System Software

iiQKA.OS 1.2

Operating and programming instructions

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iiQKA.OS 1.2 V3
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Other functions not described in this documentation may be operable in the controller. The user has no claims to these functions, however, in the case of a replacement or service work.

We have checked the content of this documentation for conformity with the hardware and software described. Nevertheless, discrepancies cannot be precluded, for which reason we are not able to guarantee total conformity. The information in this documentation is checked on a regular basis, however, and necessary corrections will be incorporated in the subsequent edition.

Subject to technical alterations without an effect on the function.

KIM-PS5-DOC

Translation of the original documentation

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Contents

1 Introduction

1.1 Target group

This documentation is aimed at users with the following knowledge and skills:

- Advanced knowledge of the robot controller system

For optimal use of KUKA products, we recommend the training courses offered by KUKA College. Information about the training program can be found at www.kuka.com or can be obtained directly from our subsidiaries.

1.2 Industrial robot documentation

The industrial robot documentation consists of the following parts:

- Documentation for the robot arm
- Documentation for the robot controller
- Documentation for the smartPAD pro
- Documentation for the System Software
- Instructions for options and accessories
- Spare parts overview in KUKA Xpert

Each set of instructions is a separate document.

1.3 Representation of warnings and notes

Safety

These warnings are provided for safety purposes and **must** be observed.

DANGER
These warnings mean that it is certain or highly probable that death or severe injuries **will** occur if no precautions are taken.

WARNING
These warnings mean that death or severe injuries **may** occur if no precautions are taken.

CAUTION
These warnings mean that minor injuries **may** occur if no precautions are taken.

NOTICE
These warnings mean that damage to property **may** occur, if no precautions are taken.

These warnings contain references to safety-relevant information or general safety measures. These warnings do not refer to individual hazards or individual precautionary measures.

This warning draws attention to procedures which serve to prevent or remedy emergencies or malfunctions:

SAFETY INSTRUCTION
The following procedure must be followed exactly!

Procedures marked with this warning **must** be followed exactly.

Notices

These notices serve to make your work easier or contain references to further information.

Tip to make your work easier or reference to further information

1.4 Licenses

The KUKA license terms are displayed on the user interface of the system software:

- In the main menu under **System Information**, **Eula** tab

The license terms of the open-source software used can be displayed on a separate laptop/PC:

1. Connect the robot controller to the network and determine the *controller IP*.

   The IP address can be found in the main menu of the system software under **System Settings** > **Network**.
2. Enter the URL <*controller IP*>/licenses/ in the web browser.

2 Product description

2.1 Product description

Description

The system software iiQKA.OS 1.2 provides all the functions required for operating the KUKA LBR iisy.

Functions

- Touch operation via the smartPAD pro
- Simple user interface for programming, configuration and diagnosis
- Regular updates for expansion of the functionalities
- Wizards
  - Start wizard for quick overview of all functions
  - Further supporting wizards that provide assistance for navigating through functions
- Programming
  - Programming for beginners
  - Graphical program display and editing with touch input
  - Expression editor for programming complex expressions
  - Create and edit program variables
  - Create, edit and execute subprograms
  - Programming a compliant robot
- 3D scene display
  - Virtual robot model
  - Simple saving of positions
  - Display and management of monitoring spaces, tools, workpieces and coordinate systems
- Calibration of tools, workpieces and coordinate systems
- I/O configuration and diagnosis
  - Support of safe signals and standard signals
  - Importing EtherCAT device description files
  - Scanning, adding, deleting EtherCAT devices
  - FSoE support: primary side can be configured
  - PROFINET support
- Safety configuration
  - Simple expansion of the existing safety configuration
  - Flexible configuration of complex applications
  - Simple integration of the Sick safety laser scanner

2.2 Overview of the industrial robot

The industrial robot consists of the following components:

- Manipulator
- Robot controller
- Teach pendant
- Connecting cables

- Software
- Options, accessories

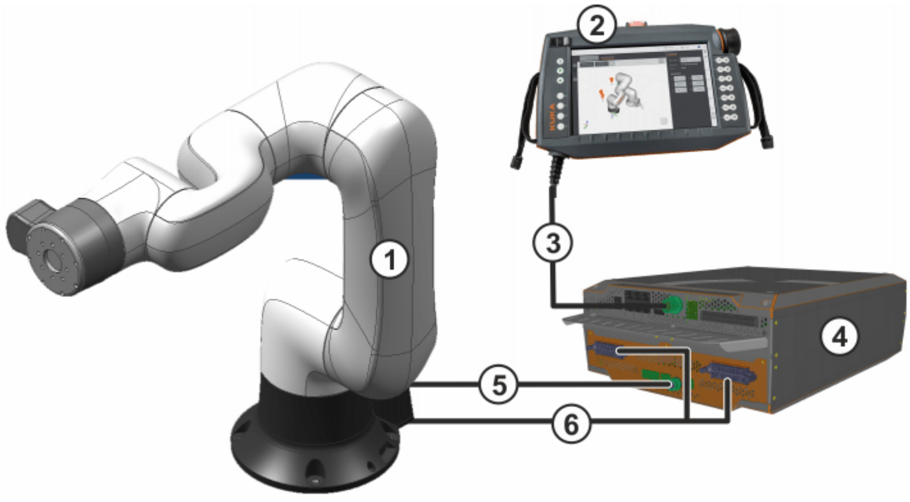


Fig. 2-1: Example of an industrial robot

1	Manipulator
2	smartPAD pro teach pendant
3	Connecting cable / smartPAD pro
4	Robot controller
5	Connecting cable / data cable
6	Connecting cable / motor cable

2.3 System requirements

The system software iiQKA.OS 1.2 can be used on the following robot controller:

- KR C5 micro
- With “Performance” system board

2.4 Network connections

The following diagram shows the Ethernet interfaces on the “Performance” system board.

- The following network interfaces can be configured in the system settings of the system software:
  - KLI OT, interface XF5
  - KLI IT, interface XF2
  - KONI, interface XF7
- At the KSI, interface XF1, a DHCP server is available on the controller side.

Fig. 2-2: Overview of interfaces for “Performance” system board

XF1	KUKA Service Interface
XF2	KUKA Line Interface (IT)
XF3	DaisyChain
XF4	DaisyChain
XF5	KUKA Line Interface (OT)
XF6	Not available
XF7	KUKA Optional Network Interface
XF8	KUKA Extension Interface (EtherCAT)

Further information about the Ethernet interfaces can be found in the assembly instructions for the robot controller KR C5 micro with KUKA iiQKA.OS.

2.5 Intended use and misuse

Use

The system software iiQKA.OS 1.2 is intended exclusively for the operation of a KUKA industrial robot.

Each version of the system software is to be operated exclusively in accordance with the specified system requirements.

Misuse

Any use or application deviating from the intended use is deemed to be misuse and is not allowed. KUKA Deutschland GmbH is not liable for any damage resulting from such misuse. The risk lies entirely with the user.

Examples of such misuse include:

- Operation of a kinematic system that is not a KUKA industrial robot
- Operation of the system software not in accordance with the specified system requirements

3 Safety

3.1 General

3.1.1 Disclaimer

The device described in this document is either an industrial robot or a component thereof.

Components of the industrial robot:

- Manipulator
- Robot controller
- Teach pendant
- Connecting cables
- Software
- Options, accessories

The industrial robot is built using state-of-the-art technology and in accordance with the recognized safety rules. Nevertheless, misuse of the industrial robot may constitute a risk to life and limb or cause damage to the industrial robot and to other material property.

The industrial robot may only be used in perfect technical condition in accordance with its intended use and only by safety-conscious persons who are fully aware of the risks involved in its operation. Use of the industrial robot is subject to compliance with this document and with the declaration of incorporation supplied together with the industrial robot. Any functional disorders, especially those affecting safety, must be rectified immediately.

Safety information

Information about safety may not be construed against the manufacturer. Even if all safety instructions are followed, this is not a guarantee that the industrial robot will not cause personal injuries or material damage.

No modifications may be carried out to the industrial robot without the authorization of the manufacturer. Unauthorized modifications will result in the loss of warranty and liability claims.

Additional components (tools, software, etc.), not supplied by the manufacturer, may be integrated into the industrial robot. The user is liable for any damage these components may cause to the industrial robot or to other material property.

In addition to the Safety chapter, this document contains further safety instructions. These must also be observed.

3.1.2 EC declaration of conformity and declaration of incorporation

The industrial robot constitutes partly completed machinery as defined by the EC Machinery Directive. The industrial robot may only be put into operation if the following preconditions are met:

- The industrial robot is integrated into a complete system.

  or: The industrial robot, together with other machinery, constitutes a complete system.

  or: All safety functions and safeguards required for operation in the complete machine as defined by the EC Machinery Directive have been added to the industrial robot.

- The complete system complies with the EC Machinery Directive. This has been confirmed by means of a conformity assessment procedure.

EC declaration of conformity

The system integrator must issue an EC declaration of conformity for the complete system in accordance with the Machinery Directive. The EC declaration of conformity forms the basis for the CE mark for the system. The industrial robot must always be operated in accordance with the applicable national laws, regulations and standards.

The robot controller has a CE mark in accordance with the EMC Directive and the Low Voltage Directive.

Declaration of incorporation

The partly completed machinery is supplied with a declaration of incorporation in accordance with Annex II B of the Machinery Directive 2006/42/EC. The assembly instructions and a list of essential requirements complied with in accordance with Annex I are integral parts of this declaration of incorporation.

The declaration of incorporation declares that the start-up of the partly completed machinery is not allowed until the partly completed machinery has been incorporated into machinery, or has been assembled with other parts to form machinery, and this machinery complies with the terms of the EC Machinery Directive, and the EC declaration of conformity is present in accordance with Annex II A.

3.1.3 Terms in the “Safety” chapter

Term	Description
Axis range	Range within which the axis may move The axis range must be defined for each axis.
Stopping distance	Stopping distance = reaction distance + braking distance The stopping distance is part of the danger zone.
Workspace	Area within which the robot may move. The workspace is derived from the individual axis ranges.
Automatic (AUT)	Operating mode for program execution. The manipulator moves at the programmed velocity.
User	The user of the industrial robot can be the management, employer or delegated person responsible for use of the industrial robot.
Commander	Operator interface on the manipulator that enables the connection of external tools as well as manual guidance of the manipulator
Danger zone	The danger zone consists of the workspace and the stopping distances of the manipulator.

CRR	**C**ontrolled **R**obot **R**etraction CRR is an operating mode which can be selected when the industrial robot is stopped by the safety controller for one of the following reasons: • Industrial robot violates an axis-specific or Cartesian monitoring space. • The tool orientation is outside the permitted range. • Industrial robot violates collision detection or the maximum TCP force monitoring function. • One or more axes are unmastered. • Mastering of one or more axis positions is not confirmed. • Calibration of one or more joint torque sensors is not confirmed. • Maximum Cartesian velocity has been exceeded. • Maximum torque of an axis has been exceeded, e.g. due to a crushing situation. After changing to CRR mode, the industrial robot may once again be moved.
KUKA smartPAD pro	Teach pendant for the robot controller The KUKA smartPAD pro has all the operator control and display functions required for operation and programming.
Manipulator	The robot arm and the associated electrical installations
HRC	Human-robot collaboration
External EMERGENCY STOP device	Triggering an external EMERGENCY STOP affects the robot controllers in the system that are integrated into the external EMERGENCY STOP circuit. **Notice:** Triggering an external EMERGENCY STOP does not (!) set the output signal for the local EMERGENCY STOP.
EMERGENCY STOP device local	• EMERGENCY STOP device on the smartPAD • Optional: additional EMERGENCY STOP device on the front door of the cabinet • Optional: additional EMERGENCY STOP device on XG58 Triggering a local EMERGENCY STOP directly affects the robot controller to which this EMERGENCY STOP is connected.
Safety zone	The safety zone is situated outside the danger zone.
Safety stop	The safety stop is triggered by the safety controller, interrupts the work procedure and causes all robot motions to come to a standstill. The safety stop can be executed as Stop category 0, as Stop category 1 (HRC) or as Stop category 1 (path-maintaining). **Note:** In this document, a safety stop of Stop category 0 is referred to as safety stop 0, a safety stop of Stop category 1 (HRC) as safety stop 1 (HRC) and a safety stop of Stop category 1 (path-maintaining) as safety stop 1 (path-maintaining).
Stop category 0	The drives are deactivated immediately and the brakes are applied. The manipulator is stopped with path-oriented braking. **Note:** This stop category is called “STOP 0” in this document.

Stop category 1 (HRC)
: The manipulator switches to compliance control with increased damping in order to reduce the acting external forces and to come to a standstill. The manipulator leaves the path in this case. At standstill, the drives are deactivated and the brakes are applied.

If Stop category 1 (HRC) is triggered by the safety controller, the safety controller monitors the braking process. Specifically, the Cartesian velocity and the external axis torques are monitored. The brakes are applied after 1 s at the latest and the drives are deactivated. Stop category 0 is executed in the event of a fault.

Note: This stop category is called “STOP 1 (HRC)” in this document.

Stop category 1 (path-maintaining)
: The manipulator is braked and stays on the programmed path. At standstill, the drives are deactivated and the brakes are applied.

If Stop category 1 (path-maintaining) is triggered by the safety controller, the safety controller monitors the braking process. After a duration of 1.5 s at the latest, or less depending on the robot type, the brakes are applied and the drives are switched off. Stop category 0 is executed in the event of a fault.

Note: This stop category is called “STOP 1 (path-maintaining)” in this document.

Stop category 2
: The drives are not deactivated and the brakes are not applied. The manipulator is braked with a path-maintaining braking ramp.

Note: This stop category is called “STOP 2” in this document.

System integrator (plant integrator)
: The system integrator is responsible for safely integrating the industrial robot into a complete system and commissioning it.

T1
: Test mode, Manual Reduced Velocity (<= 250 mm/s)

Note: With manual guidance in T1, the velocity is not reduced, but rather limited through a safety-oriented velocity monitoring in accordance with the safety configuration.

3.2 Personnel

The following persons or groups of persons are defined for the industrial robot:

- User
- Personnel

Qualification of personnel
Work on the system must only be performed by personnel that is able to assess the tasks to be carried out and detect potential hazards. Death, severe injuries or damage to property may otherwise result. The following qualifications are required:

- Adequate specialist training, knowledge and experience
- Knowledge of the relevant operating or assembly instructions, knowledge of the relevant standards
- All persons working with the industrial robot must have read and understood the industrial robot documentation, including the safety chapter.

User

The user must observe the labor laws and regulations. This includes e.g.:

- The user must comply with his monitoring obligations.
- The user must carry out briefing at defined intervals.
- The user must comply with the regulations relating to personal protective equipment (PPE).

Personnel

Personnel must be instructed, before any work is commenced, in the type of work involved and what exactly it entails as well as any hazards which may exist. Instruction must be carried out regularly. Instruction is also required after particular incidents or technical modifications.

Personnel includes:

- System integrator
- Operators, subdivided into:
  - Start-up, maintenance and service personnel
  - Operating personnel
  - Cleaning personnel

System integrator

The industrial robot is safely integrated into a complete system by the system integrator.

The system integrator is responsible for the following tasks:

- Installing the industrial robot
- Connecting the industrial robot
- Performing the risk assessment
- Implementing the required safety functions and safeguards
- Issuing the EC declaration of conformity
- Affixing the CE mark
- Creating the operating instructions for the system

Operators

The operator must meet the following preconditions:

- The operator must be trained for the work to be carried out.
- Work on the system must only be carried out by qualified personnel. These are people who, due to their specialist training, knowledge and experience, and their familiarization with the relevant standards, are able to assess the work to be carried out and detect any potential hazards.

3.3 Workspace, protected space and danger zone

Workspaces are to be restricted to the necessary minimum size.

