Being safe around collaborative and versatile robots in shared spaces

Protocol

Test Gripper for Limiting Range of Motion

GRI-LRM-1

The purpose of this protocol is to validate the safety skill "limit range of movement" for grippers of industrial robots. In this context, the skill "limit range of movement" is often used to avoid the possibility of clamping a part of an operator body during robot operations, typically pick and place tasks. The validation protocol is aimed at verifying gripper working when limits are set, by the use of Gauge blocks.

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!

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1 Introduction

The purpose of this protocol is to define an approach to validate the skill of limiting the range of motion of a gripper. Focusing only on the gripper itself within a manipulating robot, the skill can be applied to pneumatic and servo-electric grippers, whose gripping principle rely on movable jaws sliding or closing towards each other. Limiting the range of motion plays an important role if the risk of clamping human body parts occurs. To eliminate the risk specific norms characterize a minimum distance between machine mobile parts to avoid clamping parts of the human body. This protocol provides a simple procedure to validate such a skill within a manipulating environment characterized by the presence of human operators.

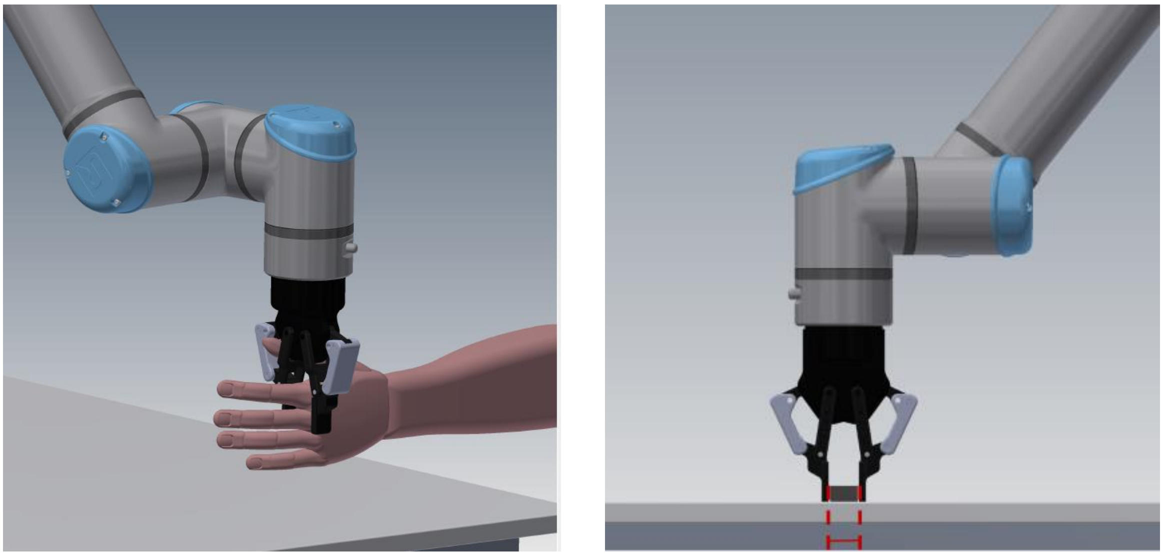

Figure 1: A gripper accidentally clamps an operator's hand during a task (left) and general approach for skill testing

1.1 Scope and limitation

This protocol is specifically limited to the following profile:

Skill	Limit range of motion
System	Gripper
Sub-System	-
Domain	cross-domain
Conditions	Environment: indoor factory Limit: set by the operator
Measurement Device(s)	Gauge blocks

⚠	**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 be 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

Industrial robot (source: EN ISO 10218-1)

Automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications

Industrial robotic system (source: EN ISO 10218-1)

System comprising:

- Industrial robot
- End effector(s)
- any machinery, equipment, devices, external auxiliary axes or sensors supporting the robot performing its task

Collaborative operation (source: EN ISO/TS 15066)

State in which a purposely designed robot system and an operator work within a collaborative workspace.

Collaborative robot (source: EN ISO 10218-2)

Robot designed for direct interaction with a human within a defined collaborative workspace.

Collaborative Workspace (source: ISO/TS 15066)

Space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation.

