COVR

Being safe around collaborative and versatile robots in shared spaces

Protocol

Test Gripper for Limiting Physical Interaction Energy

GRI-LIE-1

The specific purpose of this protocol is to validate the safety skill “limit interaction energy” by measurement for robotic grippers. In this context, the skill “limit interaction energy” is commonly used to protect workers from injuries caused by clamping and squeezing of body parts by the closing gripper. The validation of this protocol requires that the reader has a bio-fidelic measurement instrument available to measure contact forces and pressures.

Readiness Level	Description
7	Protocol is published over the toolkit, under evaluation, and open for community feedback.

COVR is a community effort and values any honest feedback to our services. Please feel free to express your opinion about this protocol. [The feedback form is only one click away.] Thanks for making COVR even better!

Disclaimer: This protocol reflects the current and collectively developed state of the art in the validation of a specific safety skill for a collaborative robot. However, you may have to adapt the described validation procedure to be feasible for your particular application, circumstances and applicable regulations. Neither the COVR project consortium as a whole nor any individual partner of the consortium takes, therefore, any responsibility for the correctness and completeness of the validation procedure described here.

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Grant agreement no. 779966
Date September 8, 2021

CONTENTS

1 Introduction

The purpose of this protocol is to validate by measurement that in the event of an accidental contact the gripper forces and pressures cannot exceed the applicable biomechanical limits (for instance, those of ISO/TS 15066 [1]. This protocol is specifically intended for the validation of crushing contacts, where the robot gripper clamps or squeezes a body part of the operator (probably the hand). The testing procedure involves a bio-fidelic measurement instrument that the protocol must use to record the contact forces and pressures (see Figure 1).

Example: A collaborative robot carries out a pick and place task next to a human operator. A typical event of misuse that precedes an accidental contact would be the operator reaching into the closing gripper in order to align the object's position. In such a situation, the gripper is likely to clamp the hand between the object and one gripper jaw.

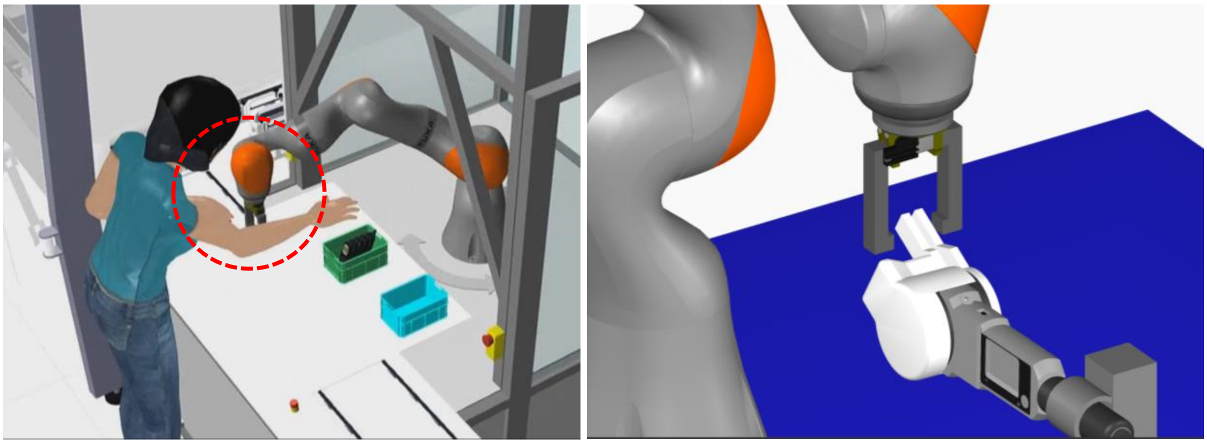

Figure 1: Exemplary situation of a clamping situation with a robotic gripper (left) and the principle test setup (right)

1.1 Scope and limitation

This protocol is specifically limited to the following profile:

Skill	limit physical interaction energy
System	robotic gripper
Sub-System	robot arm
Domain	cross-domain
Conditions	No obstacles (transient contact) obstacles (quasi-static contact)
Measurement Device(s)	bio-fidelic measurement instrument that mimics the biomechanical behavior of the human body (at least of its considered part) and that can measure contact force and pressure

⚠	**Warning** This protocol supports users to validate the effectiveness of the skill listed in the profile above. The skill should be a technical measure of the system integrator applied to mitigate the risk of one potentially hazardous situation as identified in the risk assessment, which the reader has to have done before using this protocol. In general, the risk assessment is a mandatory and helpful source to identify test situations and conditions relevant for a proper validation.