The danger zone consists of the workspace and the stopping distances of the manipulator. The danger zone must be protected by means of physical safeguards to prevent danger to persons or the risk of material damage.

The safeguards (e.g. safety gate) must be located outside the danger zone. In the event of a stop, the manipulator is braked and comes to a stop within the danger zone.

There must be no shearing or crushing hazards at the loading and transfer areas.

If there are no physical safeguards present, the requirements for collaborative operation in accordance with EN ISO 10218 must be met.

3.4 Triggers for stop reactions

Stop reactions of the industrial robot are triggered in response to operator actions or as a reaction to monitoring functions and error messages. The following tables show the stop reactions depending on the operating mode that has been set.

Permanently defined triggers

The following triggers for stop reactions are predefined by the system and invariable:

Trigger	T1, CRR	AUT
Start key released	STOP 2	
PAUSE key pressed	STOP 2	
Power switched off via main switch or device switch Or power failure	STOP 0	
Internal error in non-safety-oriented part of the robot controller	STOP 0 or STOP 1 (dependent on the cause of the error)	
Operating mode changed during operation	Safety stop 1 (path-maintaining)	
Error in the safety controller	Safety stop 0 or safety stop 1 (path-maintaining) (dependent on the cause of the error)	

User-specific triggers

The system software is supplied with a standard safety configuration. The standard safety configuration can be modified by the user and contains the following preconfigured triggers for stop reactions:

Trigger	T1, CRR	AUT
EMERGENCY STOP pressed on the smartPAD	Safety stop 1 (path-maintaining)	
Enabling switches on smartPAD and Commander released	Safety stop 1 (path-maintaining)	-
Enabling switch on smartPAD or Commander fully pressed	Safety stop 1 (path-maintaining)	-
Maximum permissible velocity for manual guidance * exceeded (enabling signal issued via Commander)	Safety stop 1 (path-maintaining)	
* Preconfigured values depend on the system software version: Up to version 1.0 (900 mm/s), from version 1.1 onwards (500 mm/s)		
Maximum permissible velocity in T1/CRR (250 mm/s) exceeded (no enabling signal issued via Commander)	Safety stop 1 (path-maintaining)	-
Maximum permissible global velocity in AUT (2000 mm/s) exceeded (deactivated by default)	-	Safety stop 1 (path-maintaining)

Trigger	T1, CRR	AUT
Safety gate opened (operator safety)	-	Safety stop 1 (path-maintaining)
External EMERGENCY STOP pressed (deactivated by default)	Safety stop 1 (path-maintaining)	

From version 1.1 onwards, the standard safety configuration of the system software also contains the following preconfigured triggers for stop reactions for collaborative operation (HRC):

Trigger	T1, CRR	AUT
Maximum permissible external torque exceeded at least one axis (30 Nm) (no enabling signal issued via Commander)	Safety stop 1 (HRC)	
Maximum permissible velocity (500 mm/s) exceeded (no enabling signal issued via Commander)	Safety stop 1 (path-maintaining)	

The user can additionally configure further triggers for stop reactions, including the associated stop category.

(>>> *9 "Safety configuration" Page 133*)

3.5 Safety functions

3.5.1 Overview of the safety functions

Safety functions are distinguished according to the safety requirements that they fulfill:

- Safety-oriented functions for the protection of personnel

  The safety-oriented functions of the industrial robot meet the following safety requirements:

  – **Category 3** and **Performance Level d** in accordance with EN ISO 13849-1

  – **SIL 2** according to EN 62061

  The requirements are only met on the following condition, however:

  – All safety-relevant mechanical and electromechanical components of the industrial robot are tested for correct functioning during start-up and at least once every 12 months, unless otherwise determined in accordance with a workplace risk assessment. These include:

    – EMERGENCY STOP device on the smartPAD
    – External EMERGENCY STOP devices (if present)
    – Enabling device on the smartPAD
    – Enabling device on the Commander
    – External enabling devices (if present)
    – Safety-oriented outputs of the discrete safety interface

  (>>> *"Function test" Page 36*)

- Non-safety-oriented functions for the protection of machines

  The non-safety-oriented functions of the industrial robot do not meet specific safety requirements.

> **DANGER**
>
> **Risk of fatal injury due to non-operational safety functions or external safeguards**
>
> In the absence of operational safety functions or safeguards, the industrial robot can cause death, severe injuries or damage to property.
>
> - If safety functions or safeguards are dismantled or deactivated, do not operate the industrial robot.

> **Integrate industrial robot into safety system of the overall system**
>
> During system planning, the safety functions of the overall system must be planned and designed. Death, severe injuries or damage to property may otherwise result.
>
> - The industrial robot must be integrated into the safety system of the overall system.

Safe state in the event of an error

In the case of a serious error in the safety controller, the following safe state is established:

- All safety-oriented outputs are set to LOW (state "0") or the safety-oriented connection is interrupted.
- The energy supply to all safety-oriented drives is interrupted.
- Application of the holding brakes of all safety-oriented drives is activated.

Safety-oriented functions

All required safety-oriented functions can be configured. Some of these safety-oriented functions are preconfigured as Safety Rules in Safety Rule Sets:

- Safety Rule Set "Operator Devices"
  - Safety Rule "Emergency Stop Operator Device"

    EMERGENCY STOP device on the smartPAD
  - Safety Rule "Enabling in Test Mode"

    Enabling device on the smartPAD and LBR iisy Commander
- Safety Rule Set "Velocity Monitoring"
  - Safety Rule "Velocity Limit Global"

    Maximum global velocity

    Disabled by default. In order to be able to use the functionality, the Safety Rule must be enabled.
  - Safety Rule "Velocity Limit T1"

    Maximum velocity in T1/CRR
  - Safety Rule "Velocity Limit Manual Guidance"

    Maximum velocity for manual guidance
- Safety Rule Set "Standard Safety Interface"

  The following preconfigured safety functions additionally require the integration of external devices via the safety interface of the robot controller.
  - Safety Rule "Safety Door"

    Operator safety (= connection for the monitoring of physical safeguards)
  - Safety Rule "Emergency Stop External"

    External EMERGENCY STOP device

Disabled by default. In order to be able to use the functionality, the Safety Rule must be enabled.

- Safety Rule “Emergency Stop Internal”

  EMERGENCY STOP output

> **i** Further information about the available safety interfaces is contained in the assembly instructions of the robot controller in the “Planning” chapter.

- Safety Rule Set “HRC (transient contact)” (available from version 1.1 of the system software onwards)
  - Safety Rule “Velocity Limit HRC (transient contact)”

    Maximum velocity for collaborative operation (HRC)
  - Safety Rule “Collision detection”

    Collision detection for collaborative operation (HRC)

Additional safety-oriented functions can also be configured, e.g.:

- External enabling device
- External safety stop
- Axis-specific workspace monitoring

(>>> *9 "Safety configuration" Page 133*)

3.5.2 Safety controller

The safety controller is a unit inside the control PC. It links safety-relevant signals and safety-relevant monitoring functions.

Safety controller tasks:

- Switching off the drives; applying the brakes
- Monitoring of the braking ramp
- Velocity monitoring
- Evaluation of safety-relevant signals
- Setting of safety-oriented outputs

3.5.3 Local EMERGENCY STOP device

This safety function is preconfigured in the Safety Rule “Emergency Stop Operator Device” in the Safety Rule Set “Operator Devices”.

As standard, the EMERGENCY STOP device of the industrial robot is the EMERGENCY STOP device on the smartPAD. The EMERGENCY STOP device must be pressed in the event of a hazardous situation or emergency.

Reaction of the industrial robot if the EMERGENCY STOP device is pressed (default configuration):

- The manipulator stops with a safety stop 1 (path-maintaining).

Before operation can be resumed, the EMERGENCY STOP device must be released.

> **i** The inputs for the local EMERGENCY STOP can be configured. A different EMERGENCY STOP device can be connected and used for the local EMERGENCY STOP.

WARNING

Danger to life and limb due to tools and equipment without EMERGENCY STOP
If tools and other equipment connected to the robot are not integrated into the EMERGENCY STOP circuit, this can result in death, severe injuries or damage to property.

- Integrate tools and other equipment into the EMERGENCY STOP circuit if they could constitute a potential hazard.

If a holder is used for the teach pendant and conceals the EMERGENCY STOP device, an external EMERGENCY STOP device must be installed that is accessible at all times.

(>>> *3.5.7 "External EMERGENCY STOP device" Page 28*)

3.5.4 Enabling device

This safety function is preconfigured in the Safety Rule “Enabling in Test Mode” in the Safety Rule Set “Operator Devices”.

The enabling devices of the industrial robot are the enabling switches on the smartPAD and on the LBR iisy Commander.

- smartPAD: 4 enabling switches
- Commander: 2 enabling switches

The enabling switches have 3 positions:

- Not pressed
- Center position
- Fully pressed (panic position)

In operating modes T1 and CRR, the manipulator can only be moved if one of these enabling switches is held in the center position (default configuration).

It is possible to hold several enabling switches on the smartPAD simultaneously in the center position or both enabling switches on the Commander. It is not possible to move the manipulator if an enabling switch on the Commander and an enabling switch on the smartPAD are held simultaneously in the center position.

In operating modes T1 and CRR, the manipulator can be stopped in the following ways:

- Press at least one enabling switch down fully.

  Fully pressing an enabling switch triggers a safety stop 1 (path-maintaining).
- Release all enabling switches.

  Releasing all (!) enabling switches held in the center position triggers a safety stop 1 (path-maintaining).

WARNING

Danger to life and limb due to lack of reaction when an enabling switch is released
Releasing one of multiple enabling switches held in the center position does not trigger a stop reaction.
If multiple switches are held in the center position, the robot controller cannot distinguish whether one of them was intentionally released or if it was unintentionally released as the result of an accident.

- Create awareness for the hazard.

If an enabling switch malfunctions (e.g. jams in the center position), the industrial robot can be stopped using one of the following methods:

- Press another enabling switch down fully.
- Actuate the EMERGENCY STOP device.
- Release the Start key.

WARNING

Danger to life and limb due to manipulation of enabling switches
The enabling switches must not be held down by adhesive tape or other means or tampered with in any other way. Death, severe injuries or damage to property may result.

- Carry out a visual inspection of the enabling switches.
- Rectify tampering or remove any foreign bodies.

3.5.5 Velocity monitoring

This safety function is preconfigured in the Safety Rule Set “Velocity Monitoring”.

By default, the Cartesian velocity of the manipulator is limited. The following Cartesian velocity limits are defined:

- Safety Rule “Velocity Limit T1”

  Maximum velocity in T1/CRR: 250 mm/s

  If the velocity limit is exceeded in T1 or CRR mode and manual guidance is not active, i.e. no enabling switch on the Commander is pressed, a safety stop 1 (path-maintaining) is triggered.

  In the case of manual guidance in T1/CRR, the velocity is not reduced, but is limited by the velocity monitoring configured in the Safety Rule “Velocity Limit Manual Guidance”. By default, this velocity limit is greater than 250 mm/s.
- Safety Rule “Velocity Limit Manual Guidance”

  Maximum velocity for manual guidance

  Preconfigured values depend on the version of the system software:

  – Up to Version 1.0: 900 mm/s
  – From Version 1.1 onwards: 500 mm/s

  When manual guidance is active, i.e. an enabling switch on the Commander is pressed, a safety stop 1 (path-maintaining) is triggered if the velocity limit is exceeded.

  The maximum velocity for manual guidance can be adapted. The value for this velocity limit must be defined in a risk assessment (recommendation: < 1000 mm/s).

  (>>> *9.18.4 "Velocity monitoring during manual guidance" Page 159*)
- Safety Rule “Velocity Limit Global” (disabled by default)

  Maximum global velocity: 2000 mm/s

  When the Safety Rule is enabled, a safety stop 1 (path-maintaining) is triggered as soon as the global velocity limit is exceeded.

3.5.6 Signal for operator safety

This safety function is preconfigured in the Safety Rule “Safety Door” in the Safety Rule Set “Standard Safety Interface”.

The “Safety Door” signal is used for monitoring physical safeguards, e.g. safety gates. According to the Safety Rule, the robot can only be moved in automatic mode if the “Safety Door” signal is set or the robot is guided manually.

Operator safety is not active as standard in the Manual Reduced Velocity (T1) and CRR modes. The signal is not evaluated.

If no physical safeguards are installed, the preconditions for collaborative operation in accordance with EN ISO 10218 must be met. In this case, the Safety Rule can be disabled or removed.

Reaction of the industrial robot in the event of a loss of signal during automatic operation (default configuration):

- The manipulator stops with a safety stop 1 (path-maintaining).

As standard, the safety gate is connected to the robot controller via input IN_A1 of safety interface XG11.1.

> Further information about the safety interface is contained in the assembly instructions of the robot controller in the “Planning” chapter.

WARNING

Danger to life and limb due to resumption of automatic operation without adequate checking

Following loss of the signal for operator safety, it must not be possible to restart automatic operation by merely closing the safeguard. Otherwise, for example, the safety gate could close unintentionally, thereby causing automatic operation to resume while there are persons in the danger zone. Death, severe injuries or damage to property may result.

- Automatic operation must not be resumed until the safeguard has been closed and the closing has been acknowledged.
- The acknowledgement must be designed in such a way that an actual check of the danger zone can be carried out first. Acknowledgement that is automatically and directly triggered by closure of the safeguard is not permitted.
- If closure is acknowledged by a device (e.g. by the PLC), the system integrator must ensure that the acknowledgement is preceded by an actual check of the danger zone.

3.5.7 External EMERGENCY STOP device

This safety function is preconfigured in the Safety Rule “Emergency Stop External” in the Safety Rule Set “Standard Safety Interface”. The Safety Rule is disabled by default.

Every operator station that can initiate a robot motion or other potentially hazardous situation must be equipped with an EMERGENCY STOP device. The system integrator is responsible for ensuring this.

Reaction of the industrial robot if the external EMERGENCY STOP device is pressed (default configuration):

- The manipulator stops with a safety stop 1 (path-maintaining).

Before operation can be resumed, the EMERGENCY STOP device must be released.

By default, external EMERGENCY STOP devices are connected via input IN_A0 of safety interface XG11.1 of the robot controller. External EMERGENCY STOP devices are not included in the scope of supply of the industrial robot.

> Further information about the safety interface is contained in the assembly instructions of the robot controller in the “Planning” chapter.

3.5.8 EMERGENCY STOP output

This safety function is preconfigured in the Safety Rule “Emergency Stop Internal” in the Safety Rule Set “Standard Safety Interface”.

The state of the EMERGENCY STOP device on the smartPAD is provided at the safety-oriented output of safety interface XG11.1 by default. If the EMERGENCY STOP is actuated, the output signal is set to LOW. Triggering an external EMERGENCY STOP does not (!) set the output signal for the local EMERGENCY STOP.

> Further information about the safety interface is contained in the assembly instructions of the robot controller in the “Planning” chapter.

3.5.9 Monitoring functions for collaborative operation (HRC)

For collaborative operation without physical safeguards, the Safety Rule Set “HRC (transient contact)” is preconfigured (available from version 1.1 of the system software onwards). The Safety Rule Set reduces the risk of transient contact during automatic operation.

The following Safety Rules are included:

- Safety Rule “Collision detection”

  Maximum external torque for collision detection: 30 Nm

  A safety stop 1 (HRC) is triggered as long as a collision is detected (maximum external torque exceeded) and manual guidance is not active, i.e. no enabling switch pressed on the Commander.
- Safety Rule “Velocity Limit HRC (transient contact)”

  Maximum velocity for collaborative operation: 500 mm/s

  A safety stop 1 (path-maintaining) is triggered if the maximum velocity limit is exceeded and manual guidance is not active, i.e. no enabling switch pressed on the Commander.