Gauge block (source: ISO 3650)

Material measure of rectangular section, made of wear-resistant material, with one pair of planar, mutually parallel measuring faces, which can be wrung to the measuring faces of other gauge blocks to make composite assemblies, or to similarly finished surfaces of auxiliary plates for length measurements.

Length of a gauge block "l" (source: ISO 3650)

Perpendicular distance between any particular point of the measuring face and the planar surface of an auxiliary plate of the same material and surface texture upon which the other measuring face has been wrung.

System integrator

Company or person who created the collaborative robot and/or brought it into productive operation. The system integrator is responsible for doing the risk assessment and must ship the collaborative robot with an instruction manual which refers to the residual risks of the robot system.

Robot operator

Person who is working with or beside the robot within the collaborative workspace.

Range of motion (ROM)

Working envelope covered by robot end-effector.

2 Concept and Objectives

According to the ISO/TS 15066 "Any clamping event between the collaborative robot system and human body regions shall occur in a way such that the person shall be able to escape independently and easily from the clamping condition". Basing on this aspect, limiting gripper range of motion can play an important role to avoid the trapping of body parts, especially for "pick and place" tasks. This can be achieved by setting a minimum closing distance by limiting the range of movement.

The concept of the verification process is to simulate the real task scenario, substituting the workpiece with a Gauge block. Based on the task risk assessment, the body parts possibly clamped within the task are known.

The minimum gaps to avoid body part clamping are identified by the norms and the Gauge blocks are chosen accordingly. The objective of the test is to set an appropriate limit to the gripper range of motion, to verify that the gripper complies with such a limit. This is achieved by checking if the Gauge block is not picked by the gripper.

2.1 Hazardous Situations

In this case, the *hazardous situation* refers to the clamping of a part of the human body. The protocol user must apply the guideline given by this document for each possible hazardous scenario in which the gripper clamps a part of the human body, identified by the risk assessment.

2.2 Target Behavior and Metrics of the Safety Skill

The target behavior of the skill "limit range of motion" in the case of a gripper is to verify that the gripper itself complies with the limit set by the user, corresponding to a mutual distance between its jaws.

The limit to apply to gripper range of movement corresponds to target metrics and is based on physical and measured quantities. They represent a minimal distance threshold, which is set depending on the risk assessment of the specific application. This value must not be exceeded by the closing jaws. The present protocol validates the skill by verifying that the gripper is unable to pick a Gauge block with appropriate dimensions, due to the given limit. From a successful verification, the output target for validating the gripper skill "limit range of motion" can be obtained, corresponding to:

- TEST PASSED ∈ {YES, NO}.

As it is further described, a successful test corresponds to a fail in picking the gauge block.

The values for the target metric should be determined during the risk assessment. For this validation protocol, the target metrics are:

- Minimum distance [$\hat{x}$ in mm] between the jaws.

3 Conditions

3.1 System

The term system refers to the robot system consisting of:

- Type of manipulator
- Type of gripper
- Type of workpiece to be picked

The protocol user must consider the specific or possible changing part of the system as system-related conditions.

Example: System Configuration

Robot Arm	
Manufacturer	The Robot Company
Model	Cobot 10
System Configuration	Safety Package
Control Software	CoControl, version 2.3.1
Gripper	
Manufacturer	The Gripper Company
Model	coGripper 5
Description	2 jaws
Configuration	(Position in the hazardous condition insert photo here)
Workpiece to be picked	
Manufacturer	My Company
Model / Type	Component
Description	20 mm x 50 mm long, 30 mm high (x, y, z)

For a proper validation test, it is necessary to establish the same gripper state as the robot will have in the picking condition. The configuration of the gripper must be clearly declared.

Please report the gripper state for each single test using the form in the Annex.

Example: System State

Configuration Gripper	**ABS**
Initial opening (mm)	70
Gripping velocity (mm/s)	30

3.2 Environment

There are no considerable environment conditions to be taken into account for test execution.

4 Test setup

4.1 Equipment

No sensing devices are necessary to fulfill the minimum requirements for test execution.

Optional: In case of relevant risk of impact due to transient contact highlighted in the risk analysis (i.e. due to sharp edges), it is suggested to use a digital camera for the acquisition and comparison of the images reporting the block before and after the limited gripping. This further system provides a more precise assessment, and a limitation tested in this way can lead to a more effective risk reduction, as it ensures that the block is not even touched by gripper jaws. Thus, this aspect should be taken into account in the risk assessment process.