1.2 Definitions and Terms

Gripper (ISO/TR 20218-1 [2])

End-effector specifically designed for grasping workpieces.

Unintended contact

Contact refers to a state in which the robot and human are in touch and applying mechanical forces to each other. A contact is considered as unintended if the robot touches the human accidentally due to failure or misuse.

Transient contact (ISO/TS 15066 [1])

Contact between an operator and part of a robot system, where the operator body part is not clamped and can recoil or retract from the moving part of the robot system. In the course of the contact force recorded over time, the transient contact phase is the part of the signal that ranges from initial contact to 500 ms thereafter.

Quasi-static contact (**ISO/TS 15066 [1]**)

Contact between an operator and part of a robot system, where the operator body part can be clamped between a moving part of a robot system and another fixed or moving part of the robot system. In the course of the contact force recorded over time, the quasi-static contact phase begins 500 ms after initial contact.

2 Concept and Objectives

The concept of the validation process is to simulate a clamping situation with a real robotic gripper and a bio-fidelic measurement instrument that mimics the biomechanical response of the human body part affected by the contact. During the test, the gripper must operate under the same conditions, as it will in its real application. The objective of the test is to validate by measurement whether the applied safety skill “limit physical interaction energy” prevents the gripper from exceeding the applicable biomechanical limit values.

2.1 Hazardous Situations

The term *hazardous situation* denotes a situation in which the gripper clamps a part of the human body (e.g. a finger or the entire hand) as introduced in Section 1.1. The protocol user must apply the guideline given by this document for every possible clamping contact identified by the risk assessment as a case of foreseeable and potentially hazardous misuse.

	Suggestion
	The intended use and the foreseeable misuse, as identified by the risk assessment, can help to clarify the potentially hazardous situations. Losing consciousness or malicious mischief/vandalism are no typical cases of foreseeable misuse.

2.2 Target Behavior and Metrics of the Safety Skill

The target behavior of the skill “limit physical interaction energy” is to prevent the robot from exceeding the biomechanical limit values referenced in the risk assessment.

The target metrics are values based on physical and measurable quantities. They represent a threshold that the output values of the test must not exceed to pass the test successfully. For validating the robot skill “limit physical interaction energy”, the output values are:

- Maximum force F_{TR} for the transient contact phase
- Maximum force F_{QS} for the quasi-static contact phase
- Maximum pressure p_{TR} (normal stress) for the transient contact phase
- Maximum pressure p_{QS} (normal stress) for the quasi-static contact phase

The target metrics shall be specified during the risk assessment. For this validation protocol, the target metrics are limits of the output values:

- Force limit $\hat{F}_{TR}$ for transient contact (maximum allowable impact force)
- Force limit $\hat{F}_{QS}$ for quasi-static contact (maximum allowable clamping force)
- Pressure limit $\hat{p}_{TR}$ for transient contact (maximum allowable normal impact stress)
- Pressure limit $\hat{p}_{QS}$ for quasi-static contact (maximum allowable clamping pressure)

The target metric can vary for different parts of the human, so it is crucial to ensure which metric value applies to which body part. Please report the values of the target metric for each test using the form in Annex 0.

Example: Endangered Body Part and Limit Values

Body Part	Force (N)		Pressure (N/cm²)		Stiffness (N/mm)
	QS	TR	QS	TR	
Back of the hand	140	280	190	380	75
Source	ISO/TS 15066 [1]				

3 Conditions

In case the conditions under which the hazardous situation occurs can alter, it is recommended to create a test plan that includes all reasonable and relevant combinations of the conditions. The user must test the applied skill for each combination. Therefore, it is important to know the conditions with the most significant influence on the target metrics. Please report all conditions, represented by values, for each test using the form in Annex 0.