Instructions on using the Safety Rule Set:

- To operate the robot without physical safeguards, the Safety Rule “Safety Door” must be deactivated.

  (>>> *3.5.6 "Signal for operator safety" Page 27*)
- The Safety Rule Set does not provide sufficient risk reduction against potential crushing hazards.
- For collaborative operation, it is advisable to comply with the safety requirements of ISO/TS 15066.

3.5.10 External enabling device

External enabling devices are required if it is necessary for more than one person to be in the danger zone of the industrial robot.

Multiple external enabling devices can be connected via the safety interface of the robot controller. External enabling devices are not included in the scope of supply of the industrial robot.

> Further information about the available safety interfaces is contained in the assembly instructions of the robot controller in the “Planning” chapter.

3.6 Additional protective equipment

3.6.1 Jog mode

In the operating modes T1 (Manual Reduced Velocity) and CRR, the robot controller can only execute programs in jog mode. This means that it is necessary to hold down an enabling switch and the Start key in order to execute a program.

- Releasing the enabling switch on the teach pendant triggers a safety stop 1 (path-maintaining).
- Pressing the enabling switch on the teach pendant fully down triggers a safety stop 1 (path-maintaining).
- Releasing the Start key triggers a stop of Stop category 2.

3.6.2 Software limit switches

The axis ranges of all manipulator axes are limited by means of non-safety-oriented software limit switches. These software limit switches only serve as machine protection and are preset in such a way that the manipulator is stopped under servo control if the axis limit is exceeded, thereby preventing damage to the mechanical equipment.

3.6.3 Options for moving the manipulator without drive energy

Qualification of personnel with regard to behavior in emergency situations
In emergencies or other exceptional situations, it may be necessary to move the manipulator without drive energy.

- Personnel must be trained in how to move the manipulator without drive energy.

In order to be able to move the manipulator after an accident or malfunction without drive energy, it must be either dismounted or pushed against the brakes.

NOTICE

Damage to property due to moving the manipulator without drive energy
Moving the manipulator without drive energy can damage the motor brakes of the axes concerned.

- Only move the manipulator without drive energy in emergencies, e.g. for rescuing persons.
- Perform brake test.
  The motor must be replaced if the brake has been damaged.

3.6.4 Labeling on the industrial robot

All plates, labels, symbols and marks constitute safety-relevant parts of the industrial robot. They must not be modified or removed.

Labeling on the industrial robot consists of:

- Identification plates
- Warning signs
- Safety symbols

- Designation labels
- Cable markings
- Rating plates

Further information is contained in the technical data of the operating instructions or assembly instructions of the components of the industrial robot.

3.6.5 External safeguards

The access of persons to the danger zone of the industrial robot must be prevented by means of safeguards. It is the responsibility of the system integrator to ensure this.

If there are no physical safeguards present, the requirements for collaborative operation in accordance with EN ISO 10218 must be met.

Physical safeguards must meet the following requirements:

- They meet the requirements of EN ISO 14120.
- They prevent access of persons to the danger zone and cannot be easily circumvented.
- They are sufficiently fastened and can withstand all forces that are likely to occur in the course of operation, whether from inside or outside the enclosure.
- They do not, themselves, represent a hazard or potential hazard.
- Prescribed clearances, e.g. to danger zones, are adhered to.

Safety gates (maintenance gates) must meet the following requirements:

- They are reduced to an absolute minimum.
- The interlocks (e.g. safety gate switches) are linked to the configured operator safety inputs of the robot controller.
- Switching devices, switches and the type of switching conform to the requirements of Performance Level d and category 3 according to EN ISO 13849-1.
- Depending on the hazard situation: the safety gate is additionally safeguarded by means of a locking mechanism that only allows the gate to be opened if the manipulator is safely at a standstill.
- The device for setting the signal for operator safety, e.g. the button for acknowledging the safety gate, is located outside the space limited by the safeguards.

Further information is contained in the corresponding standards and regulations. These also include EN ISO 14120.

Other safety equipment

Other safety equipment must be integrated into the system in accordance with the corresponding standards and regulations.

3.7 Mode selection

The operating mode can be changed by displaying the mode in the status bar of the user interface.

Do not change the operating mode while a program is running. If the operating mode is changed, the industrial robot stops with a safety stop 1 (path-maintaining).

Operating modes

The industrial robot can be operated in the following modes:

- Manual Reduced Velocity (T1)
- Automatic (AUT)
- Controlled robot retraction (CRR)

Operating mode	Use	Velocities
T1	Programming, teaching and testing of programs	• Program verification: Reduced programmed velocity, maximum 250 mm/s • Jog mode: Jog velocity, maximum 250 mm/s • Manual guidance: No limitation of the velocity, but safety-oriented velocity monitoring in accordance with the safety configuration
AUT	Automatic execution of programs For industrial robots with and without higher-level controllers	• Program mode: Programmed velocity • Jog mode: Not possible • Manual guidance: Safety-oriented velocity monitoring in accordance with the safety configuration

Operating mode	Use	Velocities
CRR	CRR is an operating mode which can be selected when the industrial robot is stopped by the safety controller for one of the following reasons: • Industrial robot violates an axis-specific or Cartesian monitoring space. • The tool orientation is outside the permitted range. • Industrial robot violates collision detection or the maximum TCP force monitoring function. • One or more axes are unmastered. • Mastering of one or more axis positions is not confirmed. • Calibration of one or more joint torque sensors is not confirmed. • Maximum Cartesian velocity has been exceeded. • Maximum torque of an axis has been exceeded, e.g. due to a crushing situation. After changing to CRR mode, the industrial robot may once again be moved. If the cause of the stop is no longer present and no further stop is requested for 4 seconds by one of the specified causes, the operating mode switches automatically to T1.	• Program verification: Reduced programmed velocity, maximum 250 mm/s • Jog mode: Jog velocity, maximum 250 mm/s • Manual guidance: No limitation of the velocity, but safety-oriented velocity monitoring in accordance with the safety configuration

3.8 Safety measures

3.8.1 General safety measures

The industrial robot may only be used in perfect technical condition in accordance with its intended use and only by safety-conscious persons. Operator errors can result in personal injury and damage to property.

It is important to be prepared for possible movements of the industrial robot even after the robot controller has been switched off and locked out. Incorrect installation (e.g. overload) or mechanical defects (e.g. brake defect) can cause the manipulator to sag. If work is to be carried out on a switched-off industrial robot, the manipulator must first be moved into a position in which it is unable to move on its own, whether the payload is mounted or not. If this is not possible, the manipulator must be secured by appropriate means.

DANGER

Risk of fatal injury due to non-operational safety functions or external safeguards
In the absence of operational safety functions or safeguards, the industrial robot can cause death, severe injuries or damage to property.

- If safety functions or safeguards are dismantled or deactivated, do not operate the industrial robot.

DANGER

Danger to life and limb of persons under the robot arm
Sagging or falling parts can cause death or serious injuries. This applies at all times, e.g. also for assembly tasks or with the controller switched off.

- Never loiter under the robot arm.

Implants

WARNING

Danger to life due to malfunction of implants caused by motors and brakes
Electric motors and brakes generate electric and magnetic fields. The fields can cause malfunctions in active implants, e.g. pacemakers.

- Affected persons must maintain a minimum distance of 300 mm from motors and brakes. This applies to both energized and deenergized motors and brakes.

smartPAD

The user must ensure that the industrial robot is only operated with the smartPAD pro by authorized persons.

If more than one smartPAD is used in the overall system, it must be ensured that it is clearly recognizable which smartPAD is connected to which industrial robot. They must not be interchanged.

The enabling switches on the smartPAD must be subjected to a function test at least once every 12 months and in certain specific cases.

(>>> *"Function test" Page 36*)

Modifications

After modifications to the industrial robot, checks must be carried out to ensure the required safety level. The valid national or regional work safety regulations must be observed for this check. The correct functioning of all safety functions must also be tested.

New or modified programs must always be tested first in Manual Reduced Velocity mode (T1).

After modifications to the industrial robot, existing programs must always be tested first in Manual Reduced Velocity mode (T1). This applies to all components of the industrial robot and includes modifications to the software and configuration settings.

Faults

In the case of faults on the industrial robot, the following safety measures must be implemented immediately:

- Switch off the robot controller and secure it (e.g. with a padlock) to prevent unauthorized persons from switching it on again.

- Indicate the fault by means of a label with a corresponding warning (tagout).
- Keep a record of the faults.

Carry out a functional test after the fault has been rectified.

3.8.2 Transportation

Manipulator

The prescribed transport position of the manipulator must be observed. Transportation must be carried out in accordance with the operating instructions or assembly instructions of the robot.

Avoid vibrations and impacts during transportation in order to prevent damage to the manipulator.

Robot controller

The prescribed transport position of the robot controller must be observed. Transportation must be carried out in accordance with the operating instructions or assembly instructions of the robot controller.

Avoid vibrations and impacts during transportation in order to prevent damage to the robot controller.

3.8.3 Start-up and recommissioning

⚠

Changing default passwords
The system software is supplied with default passwords for the user groups. If the passwords are not changed, this enables unauthorized persons to log on.

- Before start-up, change the passwords for the user groups.
- Only communicate the passwords to authorized personnel.

Before starting up systems and devices for the first time, a check must be carried out to ensure that the systems and devices are complete and operational, that they can be operated safely and that any damage is detected.

The valid national or regional work safety regulations must be observed for this check. The correct functioning of all safety functions must also be tested.

⚠

WARNING

Danger to life and limb due to incorrectly assigned cables
The robot controller is preconfigured for the specific industrial robot. The manipulator and other components can receive incorrect data if they are connected to a different robot controller. Death, severe injuries or damage to property may result.

- Only connect the manipulator to the corresponding robot controller.

⚠

Do not impair safety functions
Additional components (e.g. cables and hoses) not supplied by KUKA may be integrated into the industrial robot. If the safety functions are not taken into consideration, this may result in death, severe injuries or damage to property.

- Additional components must not impair or disable safety functions.

NOTICE

Damage to property due to condensation
If the internal cabinet temperature of the robot controller differs greatly from the ambient temperature, condensation can form. This may result in damage to property.

- Wait until the internal cabinet temperature has adapted to the ambient temperature in order to avoid condensation.

Take substitute measures for minimizing risk in the case of incomplete start-up
Start-up is incomplete, for example, if not all safety functions have yet been implemented, or if a function test of the safety functions has not yet been carried out. The absence of substitute measures for minimizing risk can result in death, serious injury or damage to property.

- Additional substitute measures for minimizing risk must be taken and documented, e.g. installing a safety fence, attaching a warning sign, locking the main switch.

Function test

The following tests must be carried out before start-up and recommissioning:

General test:

It must be ensured that:

- The industrial robot is correctly installed and fastened in accordance with the specifications in the documentation.
- There are no foreign bodies or defective or loose parts on the industrial robot.
- There is no damage to the robot that could be attributed to external forces.

WARNING

Danger to life and limb resulting from external forces
The external application of force, such as an impact or a collision, can cause non-visible damage. For example, it can lead to a gradual loss of drive power from the motor, resulting in unintended movements of the manipulator.
Death, severe injuries or damage to property may result from non-visible damage.

– Check the robot for damage that could have been caused by external forces, e.g. dents or abrasion of paintwork.
– In the case of damage, the affected components must be exchanged.

- All required safety equipment is correctly installed and operational.
- The power supply ratings of the industrial robot correspond to the local supply voltage and mains type.
- The ground conductor and the equipotential bonding cable are sufficiently rated and correctly connected.
- The connecting cables are correctly connected and the connectors are locked.

Test of the safety functions:

A function test must be carried out for all the safety-oriented functions to ensure that they are working correctly.

(>>> *9.23 "Safety acceptance" Page 173*)

Test of the safety-relevant mechanical and electromechanical components:

The following tests must be performed prior to start-up and recommissioning, and at least once every 12 months unless otherwise determined in accordance with a workplace risk assessment:

- Function of all connected EMERGENCY STOP devices

  Press the EMERGENCY STOP device. A message must be displayed on the teach pendant indicating that the EMERGENCY STOP has been actuated. At the same time, no error message may be displayed about the EMERGENCY STOP device.
- Function of the enabling switches of all connected enabling devices

  Move the robot in Test mode and release the enabling switch. The robot motion must be stopped. At the same time, no error message may be displayed on the teach pendant about the enabling device.

  The test must always be carried out for all enabling switches of a connected enabling device.

  If the state of the enabling device is configured at an output, the test can also be performed via the output.
- Panic function of the enabling switches of all connected enabling devices

  Move the robot in test mode, press the enabling switch down and hold in the panic position for 3 seconds. The robot motion must be stopped. At the same time, no error message may be displayed on the teach pendant about the enabling device.

  The test must always be carried out for all enabling switches of a connected enabling device.

  If the state of the enabling device is configured at an output, the test can also be performed via the output.
- Switch-off capability of the safety-oriented outputs

  Switch robot controller off and then on again. After it is switched on, no error message may be displayed on the teach pendant relating to a safety-oriented output.

Test of the functional capability of the brakes:

For the industrial robot, a brake test is available which can be used to check whether the brake of each axis applies sufficient braking torque.

The brake test ensures that any impairment of the braking function is detected, e.g. due to wear, overheating, fouling or damage, thereby eliminating avoidable risks.

Unless otherwise determined by a risk assessment, the brake test must be performed regularly:

- The brake test must be performed for each axis before start-up and recommissioning of the industrial robot.
- The brake test must be carried out every 48 hours during operation.

A risk assessment can be used to determine whether the brake test is required for the specific application and how often the brake test must be performed.

3.8.4 Manual mode

General

Manual mode is the mode for setup work. Setup work is all the tasks that have to be carried out on the industrial robot to enable automatic operation. Setup work includes:

- Jog mode
- Teaching
- Programming
- Program verification

The following must be taken into consideration in manual mode:

- New or modified programs must always be tested first in Manual Reduced Velocity mode (T1).
- The manipulator and its tooling must never touch or project beyond the safety fence.
- Workpieces, tooling and other objects must not become jammed as a result of the industrial robot motion, nor must they lead to short-circuits or be liable to fall off.
- All setup work must be carried out, where possible, from outside the safeguarded area.

Setup work in T1

If it can be avoided, there must be no persons inside the safeguarded area.

If it is necessary to carry out setup work from inside the safeguarded area, the following must be taken into consideration in the operating mode **Manual Reduced Velocity (T1)**:

- If it can be avoided, there must be no more than one person inside the safeguarded area.
- If it is necessary for there to be several persons inside the safeguarded area, the following must be observed:
  - Each person must have an enabling device.
  - All persons must have an unimpeded view of the industrial robot.
  - Eye-contact between all persons must be possible at all times.
- The operator must be so positioned that he can see into the danger zone and get out of harm's way.
- Unexpected motions of the manipulator cannot be ruled out, e.g. in the event of a fault. For this reason, an appropriate clearance must be maintained between persons and the manipulator, including the tool. Guide value: 50 cm.

  The minimum clearance may vary depending on local circumstances, the motion program and other factors. The minimum clearance that is to apply for the specific application must be decided by the user on the basis of a risk assessment.

3.8.5 Simulation

Simulation programs do not correspond exactly to reality. Robot programs created in simulation programs must be tested in the system in **Manual Reduced Velocity mode (T1)**. It may be necessary to modify the program.

3.8.6 Automatic mode

Automatic mode is only permissible in compliance with the following safety measures:

- All safety equipment and safeguards are present and operational.

- There are no persons in the system or the requirements for collaborative operation in accordance with EN ISO 10218 have been met.
- The defined working procedures are adhered to.

If the manipulator comes to a standstill for no apparent reason, the danger zone must not be entered until an EMERGENCY STOP has been triggered.

3.8.7 Maintenance and repair

After maintenance and repair work, checks must be carried out to ensure the required safety level. The valid national or regional work safety regulations must be observed for this check. The correct functioning of all safety functions must also be tested.