There should be a frame to maintain the camera on top of the component during the acquisition, in order to obtain top-view acquisitions. The following requirements must be fulfilled by the sensor and reported in the Table in Annex A:

- Resolution > 5 Mp

Example: Camera details

Parameter	**Value**
Manufacturer	CameraManu
Model	MyCamera
Resolution	5 Mp

4.2 Method

Limiting the range of motion to avoid clamping parts of the human body means defining a closing threshold for gripper elements. These gaps must be based on normalized limits, depending on the part of the human body potentially involved. The ISO 13854 provides a list of minimum gaps to avoid crushing of parts of the human body. The most suitable for a robotic application are reported in the following table.

Body part	Gap limit
Finger	25mm
Hand/wrist/fist	100mm
Arm	120mm

If the risk analysis of a particular application highlights the possibility of clamping parts of the human body that are not properly referenced in the ISO 13854 with the related minimum gap, then the ISO 7250 is to be considered, obtaining the safety gap by applying appropriate tolerances to the typical dimension of the involved body part.

The aim of the test is to verify that the limit set for a robotic gripper works in compliance with this limitation. It is worth to highlight that some commercial grippers give the possibility of defining limits to the range of motion. The test basically consists of a pick and place task in which the unsuccessful gripping corresponds to a test success, as it means that the gripper safety configuration complies with the properly set Range of Motion (ROM) limit.

The testing equipment necessary for the test consists on a set of Gauge blocks. The test must be carried out in all the hazardous conditions identified in the risk analysis, so several blocks could be necessary for the complete test.

Since the tests have to be representative of the risks related to a specific implementation, block dimensions depend on the conditions of the specific task, such as:

- Gripper architecture (i.e. two jaws)
- Parts of the human body identified in the risk analysis as potentially affected

In case of particular gripper architectures, the blocks can be realized by custom manufacturing, with an appropriate shape (i.e. cylindrical). In this case, tolerances of 0.1 mm must be obtained. The same solution can be accepted in case the gap limit does not correspond to any normed dimension of Gauge blocks or in case of unavailability of the specific block.

Note: In case of architectures other than the two-jaw configuration, the gap limit specified by the norm must be guaranteed for each couple of closing jaws, as highlighted in the picture for a 3-jaw gripper (see Figure 2 b).

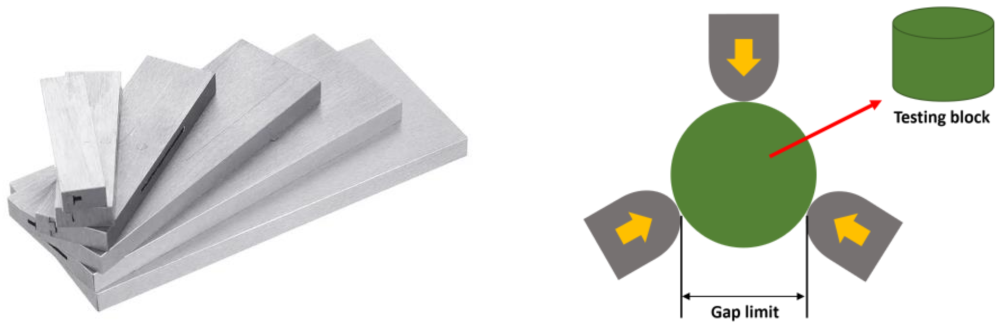

Figure 2: a) a set of Gauge blocks and b) example (3 jaws) of gap limit to consider for other gripper architectures

4.3 Data Acquisition

There are no specific requirements for camera image acquisitions. Before the acquisition, image focus must be set and the focus plane must be the same for the acquisitions of each trial. Also camera position must be maintained.

5 Procedure

5.1 Test Plan

The test plan is a summary of all situations identified in the risk assessment as hazardous due to clamping of body parts by the gripper. Therefore, the test plan provides a summary of the tests necessary to validate the skill for the specific application.

The aim of testing the skill of limiting the range of motion of a gripper is addressed with the following approach:

- Apply the appropriate limit to gripper range of motion, slightly higher than the gap limit to be validated;
- Simulate the pick and place of a block with the same length of the gap limit;
- An unsuccessful grip validates the skill test run.