3.1 System

The term *system* refers to the robotic gripper that can also include:

- Type of gripper
- Type of work piece

The protocol user must consider all parts of the gripper, which can change during its use, as different test conditions. In the event the gripper can adjust the jaws to pick up other objects, each particular adjustment corresponds to a separate test condition.

Please report the system composition for every single test using the form in Annex 0.

Example: System Configuration

Gripper	
Manufacturer	The Tool Company
Model	cotool 5
Short description	Magnetic gripper
Connected jaws	Cylindrical with D20 and L150
Control software	coControl, version 2.3.1
Workpiece	
Short description	Screw, 20 cm long

When the safety skill takes over control, its configuration likely affects gripper behavior. Hence, it is also necessary to record the applied safety configuration in the form. Unfortunately, the gripper manufacturers implement their safety functions and skills differently why there is no list to record the configured properties commonly. The protocol user must, therefore, record the available and activated configuration properties formlessly, including the assigned values. The following example shows how the formless recording can look.

Example: Safety Skill Properties

Force limit	30 N
Closing velocity	5 mm/s

In the event the gripper is able to switch between different configuration set, it is necessary to execute separate validation tests for every separate set. In addition to the safety configuration enabled, the initial state of the gripper before contact has also a significant influence on the output values. The relevant initial states are:

- Starting position of the gripper jaws
- Closing and opening velocity (both might be already limited by the applied safety configuration)
- Clamping force (might be already limited by the applied safety configuration)

The risk assessment as the primary source to determine the system states for the test should indicate the initial states directly before the considered hazard is likely to occur. Please report the states for every test using the form in Annex 0.

Example: System Initial State

Configuration Space	**Gripper**	**Jaw 1**	**Jaw 2**	**Jaw 3**
Position (deg / mm)	-	50	50	-
Closing velocity (deg/s / mm/s)	-	10	10	-
Max. Force (N)	-	20	20	-

A gripper is commonly attached to a robotic arm, unless it is used as an external tool (tensioning medium). When preparing the validation tests, the protocol user must find out if the robot program configures the gripper with parameter. It is important the user execute the validation test with the same parameters and conditions that they will have in the real application. It is important to consider all contributions of the sub-system (here, robotic arm) that affect the test outcome.

3.2 Environment

The protocol user must consider (and arrange, if applicable) the following environmental conditions for the validation tests:

- Obstacle (gripper jaw pushes body part of the human against the object under grasp)

3.3 Miscellaneous

Other relevant conditions are:

- Location and form of the contact area (part of the gripper jaw)
- Endangered body parts (parts of the human body the gripper can clamp; see Section 2.2)

Use the form of Annex 0 to record the location and shape of the clamping point on the gripper structure.

Example: Misc. Conditions

Contact Area	
Location	Workpiece (screw M12), lower side of the screw thread (face side of a cylinder)
Photo	(insert a photo here)

Report for each endangered body part the stiffness it has under a load equal to the limit value. Given the layered composition of human tissue, reference literature for limit values might distinguish between separate values for the stiffness of the soft tissue and the stiffness of the bone (see example in Section 2.2). Annex A presents a list with stiffness parameters for some parts of the human body.

4 Test Setup

4.1 Equipment

The following sensors are required to record the contact force and pressure during the validation test:

- Load-cell for force measurement over time
- Foil sensor for pressure measurement over time

The load-cell must be part of an instrument that mimics the biomechanical characteristics of the human body or at least of the endangered body parts. Figure 2 depicts the general design of such a device. It consists of an impactor attached to a changeable spring. Linear guides ensure that the impactor can move only into the active direction of the spring. The spring is further attached to a load-cell that is rigidly connected to the housing of the instrument. The sideways mounted jaws of the instrument are a peculiarity of its design that ensures the instrument can also be placed inside compact grippers with very narrow gaps between the jaws. If there is sufficient space between the gripper jaws or the object under grasp and one jaw, a soft damping material can be adhered to the jaws of the measurement instrument to improve the biomechanical behavior of the human body part. Only if the protocol user applied a damping material, an additional foil sensor for pressure measurement can be placed on top of it. Without a damping material, it is not recommended to use pressure foils.