The purpose of maintenance and repair work is to ensure that the system is kept operational or, in the event of a fault, to return the system to an operational state. Repair work includes troubleshooting in addition to the actual repair itself.

The following safety measures must be carried out when working on the industrial robot:

- Carry out work outside the danger zone. If work inside the danger zone is necessary, the user must define additional safety measures to ensure the safe protection of personnel.
- Switch off the industrial robot and secure it (e.g. with a padlock) to prevent it from being switched on again. If it is necessary to carry out work with the robot controller switched on, the user must define additional safety measures to ensure the safe protection of personnel.
- If it is necessary to carry out work with the robot controller switched on, this may only be done in operating mode T1.
- Label the system with a sign indicating that work is in progress. This sign must remain in place, even during temporary interruptions to the work.
- The EMERGENCY STOP devices must remain active. If safety functions or safeguards are deactivated during maintenance or repair work, they must be reactivated immediately after the work is completed.

DANGER

Danger to life and limb due to live parts
The robot system must be disconnected from the mains power supply prior to work on live parts. It is not sufficient to trigger an EMERGENCY STOP or safety stop, because parts remain live. Death or severe injuries may result.

- Before commencing work on live parts, turn off the main switch and secure it against being switched on again.

  If the controller variant in question does not have a main switch (e.g. KR C5 micro), turn off the device switch then disconnect the power cable and secure it so it cannot be reconnected.
- Then check to ensure that the system is deenergized.
- Inform the individuals involved that the robot controller is switched off. (e.g. by affixing a warning sign)

Faulty components must be replaced using new components with the same article numbers or equivalent components approved by KUKA Deutschland GmbH for this purpose.

Cleaning and preventive maintenance work is to be carried out in accordance with the operating instructions.

Robot controller

Even when the robot controller is switched off, parts connected to peripheral devices may still carry voltage. The external power sources must therefore be switched off if work is to be carried out on the robot controller.

The ESD regulations must be adhered to when working on components in the robot controller.

Voltages in excess of 50 V (up to 780 V) can be present in various components for several minutes after the robot controller has been switched off! To prevent life-threatening injuries, no work may be carried out on the industrial robot in this time.

On robot controllers with transformers, the transformers must be disconnected before working on components in the robot controller.

Water and dust must be prevented from entering the robot controller.

Hazardous substances

The following safety measures must be carried out when handling hazardous substances:

- Avoid prolonged and repeated intensive contact with the skin.
- Avoid breathing in oil spray or vapors.
- Clean skin and apply skin cream.

Use current safety data sheets
Knowledge of the safety data sheets of the substances and mixtures used is a prerequisite for the safe use of KUKA products. Death, injuries or damage to property may otherwise result.

- Request up-to-date safety data sheets from the manufacturers of hazardous substances regularly.

3.8.8 Decommissioning, storage and disposal

The industrial robot must be decommissioned, stored and disposed of in accordance with the applicable national laws, regulations and standards.

3.8.9 Safety measures for Single Point of Control

The industrial robot can be controlled exclusively via the connected KUKA smartPAD pro. The “Single Point of Control” principle (SPOC) has been implemented and is assured by the system. No additional safety measures are required.

3.9 IT security

3.9.1 Introduction

General information

KUKA products must only be used in perfect technical condition in accordance with their intended use and only by safety-conscious persons.

In particular, safety-conscious use includes being operated in an IT environment which meets the current security-relevant standards and for which there is an overall concept for IT security.

> **Take measures to ensure IT security**
> IT security involves not only aspects of information and data processing as such, but also affects at least the following areas:
>
> - Technology, organization, personnel, infrastructure
>
> KUKA urgently recommends that users implement an information security management system for their products which designs, coordinates and monitors the tasks related to information security.

Sources for information about IT security for companies include:

- Independent consulting firms
- National cybersecurity authorities

National authorities often make their recommendations available on the Internet.

Integration into an existing IT environment

The following information about IT security must be considered together with the integrator's and user's overall concept for IT security. On the basis of threat modeling and risk analyses, appropriate protective measures must be derived and implemented for the respective use of the product. These protective measures may be located in the following areas, among others:

- Network segmentation (firewalls)
- Access protection (authentication and authorization)
- Encryption
- Logging
- Auditing
- Physical access protection

It is the responsibility of the integrator and the user to ensure that the systems and components associated with this product and the infrastructure into which they are integrated provide adequate protection against IT security threats. This includes, among other things, protective measures against:

- Malware
- Unauthorized access
- Impacts on the availability of the system
- Theft or loss of information

Product support lifecycle

The products used must be in an active product support lifecycle and must not have been discontinued by the manufacturer. If this is not the case, an upgrade or replacement must be obtained in order to be able to maintain IT security. If this is not possible, further IT security measures (depending on the IT security policies and other requirements) must be taken in order to minimize the risk of operating a discontinued product.

Up-to-date information about the product

The latest information about the product, including information on IT security, is provided and updated in KUKA Xpert and must be accessed, checked and observed there by the integrator and user.

3.9.2 Measures for secure operation of the product

3.9.2.1 Physical access protection

The system integrator and user must take external measures to ensure that only authorized and trained persons have physical access to the system and its components, as well as connected systems, components and networks. Examples of this include access restrictions to the rooms or separately access-protected cabinets in which the respective system and components, such as the robot controller and teach pendant, are housed permanently or when not in use.

3.9.2.2 Network connection

The system has network interfaces for integration into IT and OT networks. If the network connectivity enables connections where trust boundaries would be transgressed, the following points must be considered in detail:

- Threats and risks associated with them
- Additional measures that may need to be taken to protect the system

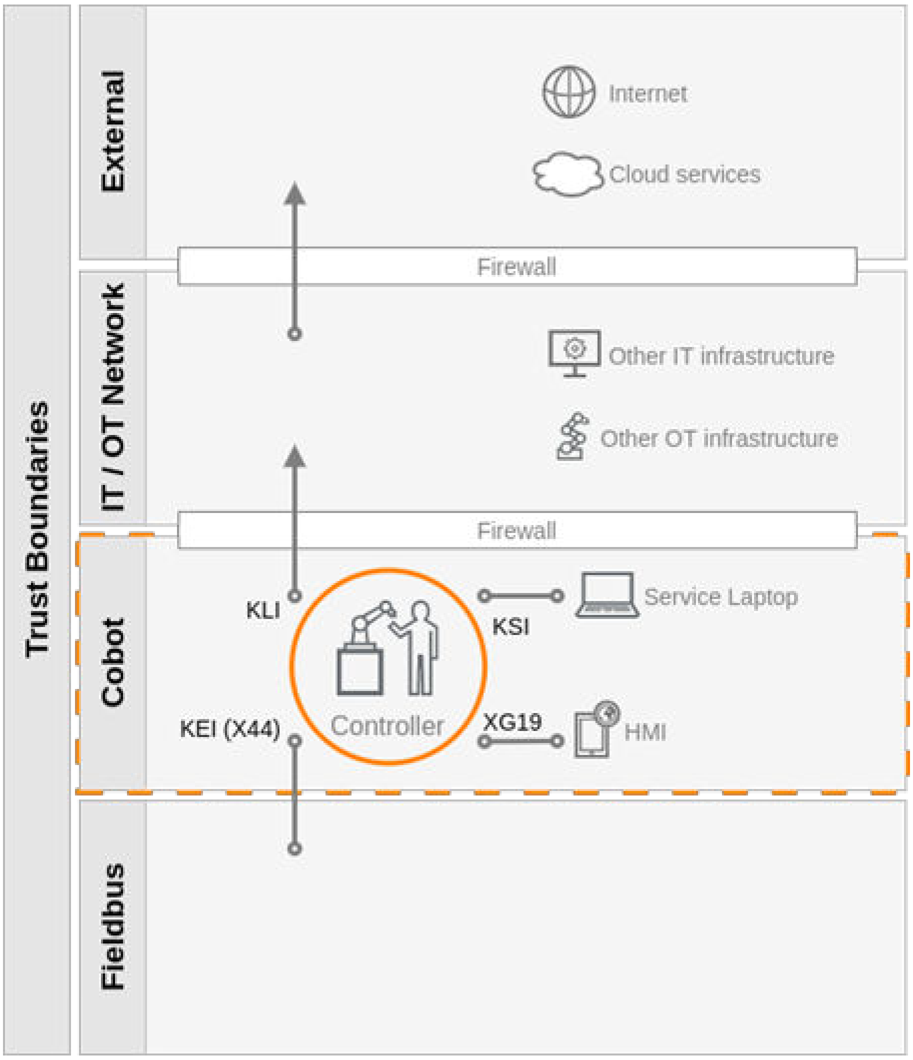


Fig. 3-1: Trust boundaries and network connectivity

Network requirements

The robot controller (including the teach pendant) may only be used in internal, segmented and inaccessible networks. Use in networks that are not separately protected is not permitted. It is recommended to use firewall solutions in order to allow only network connections between the robot controller and other systems that are actually necessary.

3.9.2.3 Access management

Standard access data

Access to the robot controller via the teach pendant is protected so that only authorized users can access the system and execute actions. The default passwords preset on delivery must be changed immediately in accordance with the local IT security requirements. No passwords that are easy to guess may be used.

> Detailed information about changing the passwords can be found in the chapter "General configuration" of the iiQKA.OS documentation.

Authorization concept

> Information about the authorization concept can be found in the chapter "General configuration" of the iiQKA.OS documentation.

Automatic logoff

- If no actions are carried out on the user interface for a specified time, the current user is automatically logged out. Different times apply depending on the user role:
  - User: After 30 min. of inactivity
  - Administrator: After 10 min. of inactivity
  - Safety Commissioning Engineer: After 5 min. of inactivity

Requirements on the configuration of access protection

- All user roles must be protected using strong passwords.
- Depending on the local requirements, the implementation of an authorization concept is necessary.
- Users should be assigned only the minimum permissions required for their respective tasks.
- Granted permissions must be regularly checked to ensure that they are correct and up to date, and changes must be implemented promptly.

3.9.2.4 Software updates

KUKA offers software updates and upgrades and, if necessary, separate security updates for secure operation of the system. These must be implemented in accordance with the customer-specific requirements when using the system.

> Information about the software update procedure can be found in the chapter "General operation" of the iiQKA.OS documentation.

3.9.2.5 Data backup

In accordance with the customer-specific requirements when using the system, a data backup concept must be established and implemented so that all necessary data can be restored in the event of data loss on the robot controller or an associated component.

> Information about the procedure for data backup can be found in the chapter “General operation” of the iiQKA.OS documentation.

3.9.2.6 USB interfaces

Only trustworthy USB devices may be connected to the system. Only content that comes from trustworthy sources and, if necessary, has been previously checked with an antivirus program may be written to the USB devices. The data written to USB devices in the course of a data backup or export may contain sensitive data. Appropriate IT security measures should therefore be taken to protect these data accordingly.

3.9.2.7 Customer service access

The system features emergency SSH access to the Linux kernel system, which is not enabled by default and can only be used by the customer and KUKA Customer Support with local access to the system. This access (Service Account) can be temporarily enabled via the HMI or via the KSI interface (with an enabling tool). Administrator privileges are required for enabling access. After access has been enabled, an SSH service is active at TCP port 22 on the KLI and KSI interfaces. It is only possible to log on via SSH with the access data of KUKA Customer Support. Access is automatically disabled 30 minutes after enabling.

If customer service is required, it must be ensured that the SSH connection is established to the correct system (e.g. using a dedicated network cable to the robot controller). Each robot controller has an individual SSH host key, enabling the robot controller to be identified for future connections via the fingerprint of the SSH host key.

SSH access is intended for emergencies in which analysis or repair of the software components is not otherwise possible, and it may no longer be available in future versions of the product.

> Information about enabling customer service access (Service Account) can be found in the chapter “General configuration” of the iiQKA.OS documentation.

3.9.2.8 Developer mode

Developer mode can be activated via the Administrator user role. As long as Developer mode is activated, the SSH service at port 22 is accessible from the network and the user can log on to the system via SSH with the password set when activating the mode. This SSH access can be used to install specially signed extensions for development purposes. On exiting Developer mode, SSH access is disabled and the system is reset to its state before Developer mode was activated.

3.9.3 IT security features of the product

3.9.3.1 General

On the basis of threat modeling and risk analyses, potential threats were identified and necessary protective measures for the system were derived. The following sections outline what these basic measures are, what threats these measures target, and what broader aspects the system integrator and user additionally need to consider. Since the system is subject to ongoing development, only the most important protective measures are explained here.

3.9.3.2 Firewalls

Description

The system has a firewall that protects against undesired network access. Certain connections necessary for the system to function are only allowed via defined interfaces. All other connections are blocked by the system.

Threats taken into consideration

The following potential threats were considered during the planning of the described function:

- An attacker could access internal network services of the robot controller or other components via the network.
- An attacker could use the network to access network services that have been inadvertently enabled or network services that have been enabled for temporary purposes only (e.g. for analytics).
- An attacker could exploit another vulnerability to start their own service for various purposes or provide an existing service via a modified configuration that could allow them direct access to the system (e.g. a shell or FTP server).

Permitted connections

Up to version 1.0 of the system software, the firewall configuration of the system cannot be adapted by the user. The following connections and related services are allowed in the standard installation:

- **KLI IT interface**
  - Incoming: TCP port 22 (SSH) – customer service access
  - Incoming: TCP port 80 (HTTP) – license information
- **KLI OT interface**
  - Incoming: TCP port 22 (SSH) – customer service access
  - Incoming: TCP port 80 (HTTP) – license information
- **KONI interface**
  - Incoming: TCP port 22 (SSH) – customer service access
- **KSI interface**
  - Incoming: TCP port 22 (SSH) – customer service access
  - Incoming: TCP port 80 (HTTP) – license information
  - Incoming: TCP port 49162 – enabling of customer service access by customer

From version 1.1 of the system software onwards, the firewall configuration can be viewed by the user in the system settings. The following connections and related services are allowed in the standard installation:

- **KLI IT interface**
  - Incoming: TCP port 22 (SSH) – customer service access
  - Incoming: TCP port 80 (HTTP) – license information
- **KLI OT interface**
  - Incoming: TCP port 22 (SSH) – customer service access
  - Incoming: TCP port 80 (HTTP) – license information
  - Incoming: TCP port 44818 and UDP port 2222 – EtherNet/IP, can be switched off
- **KONI interface**
  - Incoming: TCP port 22 (SSH) – customer service access
- **KSI interface**
  - Incoming: TCP port 22 (SSH) – customer service access
  - Incoming: TCP port 80 (HTTP) – license information
  - Incoming: TCP port 49162 – enabling of customer service access by customer

Optional toolboxes can also provide additional services and open the ports these require. The corresponding firewall rules are also displayed in the system settings.

Unnecessary firewall rules can be deactivated in the system settings. The correct functioning of the system or toolbox cannot be guaranteed in this case.

> Information about deactivating the firewall rules can be found in the chapter "General configuration" of the iiQKA.OS documentation.

3.9.3.3 Encryption of communication

Description

With a few exceptions, communication with the system takes place in encrypted form and using procedures selected in accordance with the current state of the art. Encrypted communication relationships:

- HTTPS between robot controller and my.kuka.com (access to software updates)
- HTTPS between robot controller and KUKA Update Service (access to software updates)
- SSH (if enabled) between local customer PC or customer service PC and robot controller

Exceptions to encrypted communication:

- DHCP (local)
- DNS (local)
- HTTP access to license information

Threats taken into consideration

The following potential threat was considered during the planning of the described function:

- An attacker who is able to monitor, read or redirect network traffic locally or remotely could obtain sensitive information, modify it or compromise the system.