Each test of the protocol must consider the following conditions:

- Hosting system (robot arm)
    - Type of robot
    - Repeatability
- Main system (gripper)
    - Type of gripper
    - Architecture
    - Stroke
    - Repeatability
    - Limit set
- Miscellaneous
    - Dimensions (and shape) of the Gauge block
    - Part of the body potentially clamped

Example: Detailed test conditions

Robot arm	
Type of robot	Cobot 10, The robot company
Repeatability	0.1 mm
Gripper	
Type of gripper	coGripper 5, The gripper company
Architecture	Two-jaws
Stroke	70mm
Repeatability	0.1mm
Limit set	25.7mm
Miscellaneous	

Gauge Block	Parallelepiped, 25mm
Part of the body	Fingers

5.2 Preparation

5.2.1 Test Arrangement

Optional: The vision system must be installed in order to be able to acquire the top view of the placed Gauge block, with the focus on the support plane. If a fixed installation can interfere with the gripper or the manipulator during the test execution, then a removable frame should be used. Frame on-table positioning must be replicable, in order to acquire comparable pictures. The camera must be connected to the computer and the positioning should be checked with sample acquisition(s).

The Gauge block(s) must be selected in accordance with the risk assessment, depending on potentially involved body parts, gripper architecture and stroke.

The testing robot program must be coded, considering that the specific task (i.e. pick and place) must be reproduced, with appropriate modifications for the test. Considering *Home→A→B* as the path of the task to be validated, the program must perform the same path with the following modifications:

- The testing block must be used in place of the workpiece. It must rely on a horizontal surface; in some cases, this could lead to slight modifications of task configuration.
- A preliminary robot subtask must be included in the program, aimed at placing the testing block in position “A”.
- For the actual test, any intrinsic control check of the pick must be disabled (example: gripper closing until a force is detected).
- The ROM limit $\bar{L}$ is calculated according to

$$\bar{L} \geq \hat{x} + 2(R + r) + 1\,\text{mm}$$

- where $\hat{x}$ represents the minimal gap indicated by the ISO 13854, thus corresponds to the Gauge block length, R indicates the repeatability of the manipulator and r the repeatability of the gripper.

Note: In case of gripper architecture other than two jaws, the actual ROM limit to be set for the gripper is obtained by $\bar{L}$ according to appropriate geometrical considerations.