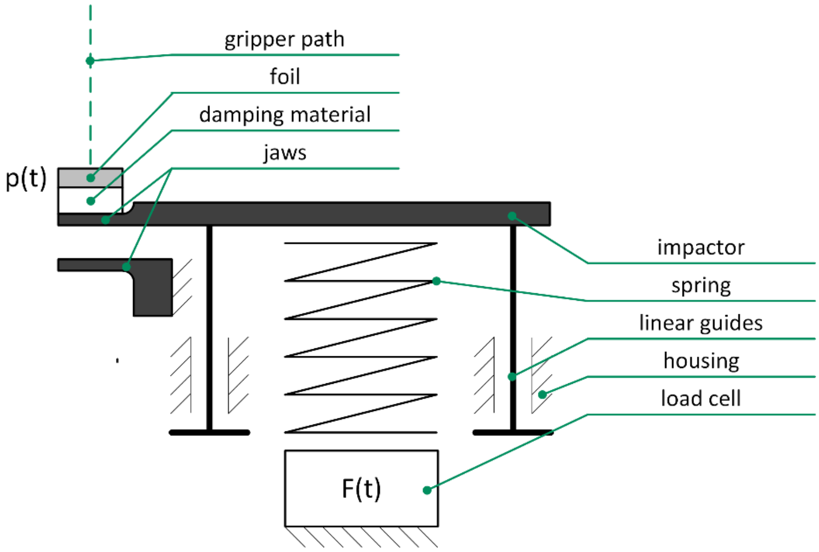

Figure 2: General design of the instrument for measuring gripper closing forces

The load cell to measure the contact force must fulfill the following requirements:

	Minimum	Recommended
Number of axes	1	1
Calibrated range	0 … 300 N	0 … 1000 N
Relative error (linearity)	<2%	<0.5%

Table 1. Requirements for load cell (sensor for measuring the contact force)

The foil sensor for measuring the contact pressure (normal stress within the contact area) must allow for continuous (pressure over time) or peak measurement (maximum pressure only). It must made of a flexible material that enables the foil to withstand the deformations of the damping material during the test. The foil sensor must fulfill the following requirements:

	Minimum	Recommended
Calibrated range	500 N/cm^2	750 N/cm^2
Density (sensor cell per area)	4 cm^{-2}	16 cm^{-2}
Relative error (linearity)	<20%	<10%

Table 2. Requirements for foil sensor (sensor for measuring the pressure within the contact area)

Note 1: It may be necessary to equilibrate and calibrate the foil sensor before using it. This protocol does not give any guidelines to prepare the foil sensor for the measurement, since the procedure depends significantly on the foil's specifics and measurement principle. Refer to the documentation (datasheet or manual) of the manufacturer.

Note 2: Some foil sensors allow for adjusting the measurement sensitivity. Use always the highest possible sensitivity so that the result is still within the measurement range. The sensitivity is too high if the signal of at least one measurement cell of the foil saturates.

Note 3: Assure that the dimensions of the foil sensor are slightly larger than the actual contact area.

Use the form in Annex 0 to report the capabilities of both sensors used for the validation.

Example: Sensors

Feature	**Force Sensor**	**Pressure Sensor**
Manufacturer and type	Sensor Company, PE 1000	Sensor Company, Foil 750
Calibrated range	1000 N	750 N/cm^2
Miscellaneous	Number of axes: 1	Density: 20 cm^{-2}

4.2 Method

Essentials for data acquisition are:

- A computer for measurement control
- All devices and software (running on the computer) necessary to control the sensing devices and to record their signals (incl. data logger, charge amplifier, etc.)

Note: The manufacturers of the commercially available measurement systems usually provide software to control their devices and to analyze the results. Please ensure that you have access to such software, especially for your instruments. If there are separate tools for force and pressure measuring, run both tools in parallel.

Data acquisition for all signals (force and pressure) must comply with the following requirements:

	Minimum	**Recommended**
Sampling frequency	2’000 Hz	10’000 Hz
ADC resolution	12 bit	16 bit
Time to contact	2 s	5 s

Table 3. Requirements for data acquisition

Note: Ensure that the sensor has a sufficient bandwidth that allows to sample the signals at the envisaged sampling frequency.