Cryptographic techniques used

The following cryptographic techniques are used:

SSL/TLS connections

- KUKA Update Service:
  TLS 1.2 and TLS 1.3
- Web UI on the robot controller (accessible via smartPAD only):
  TLS 1.1 and TLS 1.2
- Enabling of customer service access via KSI interface:
  TLS 1.2 and TLS 1.3

SSH customer service access

- SSH protocol version 2.0
- SSH encryption algorithms:
  chacha20-poly1305@openssh.com, aes128-ctr, aes192-ctr, aes256-ctr, aes128-gcm@openssh.com, aes256-gcm@openssh.com
- SSH key exchange algorithms:
  curve25519-sha256, curve25519-sha256@libssh.org, ecdh-sha2-nistp256, ecdh-sha2-nistp384, ecdh-sha2-nistp521, diffie-hellman-group-exchange-sha256, diffie-hellman-group16-sha512, diffie-hellman-group18-sha512, diffie-hellman-group14-sha256
- Signature verification of software artifacts:
  4096-bit RSA key and SHA-256 hashing
- Password hashing technique for HMI users:
  Argon2

3.9.3.4 Checking of software updates

Software artifacts such as software updates and extensions are checked for integrity and a valid cryptographic signature by the system prior to installation. Only software artifacts signed by KUKA are accepted and installed. This only applies as long as the system has not been switched to Developer mode. (>>> *3.9.2.8 "Developer mode" Page 44*)

3.9.3.5 Preventing the installation of older software

Description

Software artifacts can only be updated through higher versions. It is not possible to install older versions (downgrades).

Threats taken into consideration

The following potential threats were considered during the planning of the described function:

- An attacker with temporary access to the system could gain deeper access or persistence to the system by installing an older software artifact – and any vulnerabilities potentially contained therein.
- It should not be possible to exploit a vulnerability in the authorization of software updates or a vulnerability that allows arbitrary software updates to be copied onto the system in order to install older versions.
- If an older software update is foisted on an administrator, it should not be possible to use it to install older versions.

3.9.3.6 Subdivision of the system

Description

Various techniques are used to separate individual software components and services from one another and to restrict their permissions so that only those interactions between software components that are actually necessary are possible. In the event that a single software component is compromised, this makes it much more difficult for an attacker to infiltrate the rest of the system.

Threats taken into consideration

The following potential threats were considered during the planning of the described function:

- A vulnerability in a single software component could be exploited to compromise the entire system.
- A vulnerability in a single software component could be exploited to influence functions provided by other software components.
- A vulnerability in a single software component could be exploited to obtain information that is processed, managed or saved by other software components.

3.9.3.7 Removal of non-essential software components and functions

Description

Non-essential software components and software functions have been removed to reduce the attack surface. Examples include kernel functions, kernel modules, userspace applications and application extensions that are not required.

Threats taken into consideration

The following potential threats were considered during the planning of the described function:

- Compromise of the system through exploitation of a vulnerability in a non-essential software component or function.
- An attacker has the opportunity to quickly and easily infiltrate the system and achieve their objectives, as various standard applications are available that significantly minimize the effort required to do so.

3.9.3.8 Decommissioning the system

The system currently does not offer a function for securely deleting the complete system. If there is a need to delete the complete system, KUKA Customer Support should be contacted. Otherwise, it is recommended to remove the hard drive and logically erase and physically destroy it depending on the local IT security policies.

3.9.3.9 Further information on IT security

Further information about IT security can be found through the following channels:

- KUKA Xpert
- KUKA Customer Support
- https://www.kuka.com/cybersecurity

4 General operation

4.1 Overview of the user interface

The basic elements of the user interface are described here. The following elements are always present:

- Status bar (upper edge of screen)
- Control bar for jogging (right-hand edge of screen)
- Program control bar (left-hand edge of screen)
- Main view in the center

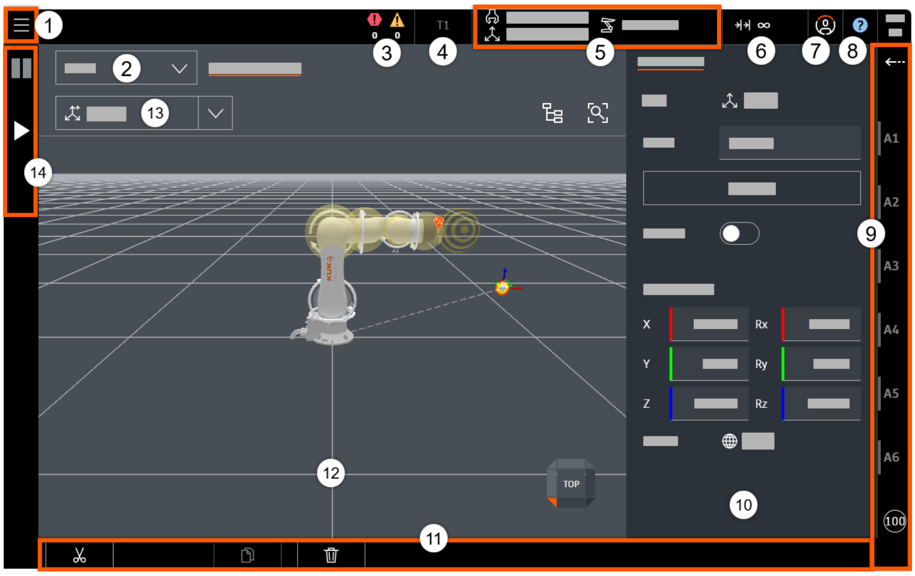


Fig. 4-1: Overview of the user interface

Item	Description
1	Main menu The main menu can be used, for example, to execute system functions, configure network settings or display system information and help.
2	Feature menu The Feature menu offers all the functions required for start-up, configuration and programming of the robot.
3	Alert display Further information about the alert display can be found in the help function under “Diagnosis”.
4	Display/selection of the operating mode It is possible to change the operating mode via the display. (>>> *4.4 "Changing the operating mode" Page 52*)

Item	Description
5	Display of the tool and display/setting of the motion frame and the reference system for jogging • A different motion frame can be set via the display. Besides the robot flange, all TCPs created for the tool are available for selection. Additionally, the configured workpieces can be selected. Further information about the configuration of tools and workpieces can be found in the help function under “Payload configuration” and under “3D scene”. • A different reference system for jogging can be set via the display. (>>> *4.12 "Moving the robot manually" Page 62*)
6	Display/setting of continuous/incremental jogging The display can be used to activate or deactivate incremental jogging as well as to set the increments for incremental jogging. (>>> *4.12.3 "Incremental jogging" Page 66*)
7	User button Using this button, the user can switch to another user role or log out. (>>> *4.5 "Changing the user role" Page 53*)
8	Help button Activates or deactivates the context help. If the context help is activated, the button is highlighted in orange. (>>> *4.7 "Help" Page 54*)
9	Control bar for jogging
10	Parameter view/detail view Displays the parameters and properties or the details of an element selected in the main view.
11	Toolbar of the current view Different tools are available (or no tools) depending on the view.
12	Main view Shows the main view of the function selected in the Feature menu.
13	Menu of the current view

Item	Description
14	Program control bar Displays by means of icons the current function that can be executed using smartPAD keys. The icon is highlighted in white if the function is available. • Pause key The Pause key can be used to pause a running program or to reset a paused program. • Start key The Start key can be used to start a program or to resume a paused program. The Start key can also be used to manually address frames or to move the robot back onto the programmed path. • Start backwards key (without function) (>>> *4.14 "Program execution" Page 73*)

4.2 Changing the user interface language

The language of the user interface can be changed. To do so, select **Language** in the main menu.

The following languages are available:

Chinese (simplified)	Dutch
Danish	Polish
German	Portuguese
English	Romanian
Finnish	Swedish
French	Slovak
Italian	Spanish
Japanese	Czech
Korean	Turkish
	Hungarian

- The layout of the on-screen keyboard is automatically linked to the selected language if the check mark at **Synchronize with language** is set.
- The layout of the on-screen keyboard can be set independently of the selected language by removing the check mark at **Synchronize with language**.
- If no keyboard layout is available for the selected language, the English key assignment is used.

4.3 Shutting down or restarting the robot controller

Description

The robot controller can be shut down or restarted via the main menu.

Precondition

- Operating mode T1

Procedure

- In the main menu, select the desired entry:
  - **Shut down**
    The robot controller shuts down.
  - **Restart**
    The robot controller shuts down and restarts with a cold start.

4.4 Changing the operating mode

The operating mode can be changed by displaying the mode in the status bar of the user interface.

> Do not change the operating mode while a program is running. If the operating mode is changed, the industrial robot stops with a safety stop 1 (path-maintaining).

Operating mode	Use	Velocities
T1	Programming, teaching and testing of programs	• Program verification: Reduced programmed velocity, maximum 250 mm/s • Jog mode: Jog velocity, maximum 250 mm/s • Manual guidance: No limitation of the velocity, but safety-oriented velocity monitoring in accordance with the safety configuration
AUT	Automatic execution of programs For industrial robots with and without higher-level controllers	• Program mode: Programmed velocity • Jog mode: Not possible • Manual guidance: Safety-oriented velocity monitoring in accordance with the safety configuration

Operating mode	Use	Velocities
CRR	CRR is an operating mode which can be selected when the industrial robot is stopped by the safety controller for one of the following reasons: • Industrial robot violates an axis-specific or Cartesian monitoring space. • The tool orientation is outside the permitted range. • Industrial robot violates collision detection or the maximum TCP force monitoring function. • One or more axes are unmastered. • Mastering of one or more axis positions is not confirmed. • Calibration of one or more joint torque sensors is not confirmed. • Maximum Cartesian velocity has been exceeded. • Maximum torque of an axis has been exceeded, e.g. due to a crushing situation. After changing to CRR mode, the industrial robot may once again be moved. If the cause of the stop is no longer present and no further stop is requested for 4 seconds by one of the specified causes, the operating mode switches automatically to T1.	• Program verification: Reduced programmed velocity, maximum 250 mm/s • Jog mode: Jog velocity, maximum 250 mm/s • Manual guidance: No limitation of the velocity, but safety-oriented velocity monitoring in accordance with the safety configuration

4.5 Changing the user role

The user role can be changed by means of the user button in the status bar of the user interface. Each user role is protected by means of a password.

- **Change Role**

  The current user remains logged on until another user has logged on with entry of the password. The role change can be canceled (close the dialog via the X).
- **Logout**

  The current user is logged out. To close the dialog, the user must log on again with entry of the password.

- If no actions are carried out on the user interface for a specified time, the current user is automatically logged out. Different times apply depending on the user role:
  - User: After 30 min. of inactivity
  - Administrator: After 10 min. of inactivity
  - Safety Commissioning Engineer: After 5 min. of inactivity

- If no user is logged on, the following operator actions are still possible:
  - Stopping or pausing a program using the buttons on the smartPAD.

4.6 Displaying system information

Description

The following system information is available:

Tab	Description
Info	• Version of the KUKA Linux kernel system • Version of the iiQKA.OS system software • Robot type • Name of the robot controller
Toolboxes	Name and version of the installed toolboxes including basic toolboxes (machine data of the robot; translation files for the system software)
smartPAD	• Firmware version of the connected smartPAD • Serial number of the connected smartPAD
Eula	KUKA license conditions

Procedure

- In the main menu, select **System Information**.

4.7 Help

Description

The following help functions are available:

- Help center

  All available instructions and support materials can be found in the help center.
- Context help

  The context help makes it possible to display help for selected features directly in the interface context.

Procedure

Call the help center:

- In the main menu, select **Help**.

Activate and display the context help:

1. Activate context help by pressing the help button in the status bar. If the context help is activated, the button is highlighted in orange.

Button	Description
	Context help is deactivated (dark display mode).
	Context help is activated.

2. On the user interface, select the feature for which the context aid is to be displayed.
3. If no context help is available for the selected feature, this is indicated in a pop-up message: The help center can be called using the **Open Help** button.

4.8 Backup & Restore

Description

The **Backup & Restore** dialog makes it possible to back up and restore user-specific data. These data are:

- System settings
- I/O configuration
- Safety configuration
- Scene
- All programs

A USB stick is required as the storage medium. The USB stick must meet the following requirements:

- Formatted as FAT32 or exFAT
- Sufficient free space

NOTICE

Data loss due to defective USB stick

A defect on the USB stick can cause a faulty backup to be created. In this case, the backup cannot be restored. Restoration can also fail if a correct backup has been created and a defect subsequently occurs on the USB stick.

- Before every backup process, check the functionality of the USB stick.
- Beyond this, save each backup at a second external storage location.

Overview

The following functions are available in the **Backup & Restore** dialog window:

- Create a new backup
- Restoring a backup
- Deleting a backup

Once a change to the software installed on the robot controller is made, all backups created up to that point are invalid:

- Update/upgrade of the system software
- Update/upgrade of a toolbox
- Reinstallation of a toolbox

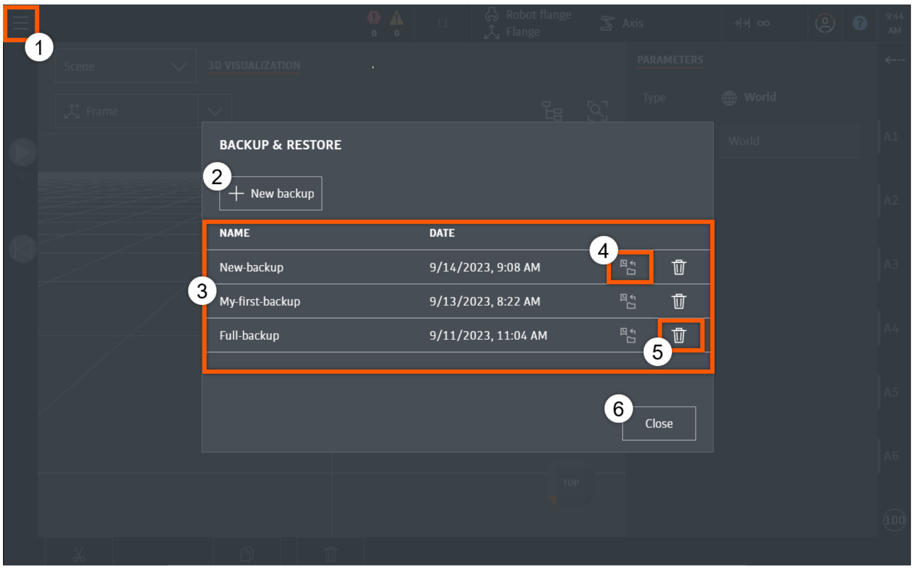


Fig. 4-2: Backup & Restore

1	Main menu
2	**New backup** button
3	List of available backups
4	Restore button
5	Delete button (recycle bin)
6	Close button

Precondition

- Restoring a backup: “Safety maintenance” user role
- Operating mode T1 or CRR
- USB stick is connected to the robot controller.
- No program is running.

Procedure

Creating a backup:

1. Open the **Backup & Restore** dialog window via the main menu and select the **New backup** button.
2. Enter a name for the backup and start the creation process using the **Create backup** button.

   The progress of the process is displayed. Once the process is complete, the robot controller is automatically restarted.

NOTICE

Data loss due to premature removal of the USB stick
If the USB stick is removed while data are still being written, data may be lost.

- Do not remove the USB stick until the robot controller has rebooted.

Restoring a backup:

1. Open the **Backup & Restore** dialog window via the main menu and begin restoring the desired backup using the corresponding Restore button.

The progress of the process is displayed. Once the process is complete, the robot controller is automatically restarted.

2. If the restored safety configuration differs from the previous one, it must be re-approved.

Deleting a backup:

- Open the **Backup & Restore** dialog window via the main menu and delete the desired backup using the corresponding Delete button (recycle bin).

4.9 Software

Description

The **Software** dialog window allows you to search for updates and upgrades for the packages installed on the robot controller as well as to execute updates and upgrades. It is also possible to search for compatible toolboxes and to install and uninstall the toolboxes.