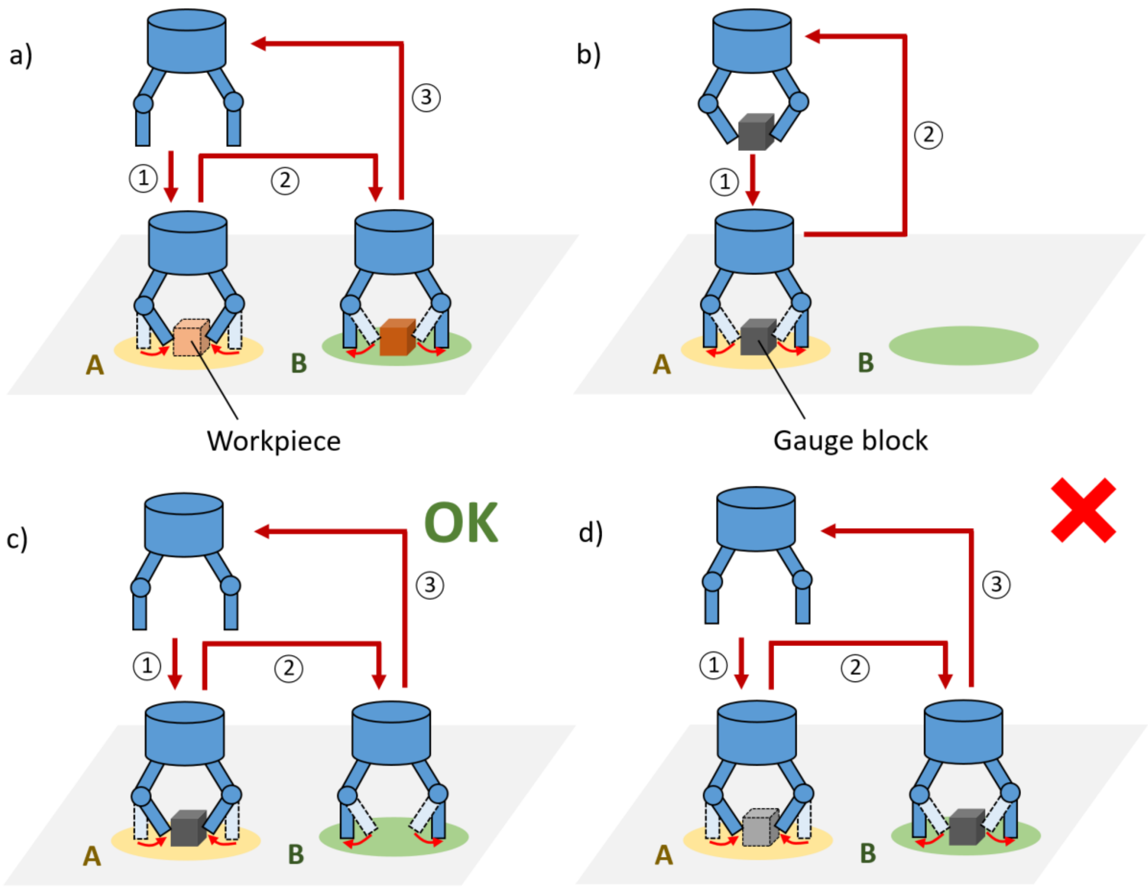

Figure 3: a) Original pick and place collaborative task to validate, b) preliminary subtask for validation, c) successful validation of the ROM limit and d) unsuccessful validation.

5.2.2 System Conditions

The protocol user must execute the tests in the same condition of the specific application. This includes the following steps:

- Install the gripper on the robot
- Switch on the whole robotic system one hour before beginning the tests (warm-up phase).
- Install the test program, coded with the indications given in the previous paragraph.

5.2.3 Environmental conditions

The illumination of the environment must be sufficient and appropriate for the image acquisition. If this not possible for some reason, a specific illuminator for the vision system should be installed.

5.3 Test Execution

Apply the following test procedure for each specified test case separately.

- Place the testing block in position "A".

Optional: Acquire the image of the block from the top view, in order to acquire the in-plane position. If the camera is installed on a removable frame, then it should be properly and repeatability positioned. After the acquisition, the frame must be removed.

- Start robot task. The robot will move to "A", try to pick the block and then move to "B", likely after an unsuccessful pick of the Gauge block.
- Visually check the position of the Gauge block, which must be unchanged. Optional: Acquire a second image of the block from the top view. The conditions of the previous acquisition must be replicated.
- Repeat the test at least 5 times.
- The validation can be considered successful if in all the runs the testing block is not picked by the gripper.

Optional: compare the two images and check the testing block was not even moved by the gripper.

5.4 Data Analysis

Optional: The set of two images acquired for each run must be compared. This can be done with any software enabling automated image analysis or, alternatively, enabling the possibility of measuring distances and positions.

5.5 Report

Use the form in Annex A 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 the proof that the applied safety skill is effective and gives the expected protection to the robot operator working beside the collaborative robot. 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	Test 4	Test 5	Test Passed
Gripper test ID	YES	YES	YES	NO	YES	NO
Pictures (optional)						

6 Annexes

A Report Form

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

System Configuration

Robot Arm	
Manufacturer	
Model	
System Configuration	
Control Software	
Gripper	
Manufacturer	
Model	
Description	
Configuration	
Workpiece to be picked	
Manufacturer	
Model / Type	
Description	

System State

Configuration - Gripper	**ABS**
Initial opening (mm)	
Gripping velocity (mm/s)	

Camera details

Parameter	**Value**
Manufacturer	
Model	
Resolution	

Detailed test conditions

Robot arm	
Type of robot	
Repeatability	
Gripper	
Type of gripper	
Architecture	
Stroke	
Repeatability	
Limit set	
Miscellaneous	
Gauge Block	
Part of the body	

Summary

	Test 1	Test 2	Test 3	Test 4	Test 5	Test Passed
Gripper test ID						
Pictures (optional)						