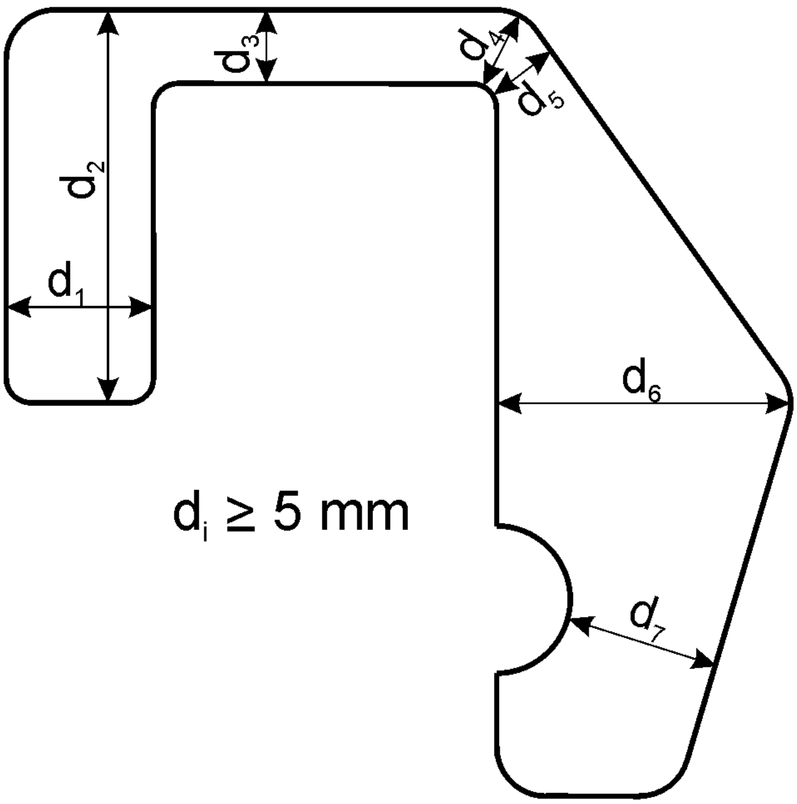

Figure 3: Collision areas with different distances of the external lines

5.2 Medical/biomechanical requirements

In this section, the medical/biomechanical requirements, a defined body model with main and individual regions, relevant injury criteria with their limit values, and characteristic values for the deformation constant of the established body regions are given. The limit values of the injury criteria have been stipulated on the basis of a literature survey. They shall be regarded as orientation values and might be adjusted owing to future research.

a) The medical/biomechanical requirements of these BG/BGIA recommendations refer to the individual body regions of the body model shown in Table 1 (see page 14). The body model establishes 4 main body regions and 15 individual body regions within the main regions so all anthropometric points of the body surface can be allocated in the body model.

b) To establish and delimit the individual body regions exposed in a collision risk, the body model according to Table 1 is used. All body regions can be identified through codification. In risk analysis, the individual body regions assigned to a collision risk are determined.

c) In the established main and individual body regions according to Table 1, only those stresses on the skin and underlying connecting or muscle tissue may occur where there was no deeper skin/tissue penetration accompanied by bloody wounds, fractures or other skeletal damages.

d) Furthermore, no injuries in which the injury severity category 1 of the Abbreviated Injury Scale (AIS[1]) and injury severities with the codifications for surface injuries of the ICD-10-GM 2006[2] may be exceeded.

e) In a collision risk occurring during intended use, the injury risk for the sense organs (eyes, ears, nose and mouth) must be lowered through special protective measures (goggles, for example).

f) The occupational safety measures listed herein do not ensure a sufficient protective effect in case of misuse inside a collaborative plant or by consciously provoking a collision with the collaborative robot.

g) The injury severity that refers to all individual body regions is sufficiently encompassed by the following injury criteria:

   - Clamping/Squeezing force (CSF, unit: N)
   - Impact force (IMF, unit: N)
   - Pressure/Surface pressing (PSP, unit: N/cm²)

   The injury severity area tolerated in the respective individual body regions is not exceeded if the limit values of the injury criteria according to Table 2 (see page15) are observed.

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[1] Abbreviated Injury Scale – AIS 2005

[2] ICD-10-GM 2006 International Statistical Classification of Diseases and Related Health Problems

h) Deformation constants are given for the individual body regions through which the maximum compression path of the individual body regions is established until the limit values are reached. A linear deformation behavior was assumed in this.

– Compression constant (CC, unit: N/mm)

i) In a risk analysis, the limit values for the injury criteria as required values to be observed and the data of the compression constants for all individual body regions under collision risk must be included.

j) Persons working together with collaborative robots that use all required protective measures and are under a collision risk must be healthy and qualified for these tasks. The plant physician determines the qualification. As a minimum, the person should comply with the requirements of the occupational medicine policy examination G25 “Driving, Controlling and Monitoring Tasks”.

Table 1: Body model with main regions, individual regions and codification

Main body regions	Body region (BR) 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

Body region (BR) code	Body region codification (total and individual regions)
Main body regions	Name of the main body regions
Individual body regions	Name of the individual body regions

Table 2: Limit values for the forces, pressures and body deformation constant according to the body regions of the body model

Body model – Main and individual regions with codification			Limit values of the required criteria			
BR		Regions	CSF	IMF	PSP	CC
			[N]	[N]	[N/cm²]	[N/mm]
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

BR	Body region with codification	IMF	Impact force
Regi-ons	Name of the individual body region	PSP	Pressure/Surface press-ing
CSF	Clamping/Squeezing force	CC	Compression constant

5.3 Ergonomic requirements

a) The ambient working space in which a person may collide with a collaborative robot must be arranged so the person can move sufficiently enough.

b) The person's perception, attention and thought may not be limited or disrupted by the work environment and the collaborative robot.

c) If the person collides with a collaborative robot, there shall be no more non-mechanical straining operational stresses on the person (such as exposure to flows or radiations, current linkage force) owing to the occurring loads.