Time to contact denotes the time the measurement instrument start the recording of the signal before initial contact. If a sensor for test does not fulfill the minimum requirements, configure the properties at the best possible values (e.g. highest sampling rate). Please record the applied configuration using the form in Annex 0.

Example: Acquisition Configuration

Feature	**Force Sensor**	**Pressure Sensor**
Sampling frequency	10.000 Hz	1.800 Hz
ADC resolution	16 bit	8 bit
Time to contact	10 s	10 s

5 Procedure

5.1 Test Plan

The test plan is a summary of all situations the risk assessment identified as hazardous due to possible physical contact between the human (e.g. robot operator) and the gripper, incl. all combinations of applicable conditions. Therefore, the test plan provides a detailed overview of which tests are necessary to validate the skill for the considered gripper application.

The protocol user must test each clamping situation identified by the risk assessment as potentially hazardous (see Section 2.1). The tests simulate the clamping contacts the gripper may cause, whereby the measurement instrument introduced above represents the body part of the endangered human (see Section 4.1 and **Fehler! Verweisquelle konnte nicht gefunden werden.**). The objective of the test is to prove whether the contact forces and pressure exceed the metrics or not (see Section 2.2).

According to Chapter 3, the protocol must consider the following conditions:

- Gripper
    - Type of gripper
    - Type of work piece
    - Starting position of the gripper jaws (initial state)
    - Closing velocity (if available)
    - Maximum clamping force (if available)
- Sub-system
    - Robot arm
- Environment
    - Object under grasp, if available or relevant for the hazard
- Miscellaneous
    - Location and form of the contact area on the gripper structure or the object under grasp
    - Endangered body parts

For the validation test, it is necessary to measure all possible combinations of conditions that apply to the considered hazardous situation. Each combination corresponds to a particular test case. It is recommended to organize all hazardous situations and applicable conditions row-wise in a list. Each row in the list represents a particular test case that the protocol user must execute and report on using the form in Annex 0. The protocol user should repeat each test three times.

5.2 Preparation

Before executing a particular test from the test plan, it is necessary to prepare the setup and the conditions properly. The following sections gives instruction to prepare each part of the setup and all conditions with a significant influence on the target metrics. Use the form in the Annex to document all test cases.

5.2.1 Test Arrangement

Measurement Equipment

- Connect all sensors to their loggers and the loggers to your computer.
- Configure the parameter of the data acquisition within the range specified in Section 4.2
- Make sure that you can start and stop the recording of all signals from your computer and that the acquisition works as configured.

Bio-fidelic measurement Instrument

- Install the spring and apply the damping material to the impactor (see test plan). Make sure that the characteristics of the used combination fit the stiffness of the endangered body part (see Section 3.3). If the spring cannot be changed, skip this step.

- Attach the collision instrument to a mechanically stiff support that holds it in place during the test. The contact forces applied to the measurement instrument should not deform the support to a significant extent (for instance, use profiles made of aluminum).
- Assure that the contact point on the gripper strikes perpendicular on the jaws of the measurement instrument in the moment of initial contact (Figure 3).

Pressure Sensor (if applied)

- To avoid damage to the pressure foil, cover it with a PTFE foil (thickness must be <50 µm).
- Rough surfaces can result in small regions of significant peak pressures. To avoid them, use a microfiber cloth (thickness must be <500 µm).
- Make sure that the sensitive area of the foil covers the contact area completely.
- Use rubber bands or tape as fasteners to attach the foil to the impactor of the collision instrument. Ensure that the fastener does not run over the sensitive area of the pressure foil.

⚠	**Warning**
	The applied combination of spring and damping material must simulate the response behavior of the body part to be tested. In order to select the right combination, it may also be necessary to consider the shape of the contact area on the gripper surface.

⚠	**Warning**
	The stiffness of the instrument support must be 20x higher than the stiffest spring used for all tests.