Procedure

- Select **Software** in the main menu to open the dialog window.

Overview

The following tabs are available in the dialog window:

- **Operating System**
  Display of the installed operating system with the version number and description
- **Installed Toolboxes**
  Display of the installed toolboxes with the version number and description; uninstallation of the toolboxes
- **Updates**
  Display and search for available updates; performing the updates
- **Upgrades**
  Display and search for available upgrades; performing the upgrades
- **Available Toolboxes**
  Display and search for available toolboxes; installation of toolboxes
- **Settings**
  Configuration of software sources and activation/deactivation of developer mode

Software sources

Depending on the configuration, the following software sources are taken into consideration when searching for available updates, upgrades and toolboxes:

- Local source: USB stick on the robot controller
- Network source: my.kuka.com (update server)

4.9.1 Installed Toolboxes tab

Description

All installed toolboxes are displayed on the tab. Unnecessary toolboxes or toolboxes that are no longer used can be uninstalled.

Precondition

- “Administrator” user role
- Operating mode T1 or CRR
- No program is running.
- No motion is being executed.
- Developer mode is not active.

Procedure

1. Select the desired toolboxes for uninstallation (activate the check box).
2. Select the **Continue to uninstall** button. A list of the toolboxes selected for uninstallation is displayed.
   - The delete button (recycle bin) can be used to remove a toolbox from the list.
   - To make a new selection, select the **Go back** button or remove all toolboxes from the list.
3. Select the **Uninstall** button. A confirmation dialog window in which the uninstallation can be canceled or started is displayed for 60 seconds.
4. Once the 60 seconds have elapsed, uninstallation starts automatically. To start the uninstallation immediately, select the **Start** button.
   - The progress of the uninstallation process is displayed.
   - The uninstallation can be canceled at any time.
   - Once the uninstallation is complete, the user interface is refreshed.

4.9.2 Updates tab and Upgrades tab

Description

The tabs can be used to check whether software updates/upgrades are available for packages installed on the robot controller (e.g. system software, toolboxes) or firmware updates for devices (e.g. smartPAD pro). Available updates/upgrades are displayed on the corresponding tab and can be carried out.

- During an update/upgrade, all installed packages for which newer versions are available are updated.
- The procedure for updates and upgrades is the same.
  – In the case of upgrades, it must be noted that incompatible changes may be included.
  – For updates, on the other hand, compatibility is always guaranteed.

> Once a change to the software installed on the robot controller is made, all backups created up to that point are invalid:
> - Update/upgrade of the system software
> - Update/upgrade of a toolbox
> - Reinstallation of a toolbox

Precondition

Searching for updates/upgrades:

- The desired software sources are available.
  (>>> *4.9.4 "“Settings” tab" Page 60*)

Carrying out updates/upgrades:

- “Administrator” user role
- Operating mode T1 or CRR
- No program is running.
- No motion is being executed.

Procedure

1. Start the search for updates/upgrades under the corresponding tab using the **Check for updates**/**Check for upgrades** button.
   - All available software sources are included in the search.
   - If no software source is available, a corresponding error message is displayed. For example, in the following cases:
     – User not logged into my.KUKA and **USB** switch deactivated
     – **USB** switch activated and no USB stick connected to the robot controller
     – **USB** switch activated and no update/upgrade available on the USB stick
2. Select the **Update**/**Upgrade** button on the corresponding tab. A confirmation dialog window in which the update/upgrade can be canceled or started is displayed for 60 seconds.
3. Once the 60 seconds have elapsed, the update/upgrade is started automatically. To start immediately, select the **Start** button.
   - The progress of the update/upgrade is displayed.
   - The update/upgrade can be canceled at any time.
   - Once the update/upgrade is complete, depending on the software, the robot controller is restarted or the user interface is refreshed.

4.9.3 Available Toolboxes tab

Description

On the tab, it is possible to check whether installable toolboxes are available. Available toolboxes are displayed on the tab and can be installed.

Precondition

Search for toolboxes:

- The desired software sources are available.
  (>>> *4.9.4 "“Settings” tab" Page 60*)

Installation of toolboxes:

- “Administrator” user role
- Operating mode T1 or CRR
- No program is running.
- No motion is being executed.

Procedure

1. Start the search for toolboxes using the **Check for toolboxes** button.
   - All available software sources are included in the search.
   - If no source is available, a corresponding error message is displayed. For example, in the following cases:

  - User not logged into my.KUKA and **USB** switch deactivated
  - **USB** switch activated and no USB stick connected to the robot controller
  - **USB** switch activated and no installable toolbox available on USB stick
2. Select the desired toolboxes for installation (activate the check box).
3. Select the **Continue** button. A list of the toolboxes selected for installation is displayed.
   - The delete button (recycle bin) can be used to remove a toolbox from the list.
   - To make a new selection, select the **Go back** button or remove all toolboxes from the list.
4. Select the **Install** button. A confirmation dialog window in which the installation can be canceled or started is displayed for 60 seconds.
5. Once the 60 seconds have elapsed, installation starts automatically. To start the installation immediately, select the **Start** button.
   - The progress of the installation process is displayed.
   - The installation can be canceled at any time.
   - Once installation is complete, the user interface is refreshed.

4.9.4 “Settings” tab

Description

The software sources can be configured and Developer mode activated/deactivated on the tab. In Developer mode, toolboxes created with the SDK can be installed and tested on the system.

Software sources

- **USB**

  This switch can be used to enable and disable a USB stick connected to the robot controller as a source of software (precondition: “Administrator” user role).
- **my.KUKA - Authentication**

  Displays the current authentication status for my.KUKA.

  In order to be able to check whether new software or updates/upgrades are available online, it is necessary to log into my.KUKA. To be able to access my.KUKA, the robot controller must be connected to the Internet.
- **Authenticate**

  A user who is not logged in can use this button to start the authentication. The user is automatically redirected to the my.KUKA login page and can log in there with the credentials of his or her my.KUKA profile.
  - If no profile has been created yet, register with my.KUKA first (not possible using the smartPAD).
  - After successfully logging in, the user is returned to the scene view and must reopen the **Software** dialog window.
- **Logout from my.KUKA**

  A logged-in user can use this button to sign out of my.KUKA again.

Developer mode

- **Activate/Deactivate**
  This button can be used to activate/deactivate Developer mode (precondition: “Administrator” user role).
  - The progress of the activation/deactivation process is displayed.
  - Once activation/deactivation is complete, the robot controller is automatically restarted.
  - A reboot is also carried out if activation/deactivation fails or is aborted.

4.10 Firmware updates/upgrades

Description

Firmware updates/upgrades for the following devices, as is the case with all available updates/upgrades, are displayed in the **Software** dialog window and can be carried out there.

- smartPAD pro
- KSP
- TPC

Procedure

1. In the main menu, select **Software**. The dialog opens.
2. Search for an update/upgrade on the **Updates** or **Upgrades** tab and carry it out.
   (>>> *4.9.2 "Updates tab and Upgrades tab" Page 58*)

4.11 Coordinate systems

Coordinate systems or frames determine the position and orientation of an object in space.

The following coordinate systems are relevant for the robot controller:

- WORLD
- BASE
- FLANGE
- TOOL

WORLD

The WORLD coordinate system is a permanently defined Cartesian coordinate system. It is the root coordinate system for all other coordinate systems.

By default, the WORLD coordinate system is located at the robot base.

BASE

In order to define motions in Cartesian space, a reference coordinate system (base) must be specified.

By default, the WORLD coordinate system is used as the BASE coordinate system for a motion. In the 3D scene, further BASE coordinate systems can be defined relative to the WORLD coordinate system.

FLANGE

The FLANGE coordinate system describes the current position and orientation of the robot flange center point. It does not have a fixed location and is moved with the robot.

The FLANGE coordinate system is used as an origin for coordinate systems which describe tools mounted on the flange.

TOOL

The TOOL coordinate system is a Cartesian coordinate system which is located at the reference point of the currently selected load. This reference point can be the robot flange, the tool center point (TCP) of the tool mounted on the flange, or the motion frame of a gripped workpiece. Multiple TCPs can be created for a tool.

The origin of the TOOL coordinate system is generally identical to the FLANGE coordinate system. When a TCP is calibrated, the TOOL coordinate system is updated accordingly.

Position and orientation

In order to determine the position and orientation of an object, the coordinates for translation and rotation relative to a reference coordinate system (usually the parent object) are specified.

Coordinates for translation

Coordinate	Description
X	Translation along the X axis of the reference coordinate system
Y	Translation along the Y axis of the reference coordinate system
Z	Translation along the Z axis of the reference coordinate system

Coordinates for rotation

Coordinate	Description
Rx	Rotation about the X axis of the reference coordinate system
Ry	Rotation about the Y axis of the reference coordinate system
Rz	Rotation about the Z axis of the reference coordinate system

4.12 Moving the robot manually

The robot can be moved manually in the following ways:

- Axis-specific jogging

  Each axis can be moved individually in the positive or negative direction using the jog keys on the smartPAD. Incremental jogging can also be activated.

  Precondition: Operating mode T1 or CRR
- Cartesian jogging

  The set TCP or motion frame can be moved in the positive or negative direction along the axes of a coordinate system or rotated about these axes using the jog keys on the smartPAD. Incremental jogging can also be activated.

Precondition: Operating mode T1 or CRR

- Manual guidance

  The robot can be moved in all directions using a hand guiding device.

The payload data are taken into consideration both in axis-specific and Cartesian jogging and in manual guidance. It is possible to switch between different payloads, e.g. to move the robot manually with an empty gripper or with a gripped workpiece.

4.12.1 Axis-specific jogging

Description

In axis-specific jogging, each robot axis is moved individually. This makes all robot motions easy to predict.

- To do so, open the jogging options via the display in the status bar and select the option **Axis**.

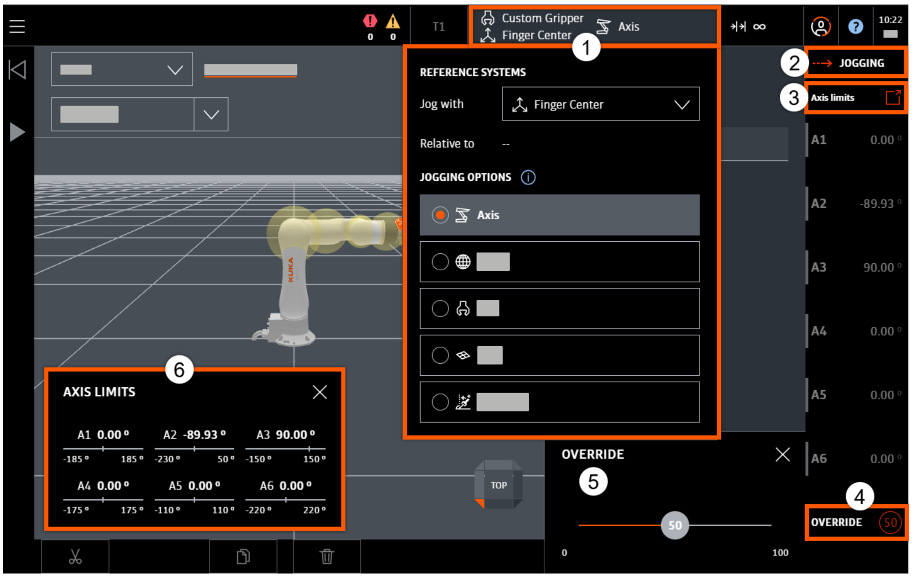


Fig. 4-3: Axis-specific jogging

1	Display/selection of jogging options
2	Show/hide control bar
3	Show/hide **Axis limits** window
4	Override button
5	Override window
6	**Axis limits** window (current axis positions)

Override

To move the robot more quickly or slowly, an override (in percent from 0 to 100%) can be set.

- The override refers to the maximum permissible velocity during jogging (250 mm/s).
- The override button opens/closes the override window and displays the current override setting.

- The override can be set either by means of the corresponding plus/minus key on the smartPAD or via the slider in the override window.
  - Plus/minus key: The override can be set in steps to the following values: 100%, 75%, 50%, 30%, 10%, 5%, 3%, 1%, 0%
  - Slider: The override can be adjusted in 1% steps.

Motion enable

In order to receive the motion enable signal, an enabling switch on the smartPAD must be pressed and held down.

- When motion is enabled, the axis designations are highlighted in white on the control bar. The axes can be moved individually in the positive or negative direction using the plus/minus jog keys on the smartPAD.
- The positive and negative direction of rotation of the axes is indicated on the robot in the 3D scene.

Axis limits

The **Axis limits** window can be opened in order to move to a specific position in a more precise manner as well as to visualize the motion range.

- In the window, the current position of each axis relative to the software limit switches is depicted graphically and in text form.
- The window can be freely moved on the user interface, so that it does not conceal any currently required contents.

4.12.2 Cartesian jogging

Description

In Cartesian jogging, the robot is moved relative to a coordinate system.

- The robot flange, a tool TCP or a workpiece can be set as a motion frame.
- The following coordinate systems can be selected in the jogging options:
  - **World**
  - **Tool/Workpiece**

    The robot is moved in the coordinate system of the selected TCP or in the motion frame of a gripped workpiece.
  - **Base**

    The robot is moved in the coordinate system of the selected base.

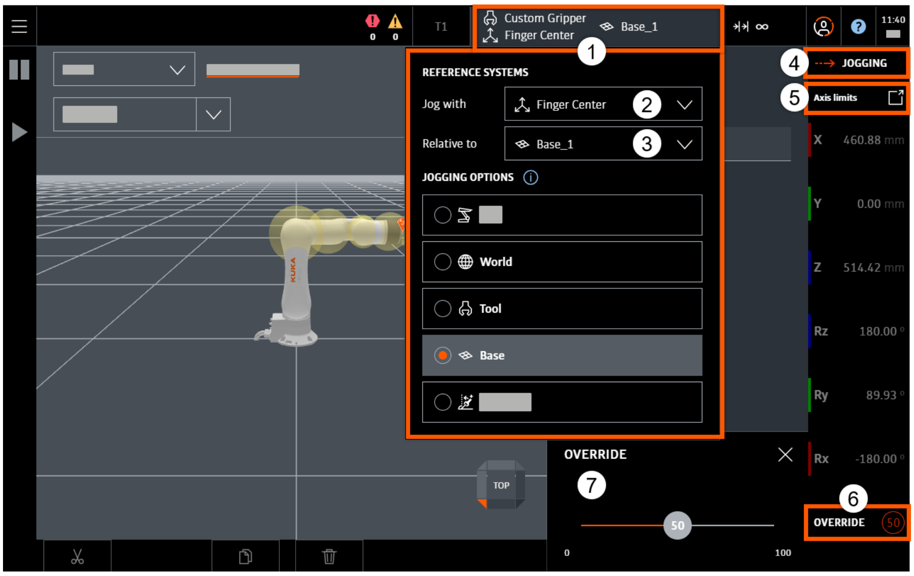


Fig. 4-4: Cartesian jogging

1 Display/selection of jogging options
2 Selection of TCP/motion frame
3 Selection of base (only with jogging option **Base**)
4 Show/hide control bar
5 Show/hide **Axis limits** window
6 Override button
7 Override window

Override

To move the robot more quickly or slowly, an override (in percent from 0 to 100%) can be set.

- The override refers to the maximum permissible velocity during jogging (250 mm/s).
- The override button opens/closes the override window and displays the current override setting.
- The override can be set either by means of the corresponding plus/minus key on the smartPAD or via the slider in the override window.
  - Plus/minus key: The override can be set in steps to the following values: 100%, 75%, 50%, 30%, 10%, 5%, 3%, 1%, 0%
  - Slider: The override can be adjusted in 1% steps.

Motion enable

In order to receive the motion enable signal, an enabling switch on the smartPAD must be pressed and held down.