5.4 Work organization requirements

a) The observance of all required occupational safety values according to risk assessment must be certified in detail.

b) When work is performed with collaborative robots, there must be access or admittance restrictions signaled by placement of signs such as "Unauthorized Access Prohibited".

c) The physical ability of a person who works with a collaborative robot and is therefore exposed to a collision risk should be checked and tested in regular intervals (see Section 5.2. j).

d) Persons who work with collaborative robots and are therefore exposed to collision risk must be informed regularly about the risks, emergencies and necessary safety measures. This is particularly important for installation, assembly or testing work, set-up operations and procedures.

e) The special basic work organization conditions for workplaces with collaborative robots must be tested and stipulated (for example, work hours, breaks, first aid cases, message book).

f) If a collision occurs, the person's fitness for work and the correct workplace design must be checked.

6 Testing the requirements

The permissible forces and pressures/surface pressings for the affected individual body regions listed in Table 1 must be tested according to relevant collision area points after setting up a workplace. To accomplish this, measuring devices with the following active principles must be used:

Force measuring devices

These devices measure static and dynamic collision forces. It should be possible to deform these measuring devices along one axis and they should have a linear deformation behavior. The malleable components of the devices (such as linear springs) must reproduce compression constants of the individual body regions (body stiffnesses, see Table 2) and be able to allow loads at least up to the limit values of the forces.

The measuring devices must have leveled, plane-parallel guided and sufficiently large collision areas in the direction of the effected collision force where the malleable measuring device components can be found between them. No permanent deformations may occur on the measuring devices as a result of the collision.

The force acting in a collision simulation must be measured with a suitable force measuring system in discrete time. The recording of the measured data must be done so all dynamic parts of the collision force are measured and registered. Owing to the composition of the measuring devices, no filtering effects may affect the measurement of the collision force, which must be determined with a maximum error of ± 1% from the measured value. Error linearity of the malleable components must lie within ± 5%.

Biofidel testing bodies

Biofidel testing bodies must be able to reproduce – for verifying the limit values for forces, see Table 2 – the mechanical movement, load and deformation behavior of the individual body regions (see table 1) according to the specific work attitude in which a collision may occur.

In the biofidel testing body, there is a force sensory mechanism that can measure the magnitude and direction of the force acting outside. Depending on collision behavior, a three dimensional force measurement must be carried out. This impact force should be measured in discrete time.

The recording of the measuring data must be done so all dynamic parts of the collision force are measured and registered. Owing to the composition of the biofidel testing body and of the force measuring system, no filtering effects may affect the measurement of the collision force, which must be determined with a maximum error of ± 1% from the measured value.

Pressure measuring devices

It must be possible to verify the limit values for the pressure/surface pressing (see Table 2) with these measuring devices. Additionally, the pressure measuring sensory system must be adapted to the relevant impact surfaces of biofidel testing bodies so the pressure can be measured during the intended movement and deformation behavior.

The pressure measuring sensory system may not cause a distorting damping of the impact impulse and have no influence whatsoever on the forces being measured, especially the peak forces. The pressure measuring devices must measure at least the highest partial pressure, but if possible the total pressure distribution within the colliding surface. The measuring sensory system must be able to measure the entire collision area and partial pressures with sensor areas ≤ 10 mm^2. Partial or peak pressure measurements must be carried out with a maximum error of ± 2.5% from the measured value.

7 Approach to be taken during the metrological compilation of injury criteria

Measuring equipment is needed for verifying compliance with the limit values for the current injury criteria stipulated for the corresponding application. These measuring instruments must fulfil the operating principles for measuring collision forces and pressures described in Section 6 and for a specific movement behavior caused by their construction design and the elements employed.

Various measuring instruments available on the market (but with technical modifications) can be used for measuring the impact or clamping/squeezing forces. Thus, the proof of the permitted force load areas required here can be done only with suitable force-measuring instruments.

Although there are various measuring methods for registering the maximum partial pressure acting on a collision surface, there are currently no standardized measuring instruments yet that can adequately fulfil the required operating principles according to Section 6 and ensure a uniform testing approach. Such measuring instruments are presently under development.

If a metrological compilation of the permissible maximum partial pressures is not possible, then calculations of the occurring pressures/surface pressings in all affected types of collisions and points are required for temporary assessment. These guiding calculations can be carried out on the basis of the principle of force measurements and more precise collision area measurements. For example, impression methods (such as impressions done with blueprints or thicker, plastic deformation layers of suitable materials) for compiling collision surfaces can be used. The measuring accuracy of the employed determination process must be given.

More biofidel measuring instruments for the synchronous compilation of the injury criteria in a person’s practice-oriented body behavior under certain collision conditions are being developed right now.

8 Example for applying the BG/BGIA recommendations

This chapter describes an easy example for applying the BG/BGIA recommendations, especially so the medical/biomechanical requirements can be met in operational practice. To illustrate the example, a certain workplace scenario is assumed for which a risk assessment must be carried out. In this example, the risks are mainly analyzed with regard to the medical/biomechanical requirements and the respective calculations for the implementation of suitable measures for achieving the protection objective are described.

Assumed workplace scenario

A work activity in an assembly space which is separated into 2 separate sub-spaces with a dividing wall is assumed as workplace scenario. One person works in the first sub-space and a collaborative robot works in the second one. The dividing wall has an especially designed window through which the person can reach into the second sub-space. Above the open window area there is a transparent wall area so the person can see what is going on in sub-space 2. The person is expected to carry out a certain work task with the help of the collaborative robot.

Work task

A series of consoles has to be assembled using various electromechanical components to become a serviceable module of a larger machine. A conveyor belt continuously supplies sub-space 1 with prepared consoles. After the console and certain quality controls have been completed, the modules have to be further transported in sub-space 1 on another conveyor belt to their next destination. The work process has been set up so the entire module production sequence can be done efficiently in a process that mixes manual and robotic activities.

Specific work task

The person in sub-space 1 takes a console off the conveyor belt and carries out several assembly steps using short electrical cables and air hoses as well as making different adjustments on the console. In sub-space 2, there is a larger work bench directly at the window of the dividing wall. A collaborative robot has been placed behind it. The person takes the console with both hands and takes it through the window opening of the dividing wall to a certain assembly installation on the work bench.

This is where the console is supposed to be fastened into a clamping frame so it can be equipped with electromechanical elements. The exact positioning and fastening of the console on the frame is done by the robot with pneumatic tongs (the robot’s tool). The person holds the console inside the catchment area of the clamping fixation point. The collaborative robot takes the console and pulls it into the clamping fixation point until it is finally positioned for being equipped.