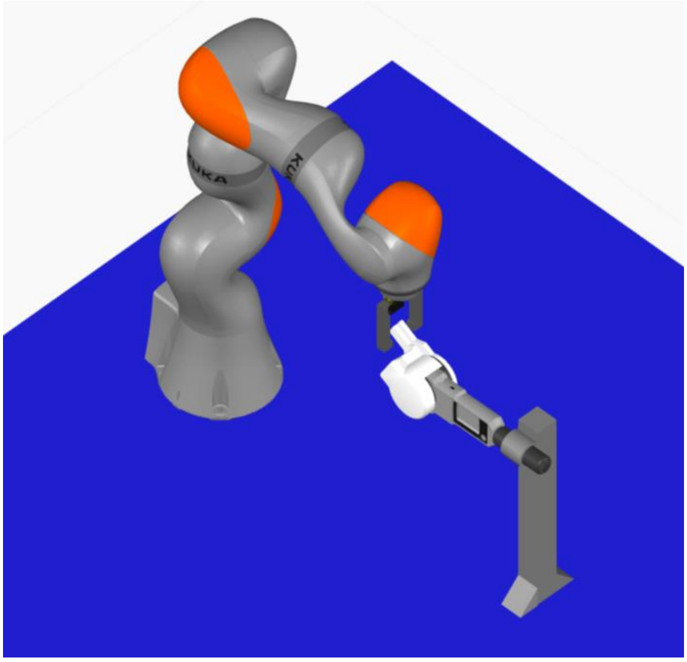

Figure 3. Schematic drawing of the setup

Use the form in Annex 0 to record the applied spring and damping material:

Example: Configuration of the Collision Instrument

Spring rate (N/mm)	75
Hardness of damping material	40 (Shore hardness)

5.2.2 System Conditions

The protocol user must configure the gripper (and possibly the sub-system, if available) exactly as it will run in the application, which includes at least the following steps:

- Switch on the gripper (and robot arm) one hour before beginning the tests (warm-up phase).
- Provide all object the gripper will handle later in the application.
- Install the final gripper program / configuration that contains all parameters needed for the application.
- Configure all available safety-functions.

⚠	**Warning**
	The safety configuration, and so the safety skill, is often a part of the robot program or inseparably connected with it. Therefore, the protocol user must not change the robot program after passing the validation successfully. It is highly recommended to store a backup of the positively tested program and to lock the robot control unit so that only authorized people can modify the program or the safety configuration. Any modification to the program may require a new validation of the safety skill.

Note: If the gripper has no safety-rated functions to limit the interaction energy, the protocol user must test the worst case scenario, which is the gripper operates at highest maximum closing velocity and clamping force, even if such a setting is not required for the application.

5.2.3 Environmental Conditions

There are no environmental conditions that the protocol user must explicitly establish for the test. However, it is highly recommended to run the tests in the same environment in which the gripper will operate later.

5.3 Test Execution

Apply the following steps for each test case:

- Move the gripper jaws slowly to the point where the clamping situation can occur (see test plan or risk assessment).
- Check if the jaws of the measuring instrument fit between the gripper jaws or between the object and on gripper jaw. The instrument is in the right orientation when the surfaces of gripper jaw hits perpendicular to its jaws (see Figure 2).
- Move the gripper jaws to their initial position.
- Take a photo of the test situation (recommended).
- Start the signal recording.
- Start the gripper movement.
- When the gripper jaws stopped after they hit the instrument's jaws, take another photo of the situation (recommended).
- Save the recorded signals.
- Release the gripper jaw by moving it under manual control backwards.

Rearrange the pressure foil and damping material on the jaws of the measurement instrument (if it slipped during the contact) and repeat the tests at least twice (see Section 5.1).

5.4 Data Analysis

After finishing the last repeat, there should be three results from three tests. It is recommended to start by filtering the signal right after recording. Since the pressure signal is technically a sequence of images (for pressure measurement over time) or a single measurement (for measuring only the peak pressure), it might be necessary to apply an additional image filter that reduces the image noise. The requirements for both filter types are:

Signal Filter (for all signals)	**Minimum**	**Recommended**
Signal filter type	1st order Butterworth low pass	4th order Butterworth low pass, zero-phase
Cut-off frequency	200 Hz	200 Hz
Image Filter (for pressure only)	**Minimum**	**Recommended**
Image filter type	(no filtering)	Gaussian filter
Standard deviation	N/A	$\sqrt{2/\pi}$

Table 4. Requirements for signal and image filtering

For image filtering, it is highly recommended to use a software that has such filters included. In general, the manufacturers of the pressure measurement system should provide such tools in combination with the sensor. Use the form in Annex 0 to record the applied filter configuration.