- When motion is enabled, the direction designations (X, Y, Z, Rz, Ry, Rx) are highlighted in white on the control bar. The robot can be moved in the positive or negative direction using the plus/minus jog keys on the smartPAD.
- The jog keys for X, Y and Z move the set TCP or motion frame along the X, Y or Z axis of the set coordinate system.
- The jog keys for Rz, Ry and Rx rotate the set TCP or motion frame about the Z, Y or X axis of the set coordinate system.

- The coordinate system, the TCP or motion frame and the directions of motion are displayed in the 3D scene. The directions of motion are indicated in color in the 3D scene and the control bar and assigned to the jog keys.

Axis limits

The **Axis limits** window can be opened in order to move to a specific position in a more precise manner as well as to visualize the motion range.

- In the window, the current position of each axis relative to the software limit switches is depicted graphically and in text form.
- The window can be freely moved on the user interface, so that it does not conceal any currently required contents.

4.12.3 Incremental jogging

Description

Incremental jogging makes it possible to move the robot a defined distance, e.g. 10 mm or 3°.

- Incremental jogging can be activated for axis-specific and Cartesian jogging.
- An enabling switch and the respective jog key must be kept pressed until the set distance has been reached. The robot stops automatically after reaching the set distance.
- If the robot motion is interrupted, e.g. by releasing the enabling switch, the interrupted increment is not resumed with the next motion; a new increment is started instead.

Areas of application:

- Positioning of equidistant points
- Moving a defined distance away from a position, e.g. in the event of a fault

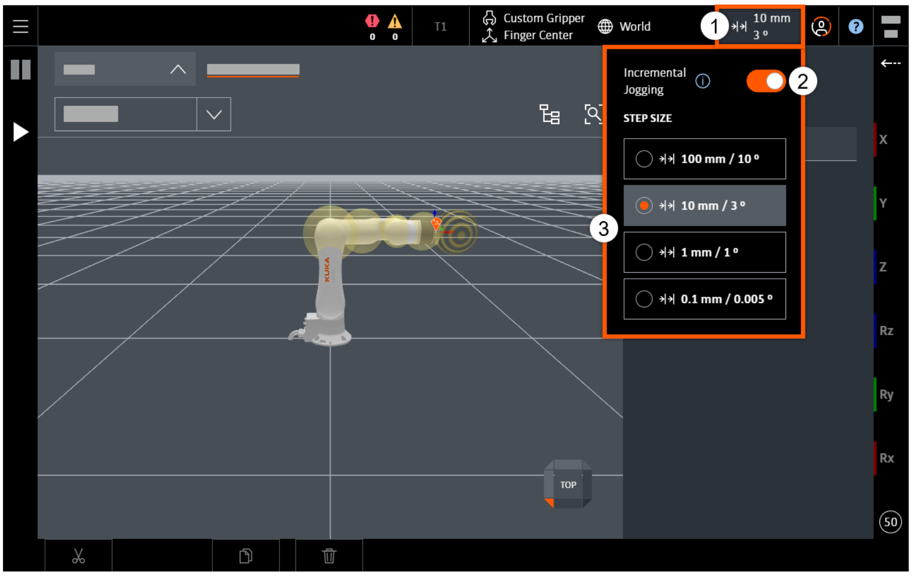


Fig. 4-5: Incremental jogging

1 Open the settings

2 Activate/deactivate incremental jogging

3 Select increment

Increments

Increment	Description
100 mm / 10°	1 increment = 100 mm or 10°
10 mm / 3°	1 increment = 10 mm or 3°
1 mm / 1°	1 increment = 1 mm or 1°
0.1 mm / 0,005°	1 increment = 0.1 mm or 0.005°

Increments in mm:

- Valid for Cartesian jogging in the X, Y or Z direction

Increments in degrees:

- Valid for Cartesian jogging in the Rz, Ry or Rx direction
- Valid for axis-specific jogging

Precondition

- Operating mode T1 or CRR

Procedure

1. Open settings via the display in the status bar.
2. Activate incremental jogging.
3. Select the desired increment. Displayed in the status bar.
4. Press and hold down an enabling switch on the smartPAD.
5. Cartesian or axis-specific jogging of the robot over the set increment can now be carried out using the jog keys.
6. If continuous jogging is to be resumed, open the settings again and deactivate incremental jogging.

4.12.4 Aligning the tool with a base

Description

The **Align Tool** jogging option makes it possible to align the tool to a base. The WORLD coordinate system can also be selected as the base.

- The tool can be aligned perpendicular to a plane of the selected base. The plane can be selected:
  - **XY-Plane**: Alignment to Z axis of the base
  - **XZ-Plane**: Alignment to Y axis of the base
  - **YZ-Plane**: Alignment to X axis of the base
- The tool can be aligned parallel to the selected plane.
- The motion between “perpendicular” and “parallel” can be continuous or incremental.

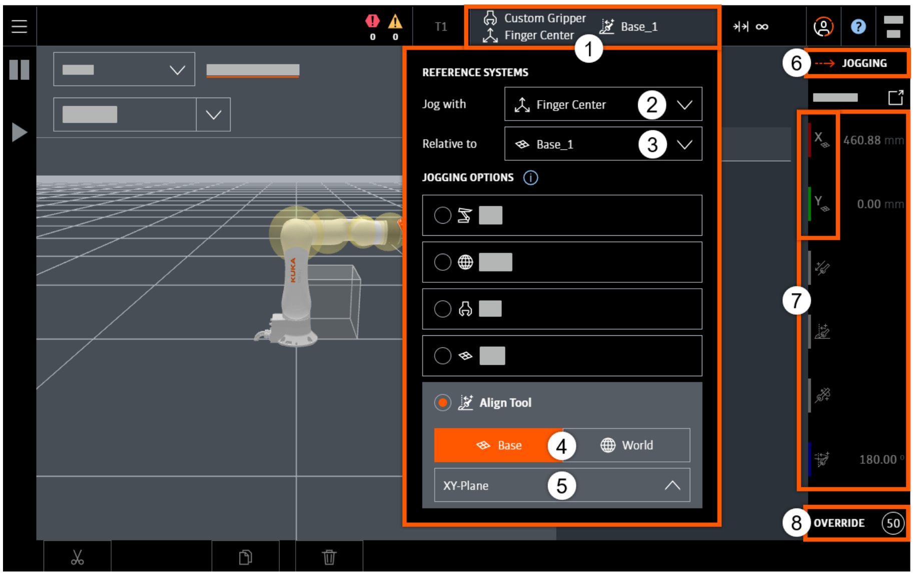


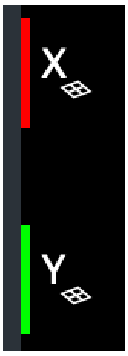
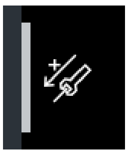
Fig. 4-6: Align Tool jogging option

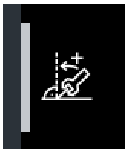
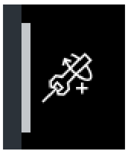
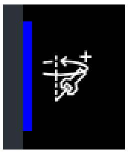
1	Display/selection of jogging options
2	Selection of TCP/motion frame
3	Selection of base
4	Alignment to a base or to the world (switch)
5	Selection of the plane
6	Show/hide control bar
7	Jog keys display
8	Override display/setting

Jog keys

Special jog keys are available for the **Align Tool** jogging option.

The tool is aligned with the base using key **4**. The other keys are assigned other jog options.

Key	Icon	Description
1+2	Example: 	**Moving the tool along the base** When the jog keys are pressed, the TCP moves along the selected plane of the base (in the example: XY plane). **Note:** The axis of the base on which the tool is aligned is always the axis perpendicular to the plane. This means the axis that is not (!) indicated by an icon (in the example: Z axis).
3		**Moving the tool in the Z direction** The tool moves in the positive or negative Z direction in the TCP coordinate system. • **Plus**: In the positive direction (+Z) • **Minus**: In negative direction (-Z)

Key	Icon	Description
4		**Aligning the tool with a base** The decisive factor is the axis that is perpendicular to the selected plane. In the example above for keys **1+2**: the Z axis in the XY plane). • **Plus**: The Z axis of the TCP moves in the direction of the perpendicular of the selected plane • **Minus**: The Z axis of the TCP moves in the direction of the counter-perpendicular of the selected plane The motion extends over a maximum of 180°. If, during the motion, the Z axis of the TCP reaches the position in which it is aligned parallel to the selected plane (i.e. 90° to the perpendicular of the plane), the robot stops there automatically. The motion can be resumed by pressing the jog key again.
5		**Rotate tool** The tool rotates about the Z axis of the TCP. • **Plus**: Clockwise • **Minus**: Counterclockwise
6		**Swivel tool** The tool pivots about the axis perpendicular to the selected plane. The angle relative to the base is not changed. • **Plus**: Clockwise • **Minus**: Counterclockwise

Precondition

- The desired override is set.
- The TCP and base for jogging have been selected.
- Operating mode T1 or CRR

Procedure

1. Move the TCP to the position from which the tool is to be aligned.
2. Align the tool to the desired base using key **4**.
   The orientation of the tool is visualized in the scene view.

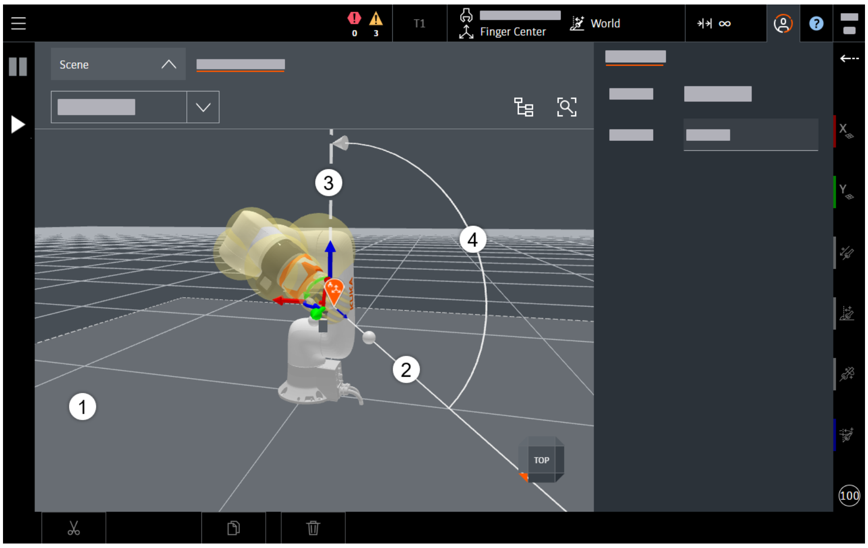


Fig. 4-7: Scene view when aligning the tool

1	Selected plane
2	Current tool orientation (Z axis of the selected TCP)
3	Perpendicular to the selected plane
4	Current direction of motion (here: plus direction / direction of the perpendicular)

3. If the tool does not start to align, it may not be possible to address the end point from the current position.

   In this case, it is advisable to move incrementally and gradually approach the end point.

   (>>> *4.12.3 "Incremental jogging" Page 66*)
4. The motion extends over a maximum of 180°. If, during the motion, the tool reaches the position in which it is aligned parallel to the selected plane, the robot stops there automatically.
5. The motion can be resumed by pressing the jog key again. As soon as the tool is aligned perpendicular to the selected plane, the robot also stops there automatically.

4.12.5 Manual guidance

Description

The robot can be guided manually with the LBR iisy Commander in all operating modes.

Procedure

1. For manual guidance, grip the Commander on the robot with both hands.
2. Press and hold down one of the enabling switches until the brakes release.

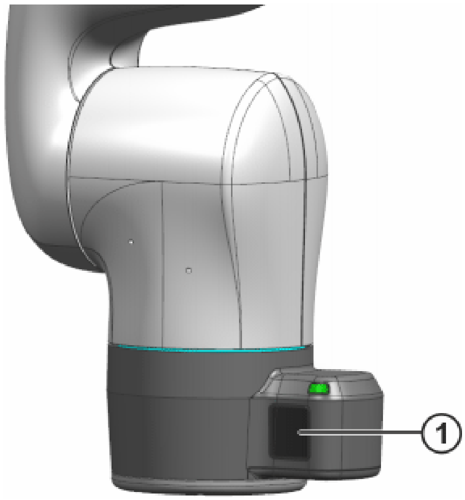


Fig. 4-8: Enabling switches on the Commander

- In manual guidance, the color of the LED ring on the Commander changes to blue.
- In addition, the user interface on the smartPAD is bordered in blue and a pop-up message indicates that manual guidance is in progress.

3. Guide the robot to the desired position.
4. Once the position has been reached, release the enabling switch. The brakes are applied again.

4.13 Operating the user interface with the Commander

Description

The Commander enables operation of the robot in certain areas without the need to use the smartPAD. The Commander has a rotary wheel and a back key for this purpose. A dashed focus frame on the user interface indicates which element is currently in focus. This focus frame can be shifted using the rotary wheel. The rotary wheel can also be pressed and thus functions as the OK key.

> Operator control of the user interface with the Commander is currently only possible in the object tree in the Feature menu **Scene**.

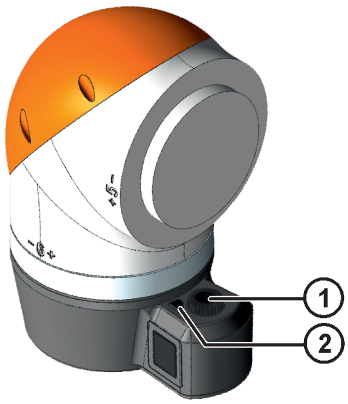


Fig. 4-9: Rotary wheel and back key on the Commander

1 Rotary wheel with OK key
2 Back key

Functions of the rotary wheel

- Turn clockwise:
  Switches to the next element down or to the right that can be focused on.
- Turn counterclockwise:
  Switches to the next element up or to the left that can be focused on.
- Short press:
  Selects the currently focused element or triggers an action.
- Long press:
  Opens a context menu if available in the focused element.
- Double press:
  Opens or hides the focused element if it contains child elements.

Functions of the back key

- Short press:
  Closes the context menu or dialog window and returns to the last focused element.
- Long press:
  No function
- Double press:
  No function

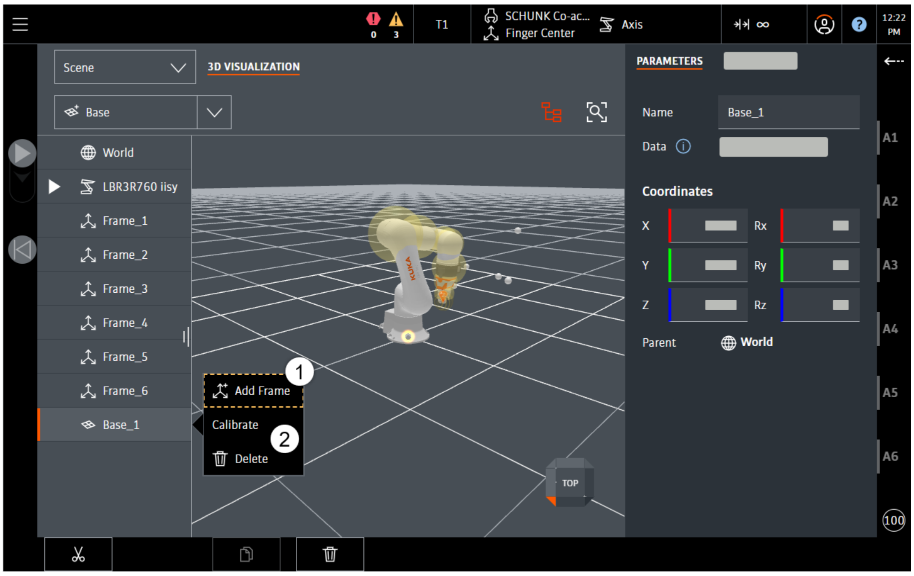


Fig. 4-10: Operating the user interface with the Commander

1 Focus frame (broken line)

2 Context menu

4.14 Program execution

A program opened in the program editor can be executed manually in T1 mode or automatically in AUT mode. The program displayed in the editor is always started, unless another program is active in the background. The current program is also displayed in the status bar.