While the robot equips the console, the previously mounted cables and hose assemblies must be held back with the hands from the console areas to be equipped. When doing this, the cables and hose assemblies must be held back in various directions so the robot’s plug-in process does not damage the wiring or the plug-in process itself is not hindered. The robot takes the plug-in elements from a conveyor belt located above the window opening of sub-space 2. After the plug-in modules have been assembled into the console, the robot pushes the equipped console once again out of its clamping fixation point so the person can take the finished module with his hands through the window opening and carry it back to sub-space 1.

In sub-space 1, the person then carries out several quality control tests on the completed console and subsequently places it on the conveyor belt so it is transported to the next work location. The entire production process for a console lasts 4 minutes; the partial tasks performed in collaborative work in sub-space 2 last two minutes.

Determination of the “collaborative operation”

During all partial tasks performed by the collaborative robot, both hand/arm regions of the person remain in the sub-space 2 for clamping the console in a fixed position, carrying out the cable and connection safety work and recycle the console in sub-space 2. In all movements of the robotic arm that occur in sub-space 2, the robotic arm and the tool used are very close to the worker’s hand/arm regions. During the entire collaborative work, the minimal distances of all upper extremity anthropometric points to the important robotic parts are between 8 and 43 cm. If the work task is performed as intended, these distances are not under-run. Therefore, for all upper extremities there is a collision risk while the activities take place in the second workspace. Clearly, we have here a collaborative task in accordance with EN ISO 10218 Part 2 whose scope can be precisely determined and for which a risk assessment must be drawn up.

Risk analysis in case of collision and measures

The robot has a force sensory system for measuring the total force in the complete work process. During the set-up, the course of the force that depends on time and precise tool position is determined and is thus given as the TARGET value for the course of the force. In 100 test runs, a spread of ± 8 N in the total course of the force was measured.

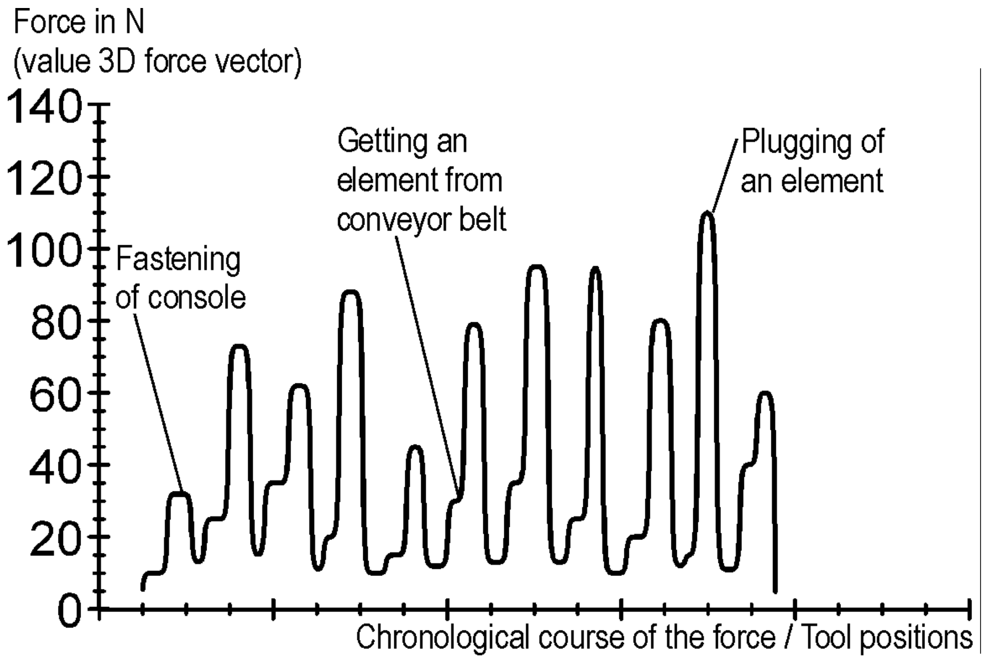

Figure 4: Target force value curve for robot tasks

In the work tasks to be performed, the course of the signal of the total force with the determined reproducibility range is applied when guiding the robot for collision detection. During the work process, the ACTUAL value of the total force (amount) is constantly compared with the TARGET value (amount) on the corresponding position point of the force value curve.

A "start of the collision incident" is detected when the reproducibility area of │± 8 N│ is established by the ACTUAL-TARGET value difference (absolute value) │ATD│.

Collision incident: I ACTUAL force value – TARGET force value I > 8 N

After a collision incident has been determined, the control system reacts directly by immediately moving back the robotic arm (with tool and possible plug-in element) to a non-critical basic position. The safety path to that position is pre-determined in the control system of the robot.

When a collision is detected, however, an external impulse occurs on the affected body region. Therefore, there is an injury risk with a certain injury severity that must lie within a permissible (i.e., tolerable) range.

To comply with the permissible injury severity for possible collisions within the collaborative work task, the medical/biomechanical requirements of the BG/BGIA recommendations are consulted. At first, the individual body regions for which there is a collision risk are determined according to the body model using the template sheet in the enclosure (see page 30). In this work process, there is a collision risk for all the upper extremities, and the individual body regions with the 3.1, 3.2 und 3.3 body region codification are marked. The overall limit values for the upper extremities are then determined with the limit values that apply to these body regions.

Since in this case only collision impacts can occur (immediate reversal after collision detection), the minimum value for the upper extremities is calculated from the 3 limit values of the injury criterion "impact force". The minimum limit value from 190 N, 220 N, and 180 N is IMF_{total} = 180 N. The values for permissible upper extremity clamping/ squeezing forces are not considered. For determining the maximum permissible partial pressure on the collision area, the minimum value from the 3 limit values for the upper extremities is taken as well, namely 50 N/cm², 50 N/cm², and 60 N/cm² with PSP_{total} = 50 N/cm².