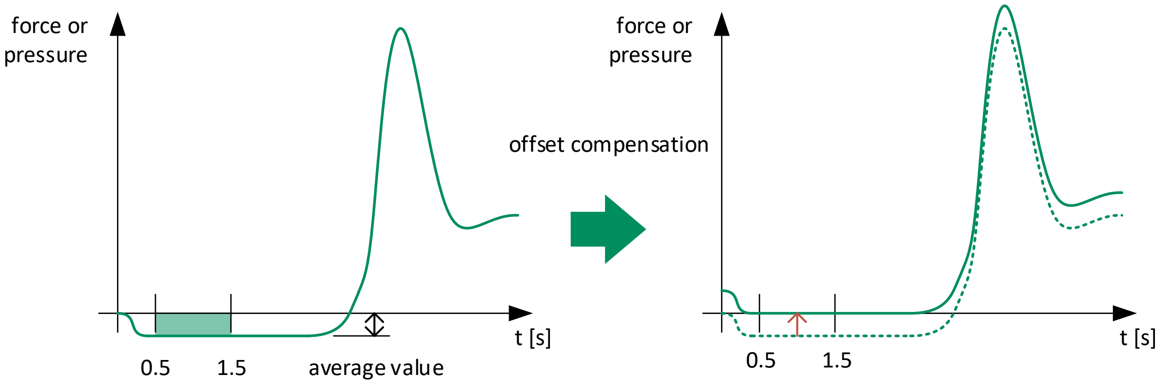

Figure 4. Procedure for Offset Compensation

Example: Signal Filter Configuration

	Force Sensor	**Pressure Sensor**
Signal filter type	4th order Butterworth low pass, zero-phase	N/A (foil measured only peak pressure)
Cut-off frequency	200 Hz	N/A
Image filter type		Gaussian filter
Standard deviation		$\sqrt{2/\pi}$

Once the signal were filter, signals offsets must be compensated by subtracting the average magnitude the signal has in the period from 0.5 s to 1.5 s (0 s marks start of signal recording). Figure 4 illustrates the procedure for the force signal.

Determine the maximum contact force and peak pressure for the transient and quasi-static contact phase. Ensure that the maximum values for the transient phase were determined within the time window from 0 s to 0.5 s and the ones for the quasi-static phase after 0.5 s, while 0 s marks the start of the contact (see Figure 5). Record the maximum values in the form which is available in Annex 0.

Note: In the event the pressure foil measures only the peak pressure, it is necessary to use the maximum value for both contact phases.

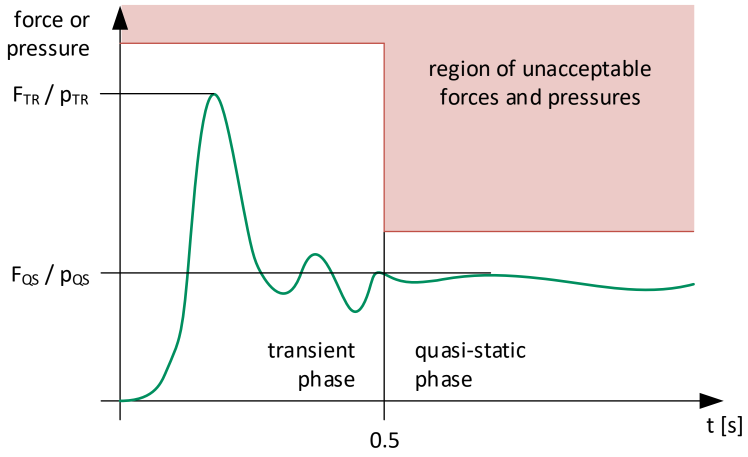

Figure 5. Representation of acceptable forces and pressures

Suggestion

To minimize the efforts for the pressure measurement, it is recommended to begin with force measurement only. If the maximum contact force is significantly below the applicable limit value, repeat the test three times including pressure measurement. If the maximum force of the first test already exceeds the force limit, the protocol user can omit pressure measurement for this test.