In addition, the maximum value from the 3 constants is taken for calculating the compression constant for the hand/arm regions, namely 30 N/mm, 40 N/mm, and 75 N/mm and established as overall compression constant CC_{total} = 75 N/mm. The collision data are summarized as follows (see table 3):

Table 3: Summary of marginal conditions and requirements for the collision case

Parameters to be determined	Determinations
Individual body regions with collision risk (determination in the template sheet, page 30)	– Body region code 3.1 “Upper arm/Elbow joint” – Body region code 3.2 “Lower arm/Hand joint” – Body region code 3.3 “Hand/Finger”
Total body region with collision risk	Complete hands and arms to shoulder region (all upper extremities)
Determined collision conditions	Impacts on upper extremities, no clamping or squeezing
Injury criteria for determined collision conditions	– Impact force – Pressure/Surface pressing
Total limit values	– Overall impact force IMF_{total} ≤ 180 N – Overall pressure PSP_{total} ≤ 50 N/cm²
Compression constant	– Compression constant CC_{total} = 75 N/mm

With a suitably designed movement behavior of the collaborative robot and a suitable constructive arrangement of the colliding robotic parts, it is possible to comply with the permissible impact force and the permissible partial pressure in the collision area.

Measures for complying with the limit value of the injury criterion “Impact Force”

According to the conditions given above, a collision is detected as soon as the reproducibility range of the TARGET force value curve of ⎪8 N⎪ is exceeded by the value of the ACTUAL-TARGET difference in the force value ⎪ATD⎪. As soon as the force vector value deviates by more than 8 N from the TARGET force value that corresponds to that position, a collision that the control system reports as collision incident occurs.

A rapidly increasing impact force is effected in the collision area created by certain robot parts and the hand/arm regions. After the collision incident is detected, a reversal of the robotic arm occurs as quickly as possible. The guiding system must carry out this reversal extremely quickly so that the increasing impact force will not exceed the limit value of IMF_{total} = 180 N in the time period between collision determination and loosening of the robot parts from the body region. The lower the magnitude of the force in which a collision incident can be detected, the lower will also be the partial pressures acting on the collision area. Apart from the limit value for the impact force that may not be exceeded, the limit value for the maximum partial pressure in the collision area may not be exceeded either. Sensitive collision detection makes it easier to comply with this requirement.

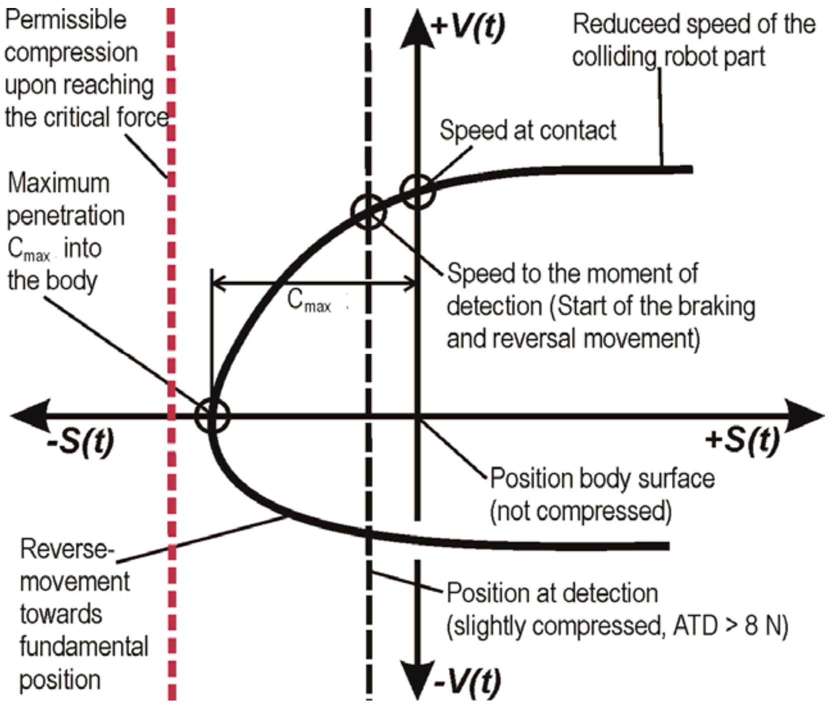

Figure 5: Speed/Path behavior of the colliding robot part in the collision phase

With the pre-determined compression constant it is possible to calculate the compression path until the critical force is reached. For an impact force IMF_{total} = 180 N and a compression constant CC_{total} = 75 N/mm, we get a compression path of 2.4 mm. The time it takes for the breaking process to reach a standstill and when the reversal process should have begun can be estimated with the braking behavior on the robot's technical collision point and especially with the impact speed. Thereby can the efficiency of the robot's control system in effecting the necessary reversal movement be judged and adapted. Depending on the backtracking path of the colliding robot part, the guiding system's reactive capacity and the robot's mechanical reacting capacity, a suitable reversal action must be determined and installed (see Figure 5) so the permissible limit value for the collision force is not exceeded.

Measures for complying with the limit value of the injury criterion "Pressure/Surface pressing"

Apart from complying with the limit value for the external overall impact force, compliance with the limit value for the injury criterion "Pressure/Surface pressing" is also necessary. The collision area changes with the duration of the collision, i.e. during the time range with contact, dynamically in shape and size. The same applies to the pressure distribution acting on it. The limit value PSP_{total} = 50 N/cm² given for the maximum pressure must be understood as limit value for the maximum partial pressure in the collision area.

Depending on colliding robot part and body region, the maximum partial pressure acting on the collision area can exceed the fixed partial pressure limit value PSP_{total} = 50 N/cm² in spite of a maintained external overall force IMF_{total}= 180 N. The partial pressure can be metrologically determined with measuring devices that have the acting principles described in Section 6.

The comparison of collision geometry of the involved robot part with reference areas can be consulted as guiding estimate to check whether the occupational safety requirement for the permissible pressure on the surface is being met. When in a collision a uniform pressure distribution is assumed in the collision area, then for achieving the protection objective there must be an acting surface of at least A_{ref} = 3.6 cm² with a prescribed limit value of 180 N for the impact force and permissible pressure/surface pressings of 50 N/cm², 50 N/cm², and 60 N/cm² on the upper extremities.

This value can be taken as guiding value for assessing the shape and size of the collision area. If in the example given here, one assumes an acting surface of at least 3.6 cm² as condition for complying with the limit value for pressure/surface pressing, then characteristic measurements for various collision area forms (reference areas) result from this value. They can be compared with the actual collision areas of the affected robot part and thus be used for a rough complied/not complied estimate of the collision pressure. The characteristic dimensions for various reference areas having the area of 3.6 cm² are given in the following table.