Example: Result from Data Analysis

	Test 1	Test 2	Test 3	MAX
Maximum force TR (N)	54	55	53	55
Maximum force QS (N)	41	38	43	43
Maximum pressure TR (N/cm^2)	102	109	90	109
Maximum pressure QS (N/cm^2)	97	93	94	97

If the highest maximum of all force and pressure values exceeds the applicable limit value, the safety skill applied to the gripper fails the test. It is then recommended to modify the gripper configuration (for instance by reducing the closing speed) and to start over with the validation process. Other options could be a modification of the safety configuration or a redesign of the gripper jaws. If the highest maximum does not exceed the limit, the gripper passes the test.

5.5 Report

Use the form in Annex 0 to report all conditions and results of the tests. After finishing the validation successfully (all tests passed), add the forms to your risk assessment. They are proof that the applied safety skill is active and prevents the gripper from violating the target metrics. Use the last section in the form to record the overall result of the test (passed/failed).

Example: Summary

	Test 1	**Test 2**	**Test 3**	**Tests Passed**
Past transient phase	yes	yes	yes	yes
Past quasi-static phase	yes	yes	no	no
Past both phases	yes	yes	no	no

6 Bibliography

[1] *Robots and robotic devices - Collaborative robots*, ISO/TS 15066, International Organization for Standardization (ISO), 2016.

[2] *Robotics - Safety design for industrial robot systems - Part 1: End-effectors*, ISO/TR 20218-1, International Organization for Standardization (ISO), 2018.

[3] Fachbereich Holz und Metall der DGUV, Ed., “DGUV-Information - Collaborative robot systems: Design of systems with "Power and Force Limiting" function,” Deutsche Gesetzliche Unfallversicherung (DGUV), 2017.

7 Annexes

A Stiffness Parameter of the Human Body

See Table 5 to find the right combination of damping material and spring for the body part you want to test with your bio-fidelic measurement instrument.

Note 1: You can neglect the data in Table 5 if you have other data available for configuring the spring-damping characteristics of your bio-fidelic measurement instrument. Nevertheless, record the source of your data in the record forms.

Note 2: Data given in Table 5 are subject to modifications.

Table 5. Combinations of damping material and spring to mimic the biomechanical characteristics for various body regions [3]

Body region	**Hardness (shore A)**	**Thickness (mm)**	**Spring (N/mm)**
Skull and Forehead	70	7	150
Face			75
Hand and Finger			75
Neck			50
Forearm and Wrist			40
Chest			25
Pelvis			25
Lower Leg	30	14	60
Upper Leg and Knee			50
Back and Shoulder			35
Upper Arm and Elbow			30
Abdomen	10	21	10

B Report Form

Use the form on the next pages to record the data for each test.

Test ID / Test no	
Hazard ID	
Description	
Photo	

Setup

Sensors

Feature	**Force Sensor**	**Pressure Sensor**
Manufacturer and type		
Calibrated range		
Miscellaneous		

Acquisition Configuration

Feature	**Force Sensor**	**Pressure Sensor**
Sampling frequency		
ADC resolution		

System Configuration

Gripper	
Manufacturer	
Model	
Short description	
Connected jaws	
Control software	

Workpiece	
Short description	

Safety Skill Properties (can be test-specific)

Test Specifics

System State

Configuration Space	**All Jaws**	**Jaw 1**	**Jaw 2**	**Jaw 3**
Position (deg / mm)				
Closing velocity (deg/s / mm/s)				
Max. Force (N)				

Misc. Conditions

Contact Area	
Location	
Photo	

Endangered Body Part and Limit Values

	Force (N)		**Pressure (N/cm²)**		
Body Part	**QS**	**TR**	**QS**	**TR**	**Stiffness (N/mm)**
Back of the hand					
Source					

Configuration of the Collision Instrument

Spring rate (N/mm)	
Hardness of damping material	

Test Result

Result from Data Analysis

Measured maximum values	Test 1	Test 2	Test 3	MAX
Maximum force TR (N)				
Maximum force QS (N)				
Maximum pressure TR (N/cm^2)				
Maximum pressure QS (N/cm^2)				

Summary

	Test 1	Test 2	Test 3	ALL yes
Pass				