Table 4: Characteristic dimensions of different reference areas with a 3.6 cm² surface area

Calculation of characteristic dimensions for a 3.6 cm² surface				
Reference areas	Characteristic dimension	Name	Value in cm	Remarks
Circle	Diameter	DC_{ref}	2.14	
Ring surface	Inside diameter	$IDR50_{ref}$	4.52	With an outside diameter of 5.00 cm
	Inside diameter	$IDR40_{ref}$	3.38	With an outside diameter of 4.00 cm
	Inside diameter	$IDR30_{ref}$	2.10	With an outside diameter of 3.00 cm
	Inside diameter	$IDR25_{ref}$	1.29	With an outside diameter of 2.50 cm
Square	Lateral length	LS_{ref}	1.89	
Rectangle	2nd lateral length	$SR25_{ref}$	1.44	With a 1st lateral length S1R of 2.50 cm
	2nd lateral length	$SR20_{ref}$	1.8	With a 1st lateral length S1R of 2.00 cm
	2nd lateral length	$SR15_{ref}$	2.4	With a 1st lateral length S1R of 1.50 cm
	2nd lateral length	$SR10_{ref}$	3.6	With a 1st lateral length S1R of 1.00 cm
	2nd lateral length	$SR5_{ref}$	7.2	With a 1st lateral length S1R of 0.50 cm

Tables 6 and 7 show the guiding data for arranging the collision areas for all individual body regions of the body model according to the model of Table 4. In addition to them, the maximum permissible compression path S_{com} and the deformation work performed DW_{ref} upon reaching a force limit value are given. If a dull collision mode with the robotic tool is assumed (tongs, see Figure 6), the collision area will be 4.8 cm² and this could mean – compared to the estimated minimum collision area of 3.6 cm² – compliance with the permissible surface pressing. Circumstances permitting, this protection objective could be achieved with small arrangements on the tool.

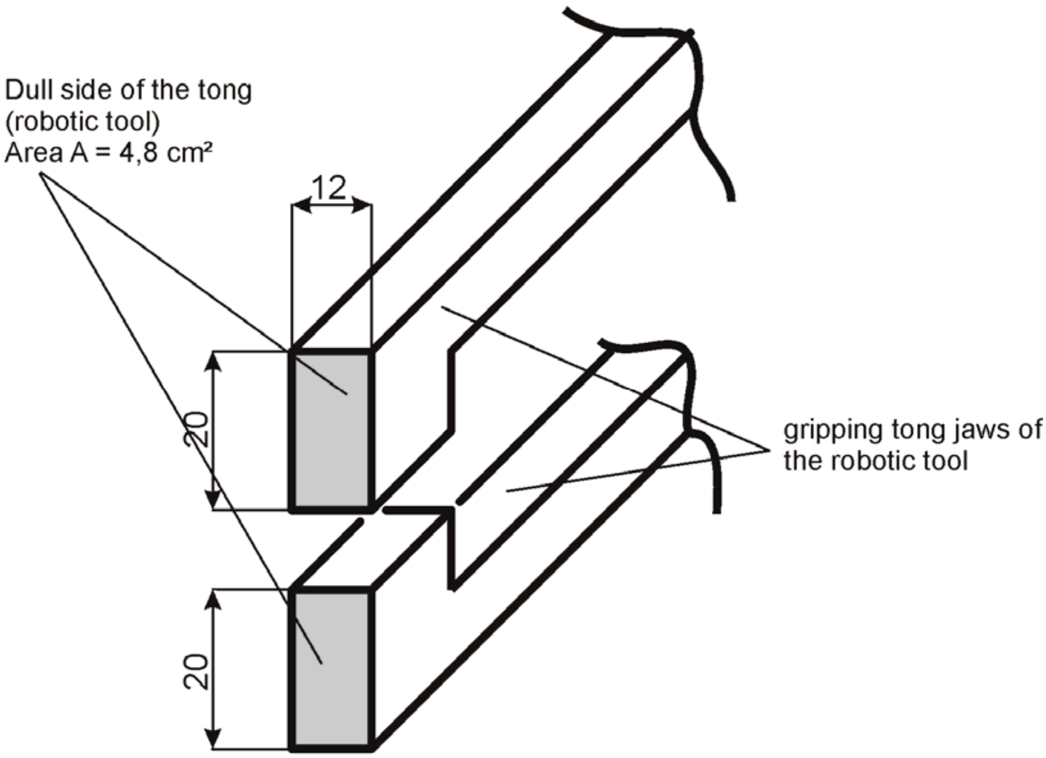

Figure 6: Gripping tong jaws of the robotic tool

Possible design changes for reducing partial pressures are an increase of the active surface measurements and an improved, three-dimensional surface shape oriented to the colliding body part. Reductions of the external peak impact force (for example, by diminishing the collision speed) also enter into the pressure distribution reduction. In this example, optimizations of the collision speed, the constructive design of the collision area, the sensitivity of the collision detection and the arrangement of the reversal process are basically a possibility. Further measures may be necessary depending on circumstances.

This example describes a typical application of the medical/biomechanical requirements of these BG/BGIA recommendations. The calculations and design aids listed as examples allow one to prevent inadmissible injury risks in intended use. The additional occupational safety requirements of these BG/BGIA recommendations must also be met for collaborative operation. The overall protection objective is achieved when all occupational safety requirements that supplement or specify the standards ISO 10218 Parts 1 and 2 are met.

9 Documentation

The requirements for the affected individual body regions and the measures and tests carried out to this effect for ensuring compliance with the requirements must be documented for the special work task and are included in the workplace risk assessment. The requirements of standard EN ISO 14121-1: 2007, Section 9 “Documentation”, apply to all required documents that must be drawn up as part of these BG/BGIA recommendations.

A template sheet for establishing affected individual body regions and subsequent applicable limit values for use in risk assessment is enclosed. After the affected body regions have been established, the minimum limit values for forces and pressure/surface pressing as well as the highest compression constant can be entered into a total line for later processing.

Enclosures

1 The template sheet contains the limit values for the injury criteria and the compression constants for all individual body regions. In a risk assessment, it can be used for determining the body regions subject to collision risk. Thus, the limit and guiding values pertaining to the affected body regions apply depending on the stipulated type of collision.

2 Definitions of guiding arrangement measurements for collision areas

3 Arrangement values based on the clamping/squeezing forces from Table 2

4 Arrangement values based on the impact forces from Table 2

5 Checklist and recommendations for applying the BG/BGIA recommendations in practice.

Enclosures

1 Template sheet for determining body regions and limit values of a collision incident from Table 2

Guiding limit values of the injury criteria and specification of the compression constants for individual body regions according to Table 1

Method

The individual body regions under collision risk are determined and marked in the column "X?". As summarizing limit values, the minimum values for forces and pressures are taken; for body deformation, the highest figure of the compression constants within the selected individual body parts is determined and documented in the last line of the table.

Main and individual regions of the body model Mark affected regions with X!				Limit values of the required criteria			
BR		X?	Regions	CSF [N]	IMF [N]	PSP [N/cm²]	CC [N/mm]
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
Summary of the limit values and deformation constants				Min	Min	Min	Max

BR	Body region	IMF	Impact force
Regions	Name of body region (total and individual regions)	PSP	Pressure/Surface pressing
CSF	Clamping/Squeezing force	CC	Compression constant

Note: Owing to future research, the limit values given in the Table can be adjusted in subsequent revisions of the BG/BGIA recommendations.

Enclosures

2 Definitions of guiding arrangement measurements for collision areas

Starting with the limit values for the injury criteria and the compression constants for the individual body regions, more measurements that can be used for arranging the collision area are obtained.

The maximum compression paths [mm] and maximum deformation work [Nm] are obtained for the individual body regions through the limit values for the force and the compression constants. From the limit values of the forces – clamping/squeezing force CSF or impact force IMF – and the pressures/surface pressings PSP, we get reference areas and their characteristic dimensions for certain basic shapes that can be used for estimating collision load under given collision area. They represent minimum specifications for collision areas acting on a plane that, when complied with, do not exceed the two limit values for force and pressure.

The table 5 gives the name, unit and definition of the measurements derived from limit values and the deformation constant.

Table 5: Name, unit and definition of derived arrangement dimensions for possible collision area

Magnitude	Unit	Derived arrangement dimensions
S_{com}	mm	Maximum compression path in the individual body region until limit values of clamping/squeezing force or impact force are reached
A_{ref}	cm²	Reference area (ratio of clamping/squeezing force or impact force and pressure/surface pressing)
DW_{ref}	Nm	Deformation work at the individual body region when the limit values of clamping/squeezing force or impact force are reached
DC_{ref}	mm	Circle – Diameter of a circular area
$IDR50_{ref}$	mm	Circular ring – Inner diameter of a circular ring with an outer diameter of 50 mm
$IDR40_{ref}$	mm	Circular ring – Inner diameter of a circular ring with an outer diameter of 40 mm
$IDR30_{ref}$	mm	Circular ring – Inner diameter of a circular ring with an outer diameter of 30 mm
$IDR25_{ref}$	mm	Circular ring – Inner diameter of a circular ring with an outer diameter of 25 mm
LS_{ref}	mm	Square – Lateral length of a square area
$SR25_{ref}$	mm	Rectangle – 2nd lateral length of a rectangular shape with a 1st lateral length of 25 mm
$SR20_{ref}$	mm	Rectangle – 2nd lateral length of a rectangular shape with a 1st lateral length of 20 mm
$SR15_{ref}$	mm	Rectangle – 2nd lateral length of a rectangular shape with a 1st lateral length of 15 mm
$SR10_{ref}$	mm	Rectangle – 2nd lateral length of a rectangular shape with a 1st lateral length of 10 mm
$SR5_{ref}$	mm	Rectangle – 2nd lateral length of a rectangular shape with a 1st lateral length of 5 mm

Starting with the limit values for the clamping/squeezing forces and the impact forces, the calculations of the guiding values are listed in the tables 6 and 7 and shown in an example.

Enclosures

3 Arrangement values based on the clamping/squeezing forces from Table 2

Table 6: Guiding constructive key data as arrangement aids based on the permissible clamping/squeezing forces

Body model with individual body regions and codification		Limit values of the requirement criteria			Compression path, compression work and surface size			Characteristic measurements of reference areas										
BR	Individual body regions	N	N/cm²	N/mm	mm	Nm	cm²	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
		CSF	PSP	CC	S_{com}	DW_{ref}	A_{ref}	DC_{ref}	$IDR50_{ref}$	$IDR40_{ref}$	$IDR30_{ref}$	$IDR25_{ref}$	LS_{ref}	$SR25_{ref}$	$SR20_{ref}$	$SR15_{ref}$	$SR10_{ref}$	$SR5_{ref}$
1.1	Skull/Forehead	130	30	150	0.87	0.06	4.33	23.5	44.1	32.4	18.7	8.6	20.8	17.3	21.7	28.9	43.3	86.7
1.2	Face	65	20	75	0.87	0.03	3.25	20.3	45.7	34.4	22.0	14.5	18.0	13.0	16.3	21.7	32.5	65.0
1.3	Neck (sides/neck)	145	50	50	2.90	0.21	2.90	19.2	46.2	35.1	23.0	16.0	17.0	11.6	14.5	19.3	29.0	58.0
1.4	Neck (front/larynx)	35	10	10	3.50	0.06	3.50	21.1	45.3	34.0	21.3	13.4	18.7	14.0	17.5	23.3	35.0	70.0
2.1	Back/Shoulders	210	70	35	6.00	0.63	3.00	19.5	46.0	34.9	22.8	15.6	17.3	12.0	15.0	20.0	30.0	60.0
2.2	Chest	140	45	25	5.60	0.39	3.11	19.9	45.9	34.7	22.4	15.1	17.6	12.4	15.6	20.7	31.1	62.2
2.3	Belly	110	35	10	11.00	0.61	3.14	20.0	45.8	34.6	22.4	15.0	17.7	12.6	15.7	21.0	31.4	62.9
2.4	Pelvis	180	75	25	7.20	0.65	2.40	17.5	46.8	36.0	24.4	17.9	15.5	9.6	12.0	16.0	24.0	48.0
2.5	Buttocks	210	80	15	14.00	1.47	2.63	18.3	46.5	35.6	23.8	17.1	16.2	10.5	13.1	17.5	26.3	52.5
3.1	Upper arm/Elbow joint	150	50	30	5.00	0.38	3.00	19.5	46.0	34.9	22.8	15.6	17.3	12.0	15.0	20.0	30.0	60.0
3.2	Lower arm/Hand joint	160	50	40	4.00	0.32	3.20	20.2	45.7	34.5	22.2	14.8	17.9	12.8	16.0	21.3	32.0	64.0
3.3	Hand/Finger	135	60	75	1.80	0.12	2.25	16.9	47.0	36.2	24.8	18.4	15.0	9.0	11.3	15.0	22.5	45.0
4.1	Thigh/Knee	220	80	50	4.40	0.48	2.75	18.7	46.4	35.4	23.4	16.6	16.6	11.0	13.8	18.3	27.5	55.0
4.2	Lower leg	140	45	60	2.33	0.16	3.11	19.9	45.9	34.7	22.4	15.1	17.6	12.4	15.6	20.7	31.1	62.2
4.3	Feet/Toes/Joint	125	45	75	1.67	0.10	2.78	18.8	46.3	35.3	23.4	16.5	16.7	11.1	13.9	18.5	27.8	55.6

Magnitude	Unit	Definition	Magnitude	Unit	Definition	Magnitude	Unit	Definition
BR		Codification of body region	A_{ref}	cm²	Pressure area	LS_{ref}	mm	Lateral length square
CSF	N	Clamping/Squeezing force	DC_{ref}	mm	Diameter circle	$SR25_{ref}$	mm	Lateral length rectangle (1^{st} side 25 mm)
PSP	N/cm²	Pressure/Surface pressing	$IDR50_{ref}$	mm	Inner diameter of circular ring (outside 50 mm)	$SR20_{ref}$	mm	Lateral length rectangle (1^{st} side 20 mm)
CC	N/mm	Compression constant	$IDR40_{ref}$	mm	Inner diameter of circular ring (outside 40 mm)	$SR15_{ref}$	mm	Lateral length rectangle (1^{st} side 15 mm)
S_{com}	mm	Maximum compression path	$IDR30_{ref}$	mm	Inner diameter of circular ring (outside 30 mm)	$SR10_{ref}$	mm	Lateral length rectangle (1^{st} side 10 mm)
DW_{ref}	Nm	Maximum compression work until S_{com}	$IDR25_{ref}$	mm	Inner diameter of circular ring (outside 25 mm)	$SR5_{ref}$	mm	Lateral length rectangle (1^{st} side 5 mm)

Enclosures

4 Arrangement values based on the impact forces from Table 2

Table 7: Guiding constructive key figures as arrangement aids based on the permissible impact forces

Body model with individual body regions and codification		Limit values of the requirement criteria			Compression path, compression work and surface size			Characteristic measurements of reference areas										
BR	Individual body regions	N	N/cm²	N/mm	mm	Nm	cm²	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
		IMF	PSP	CC	S_{com}	DW_{ref}	A_{ref}	DC_{ref}	$IDR50_{ref}$	$IDR40_{ref}$	$IDR30_{ref}$	$IDR25_{ref}$	LS_{ref}	$SR25_{ref}$	$SR20_{ref}$	$SR15_{ref}$	$SR10_{ref}$	$SR5_{ref}$
1.1	Skull/Forehead	175	30	150	1.17	0.10	5.83	27.3	41.9	29.3	12.5	-	24.2	23.3	29.2	38.9	58.3	-
1.2	Face	90	20	75	1.20	0.05	4.50	23.9	43.9	32.0	18.1	7.2	21.2	18.0	22.5	30.0	45.0	90.0
1.3	Neck (sides/neck)	190	50	50	3.80	0.36	3.80	22.0	44.9	33.4	20.4	11.9	19.5	15.2	19.0	25.3	38.0	76.0
1.4	Neck (front/larynx)	35	10	10	3.50	0.06	3.50	21.1	45.3	34.0	21.3	13.4	18.7	14.0	17.5	23.3	35.0	70.0
2.1	Back/Shoulders	250	70	35	7.14	0.89	3.57	21.3	45.2	33.8	21.1	13.0	18.9	14.3	17.9	23.8	35.7	71.4
2.2	Chest	210	45	25	8.40	0.88	4.67	24.4	43.7	31.7	17.5	5.6	21.6	18.7	23.3	31.1	46.7	93.3
2.3	Belly	160	35	10	16.00	1.28	4.57	24.1	43.8	31.9	17.8	6.6	21.4	18.3	22.9	30.5	45.7	91.4
2.4	Pelvis	250	75	25	10.00	1.25	3.33	20.6	45.6	34.3	21.8	14.2	18.3	13.3	16.7	22.2	33.3	66.7
2.5	Buttocks	250	80	15	16.67	2.08	3.13	19.9	45.8	34.7	22.4	15.1	17.7	12.5	15.6	20.8	31.3	62.5
3.1	Upper arm/Elbow joint	190	50	30	6.33	0.60	3.80	22.0	44.9	33.4	20.4	11.9	19.5	15.2	19.0	25.3	38.0	76.0
3.2	Lower arm/Hand joint	220	50	40	5.50	0.61	4.40	23.7	44.0	32.2	18.4	8.0	21.0	17.6	22.0	29.3	44.0	88.0
3.3	Hand/Finger	180	60	75	2.40	0.22	3.00	19.5	46.0	34.9	22.8	15.6	17.3	12.0	15.0	20.0	30.0	60.0
4.1	Thigh/Knee	250	80	50	5.00	0.63	3.13	19.9	45.8	34.7	22.4	15.1	17.7	12.5	15.6	20.8	31.3	62.5
4.2	Lower leg	170	45	60	2.83	0.24	3.78	21.9	44.9	33.5	20.5	12.0	19.4	15.1	18.9	25.2	37.8	75.6
4.3	Feet/Toes/Joint	160	45	75	2.13	0.17	3.56	21.3	45.2	33.9	21.1	13.1	18.9	14.2	17.8	23.7	35.6	71.1

Magnitude	Unit	Definition	Magnitude	Unit	Definition	Magnitude	Unit	Definition
BR		Codification of body region	A_{ref}	cm²	Pressure area	LS_{ref}	mm	Lateral length square
IMF	N	Impact force	DC_{ref}	mm	Diameter circle	$SR25_{ref}$	mm	Lateral length rectangle (1st side 25 mm)
PSP	N/cm²	Pressure/Surface pressing	$IDR50_{ref}$	mm	Inner diameter of circular ring (outside 50 mm)	$SR20_{ref}$	mm	Lateral length rectangle (1st side 20 mm)
CC	N/mm	Compression constant	$IDR40_{ref}$	mm	Inner diameter of circular ring (outside 40 mm)	$SR15_{ref}$	mm	Lateral length rectangle (1st side 15 mm)
S_{com}	mm	Maximum compression path	$IDR30_{ref}$	mm	Inner diameter of circular ring (outside 30 mm)	$SR10_{ref}$	mm	Lateral length rectangle (1st side 10 mm)
DW_{ref}	Nm	Maximum compression work until S_{com}	$IDR25_{ref}$	mm	Inner diameter of circular ring (outside 25 mm)	$SR5_{ref}$	mm	Lateral length rectangle (1st side 5 mm)

Enclosures

5 Checklist and recommendations for applying the BG/BGIA recommendations in practice

In a workplace application that uses a collaborative robot, the user/system integrator or person in charge of it must draw up a risk assessment. In order to assess and demonstrate a safe man-machine interaction between a person and a collaborative robot within a specific workplace application, the collision risks – primarily determined by the extent of damage (injury severity) that relevant collision incidents cause and their probability of occurring – are assessed and, if need be, minimized (risk reduction).

To assess the injury risks a person is exposed to as a result of mechanical influences originating from the collaborative robot, the listed testing basics according to Item 1 are employed. In this context, the "BG/BGIA recommendations for the Design of Workplaces with Collaborative Robots", document U 001/2009e, July 2009 edition must be especially observed, in addition to the machinery directive and the current standards for industrial robots.

This checklist is intended for supporting the drawing up of risk analyses based exclusively on the basic requirements of these BG/BGIA recommendations. Other safety considerations such as functional & electrical safety or resistance against environmental effects remain untouched or are covered by independently valid standards and checklists.

The checklist includes criteria and key words that should be heeded in a risk analysis for a collaborative robot. All elements, information, data, measurements, stipulations and results of the risk assessment must be listed in a summarized way in a suitable document, and the order of the checklist provides the appropriate structure for this.

Checklist

1 Testing basics

a) Machinery directive (2006/42/EC)

b) EN ISO 10218-1:2006 "Industrial Robots – Safety Requirements – Part 1: Robots"

c) EN ISO 10218-2:2008 "Industrial Robots – Safety Requirements – Part 2: Robotic System and Integration (draft of the standard)"

d) Supplement/Specification of the occupational safety requirements of the standards as listed in 1 b) and 1 c) by the "BG/BGIA recommendations for the design of workplaces with collaborative robots", document U 001/2009e, July 2009 edition.

2 General data pertaining to risk analysis

a) Applicant/Company (possibly sectors/person in charge)

b) User/Manufacturer/System integrator or person in charge of workplace risk assessment

c) Testing organization (testing institute, tester in charge, testing date)

d) Type and brief description of the collaborative robot used

e) Description of the workplace application (name of workplace, possibly with collaborative robot).

3 Collaborative robot

a) Specification data for using the collaborative robot in the application (precise descriptions, significant drawings and pictures)

b) Description and specification data for the collaborative robot (relevant technical data, significant drawings and pictures)

c) Description and specification data for the safeguards applied to the entire workplace and the collaborative robot

d) Document pertaining to the (associated) total effect of all workplace safeguards (integration of all safeguards, functional effects, collaboration, block diagram).

4 Descriptions and specification data of the workplace application

a) Spatial environmental conditions, entries, exits, traffic routes

b) Equipment, installations, machines, optional pieces of equipment, tools and production goods found in the work area that are relevant to the application and their positioning, including that of the collaborative robot

c) Significant synoptic and detailed drawings and pictures.

5 Descriptions and specification data of the work task and the work activities performed in the workplace application

a) All the person's relevant work activities or activity aspects

b) All the collaborative robot's relevant work activities or activity aspects

c) Chronological sequence of all work activities and collaboration or sequences of activity aspects in which a person and a collaborative robot participate

d) Important robot-to-person distance measurements in all work phases.

6 Descriptions and specification of the collaboration space, the person's activities in the collaboration space

a) Precise geometric specification of the collaboration room
(The distances have to be given with a precision of 1% from the measured value but not more precise than a distance tolerance of ± 1 mm).

7 Determination of the individual body regions with collision risk in the collaboration room

a) Please consult the process according to the "BG/BGIA recommendations for the design of workplaces with collaborative robots", document U 001/2009e, July 2009 edition.

b) The determinations for the body regions must be plausibly justified (the person's body orientations towards the collaborative robot).

c) It must be sufficiently justified in what way application and robot conditions ensure that there is no collision risk for the individual body regions not selected in the template sheet.

8 Summary of all relevant information pertaining to the work activities beset by collision risks with the limit values for injury criteria that apply to them and the guiding deformation constants (tabular form recommended; see example in Section 8 of the BG/BGIA recommendations)

9 Verification of the permissible injury severity with the limit values of the stipulated injury criteria

a) Drawing up of a list with characteristic collision incidents that covers all types of collisions in the collaboration room(s)

b) Carrying out of measurements for registering the application-contingent values of the injury criteria and comparison with the allowed limit values

c) Suitable measuring instruments for measuring the “clamping/squeezing force”, “impact force” and “pressure/surface pressing” are currently under development. The forces and pressures must be metrologically demonstrated. If measurements of the “pressure/surface pressing” injury criterion cannot be carried out, then at least significant calculations are required for it.

d) Measuring instruments for registering the injury criteria must fulfil the operating principles according to Section 6 of the BG/BGIA recommendations.

10 Drawing up of synoptic test logs

a) Test log pertaining to the “Technical requirements” according to Section 5.1 of the BG/BGIA recommendations, document U 001/2009e, July 2009 edition

b) Test log pertaining to the “Medical/biomechanical requirements” according to Section 5.2 of the BG/BGIA recommendations, document U 001/2009e, July 2009 edition

c) Test log pertaining to the “Ergonomic requirements” according to Section 5.3 of the BG/BGIA recommendations, document U 001/2009e, July 2009 edition

d) Test log pertaining to the “Work organization requirements” according to Section 5.4 of the BG/BGIA recommendations, document U 001/2009e, July 2009 edition.

11 Individual assessments of all basic conditions, specification data and tests (measurements, calculations)

12 Total assessment of the results of all partial occupational safety tests of the BG/BGIA recommendations, document U 001/2009e, July 2009 edition.