During program execution, the LED ring on the LBR iisy Commander lights up continuously green; in the case of a paused program, it flashes green.

A program can be executed in any view. In the 3D scene, the robot will move just like the robot in the real world.

4.14.1 Executing a program manually

1. Set operating mode T1.
2. Press and hold down the enabling switch on the smartPAD.
3. Press and hold down the Start key on the smartPAD.

   The program runs as long as the enabling switch and Start key remain pressed. Otherwise the program stops.

4.14.2 Executing a program automatically

1. Set the operating mode to AUT.
2. Press the Start key on the smartPAD. The program is executed automatically.

   To stop a program that has been started in Automatic mode, press the Pause key on the smartPAD.

4.14.3 Resetting a program

In order to start a paused program from the beginning, it must be reset.

- To reset the program, press the Pause key on the smartPAD.
- Alternatively, open the **RUN SETTINGS** window. There, press the **Reset Program** button.

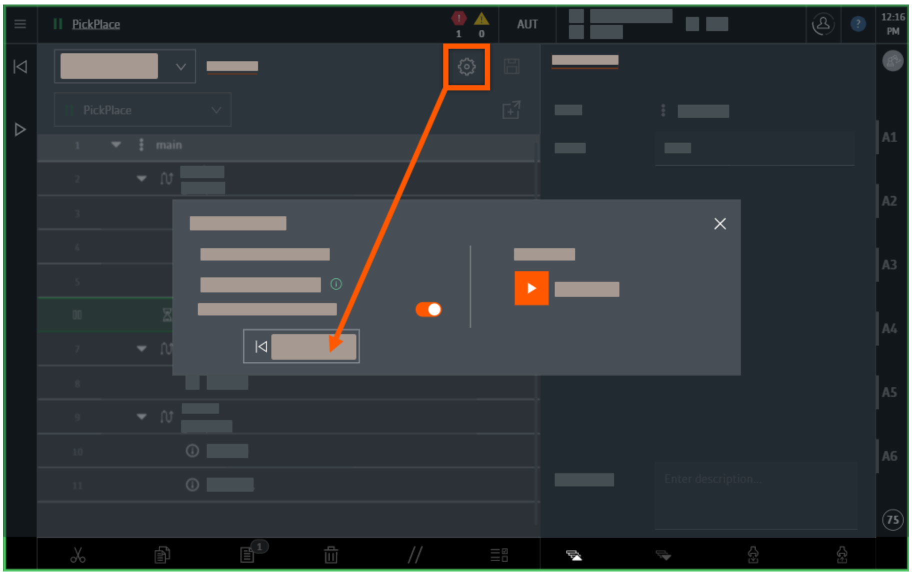


Fig. 4-11: Reset Program (RUN SETTINGS)

4.14.4 Resuming a program

A paused program can be resumed at any time from the position at which the program was interrupted. If the robot was moved manually during the pause, the robot must first be returned to this position.

- The motion back to the starting position can be started in T1 and AUT modes (using the Start key on the smartPAD).
- The enabling switch and Start key must be held down in T1 mode. Otherwise, the motion will be stopped.
- The motion is executed automatically in AUT mode after the Start key has been pressed. The motion can be stopped by pressing the Pause key.
- Once the position at which the program can be resumed has been reached, a confirmation dialog is displayed.
- The program is resumed by pressing the Start key on the smartPAD again.

4.15 Brake test

Each robot axis has at least one holding brake integrated into the motor. The brake test checks whether the braking torque is high enough. If the brake test for an axis fails, the brake is defective and must be replaced.

The brake test ensures that any impairment of the braking function is detected, e.g. due to wear, overheating, fouling or damage, thereby eliminating avoidable risks.

Unless otherwise determined by a risk assessment, the brake test must be performed regularly for all axes:

- Before start-up and recommissioning of the industrial robot

- Every 48 hours during operation

A risk assessment can be used to determine whether the brake test is required for the specific application and how often the brake test must be performed.

4.15.1 “Brake Test” view

Description

The view displays the brake test status of the individual robot axes.

Functions:

- Carrying out a brake test for all axes in one run
- Carrying out a brake test for an individual axis
- Settings for the cyclical brake test

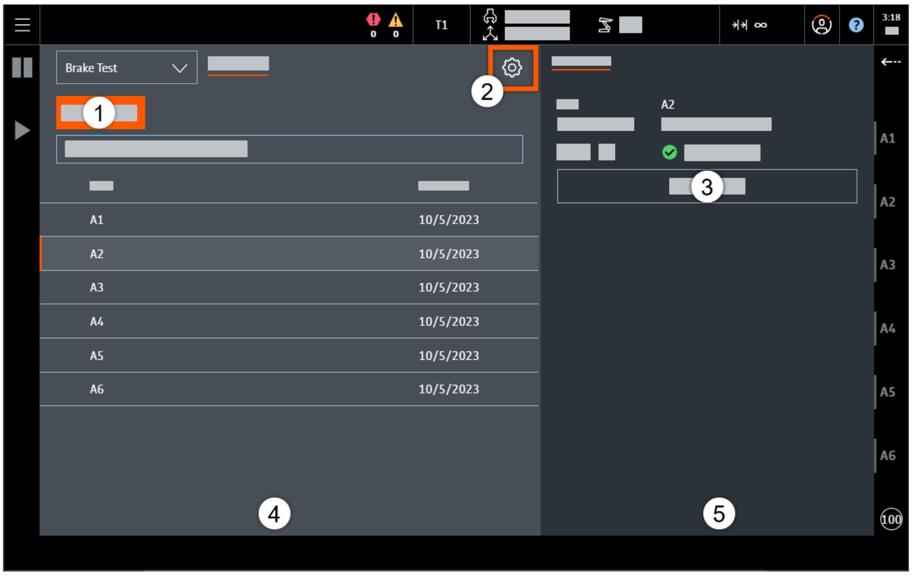


Fig. 4-12: “Brake Test” view

1 **Test all brakes**
2 Open settings for the brake test
3 **Test brake**
4 Main view
5 Detail view

Procedure

- To open the view, select **Setup** > **Brake Test** in the Feature menu.

4.15.2 Brake Test Settings

Description

In the settings, the cyclical brake test can be activated and the brake test cycle time can be set. The cycle time is composed of the following elements:

- **Test interval**
  Once this time has elapsed, the brake test is requested.

- **Grace period**
  Once the test interval has elapsed, the grace period within which the brake test has to be performed begins. When the grace period has elapsed, the robot stops.

⚠ **WARNING**

Danger to life and limb due to inadmissible program start
Program execution must not be resumed following a failed brake test or after the grace period has elapsed. Death, severe injuries or damage to property may otherwise result.
- Shut down the robot immediately after a failed brake test and replace the defective brake.
- Do not restart the program after the grace period has elapsed. Perform the brake test first.
- Only restart the program after a successful brake test.

Procedure

1. Open the settings for the brake test (cogwheel).
2. Make and accept the required settings.

4.15.3 Performing a brake test

Description

The brake test can be performed for all axes or for individual axes. A wizard guides you through the required steps.

Precondition

- Operating mode T1 or CRR
- No program is running.
- Manual guidance is not active.
- In order to open the wizard, a safety stop must additionally be active. Otherwise, the **Test all brakes** and **Test brake** buttons are deactivated.

Procedure

1. Start the brake test for all axes or an individual axis using the corresponding button. The wizard opens.
2. Follow the instructions in the wizard.
3. Once the brake test has been successfully performed, the wizard is automatically closed. The result of the brake test for each axis is displayed in the parameter view.

⚠ **WARNING**

Danger to life and limb due to inadmissible program start
Program execution must not be resumed following a failed brake test or after the grace period has elapsed. Death, severe injuries or damage to property may otherwise result.
- Shut down the robot immediately after a failed brake test and replace the defective brake.
- Do not restart the program after the grace period has elapsed. Perform the brake test first.
- Only restart the program after a successful brake test.

4.16 Mastering

Overview

Every robot must be mastered. Only with a mastered robot is it possible for taught positions to be addressed with high repeatability. An unmastered robot can only be moved manually (axis-specific jogging in T1 or CRR mode).

During mastering, the robot is moved to a defined mechanical position: the mastering position. Each robot axis is then assigned a motor angle in this position.

The standard mastering position is similar, but not identical, for all robots. The exact positions may even vary between individual robots of a single robot type.

MMD mastering

All robot axes equipped with a magnetic mastering sensor (MMD) can be mastered automatically. The mastering position of the axis (zero position) is located in the center of a defined series of magnets. It is automatically detected by the mastering sensor when it passes over the series of magnets during a rotation of the axis.

4.16.1 Mastering view

Overview

The mastering view shows the mastering status of the individual robot axes and enables the robot to be mastered. It is possible to master all axes together in a single run or individual axes.

To open the mastering view, select **Setup** > **Mastering** in the Feature menu.

- When the view is opened, the first unmastered axis is selected by default. Once all axes have been mastered, the first axis is selected.
- Mastering can be started using the following buttons:
  - **Master all axes** button in the main view
  - **Master axis** button in the detail view of a selected axis

  A wizard opens which guides the user through all the required mastering steps.

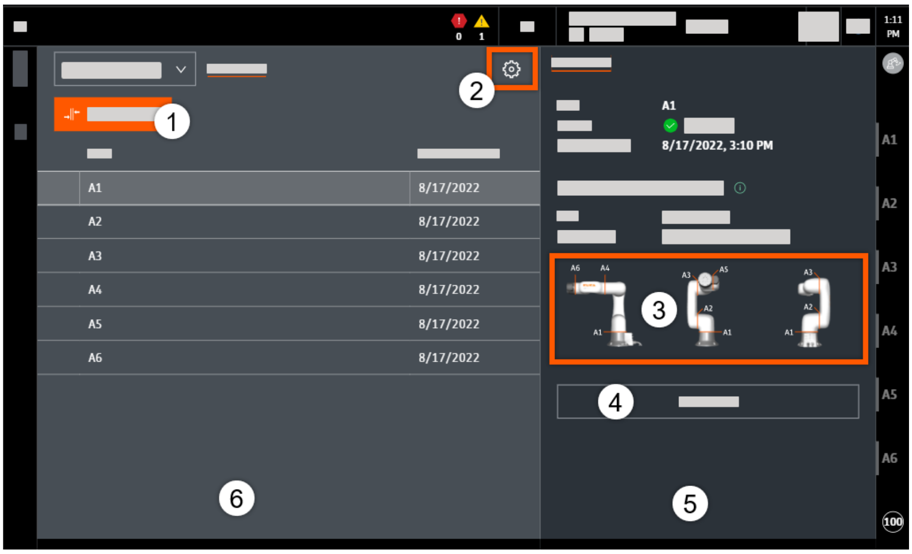


Fig. 4-13: Mastering

1	**Master all axes** button
2	Button for opening the mastering settings
3	Mastering position of the selected axis; graphical display or list of axis values after **Modify pose**
4	**Master axis** button
5	Detail view
6	Main view

4.16.2 Mastering settings

Description

The following functions can be activated in the settings:

- **Modify pose**
  - This setting allows the robot pose for mastering to be modified (**Move to pose for mastering** page in the mastering wizard).
  - It may be necessary to modify the pose if the recommended standard mastering position cannot be used, e.g. due to the conditions in the cell.
  - An individual pose can be defined for each axis.

    If at least one axis uses a user-defined pose for mastering, it is no longer possible for all axes to be mastered in a single run. The **Master all axes** button is grayed out.
  - On exiting the mastering view, the **Modify pose** function is disabled again (automatically).
  - If at least one axis is unmastered while **Modify pose** is enabled, **Modify pose** is also disabled again (automatically).
- **Ignore mastering pose**
  - This setting makes it possible to master individual axes without the robot standing in the currently configured pose for mastering.
  - Ignoring the pose may be necessary, for example, if at least one axis is unmastered and the robot cannot move to the pose due to the circumstances in the cell.

> As soon as all axes are mastered again, it is advisable to define a suitable robot pose for mastering and to modify the pose accordingly.

- If the **Ignore mastering pose** function is activated, it is no longer possible to master all axes in one run. The **Master all axes** button is grayed out.
- On exiting the mastering view, the **Ignore mastering pose** function is disabled again (automatically).

Precondition

- Change pose: All axes are mastered

4.16.3 Mastering the robot

Description

The **Master all axes** and **Master axis** buttons in the mastering view open a wizard that guides the user through the required mastering steps. These steps are essentially independent of whether all axes are mastered in a single run or a single axis is mastered.

Mastering rules

The repeatability and reproducibility of mastering are only guaranteed if the procedure is always identical. The following rules must be observed:

- Always mount the same tool on the robot for mastering.
- Always use the same robot pose for mastering.

If a different tool or a different robot pose is used for mastering than with the previous mastering, the mastering data will change.

NOTICE
Damage to property due to modified mastering data Following a change to the mastering data, frames that have already been taught may no longer be addressed correctly. Damage to property may result. • Reteach frames that have already been taught.

Precondition

- Operating mode T1 or CRR
- No program is being executed.
- Manual guidance is not active.
- In order to open the wizard, a safety stop must additionally be active. Otherwise, the **Master all axes** and **Master axis** buttons are deactivated.

Procedure

The following pages in the wizard must be executed one after the other in order to master the robot. Once a step has been successfully completed, it is possible to switch to the next page with the **Next** button.

1. **Set preconditions**
   - **Set mastering tool**

The currently active tool mounted on the robot must be selected for mastering. If the active tool differs from the tool used for the previous mastering, the user has the following options:

– Use the load data of the tool from the previous mastering again.
– Use the load data of the currently active tool.

NOTICE
Damage to property due to use of incorrect load data The load data of the tool selected in the wizard are used for the mastering motion. If a tool with different load data is mounted on the robot, this can result in unexpected robot motions and damage to property. – Make sure that the selected tool is actually mounted on the robot.

- **Move to pose for mastering**

  For mastering, the robot must be in a defined pose.

  The following functions are available:

  – Option **Move to pose**

    If the option is activated, the robot can automatically move to the defined pose when an enabling switch and the Start key on the smartPAD are pressed.

  – Alternatively, each axis can be moved to the defined pose individually using the jog keys on the smartPAD.

  – **Modify pose** button

    The button is only active if the **Modify pose** function is enabled in the mastering settings, all axes are mastered and an individual axis has been selected for mastering.

    (>>> *4.16.2 "Mastering settings" Page 78*)

    Opens a dialog for modifying the robot pose for mastering. The pose can be taught, its axis values entered manually or reset to the default settings.

> **i** If the currently defined pose cannot be addressed and cannot be changed due to at least one unmastered axis, the **Ignore mastering pose** function can be activated in the mastering settings. (>>> *4.16.2 "Mastering settings" Page 78*)
> If the setting is activated, it is possible to skip the page and switch directly to the next page.

- **Check position visually**

  The page is only displayed if the axis to be mastered has a user-defined pose for mastering and if at least one axis has been unmastered.

  In this case, it is not ensured that unmastered axes are actually in the correct mastering positions, even though this is displayed in the wizard. It must be checked visually on the robot that the real positions of the unmastered axes match the expected positions:

  – If the positions match, press the **Position visually checked** check box and then **Next**.
  – If the positions do not yet match, move the unmastered axes to the correct positions first.

2. **Execute mastering**

Press and hold down the enabling switch and Start key on the smartPAD as long as the mastering motion is in progress. Otherwise mastering will be aborted.

3. **Check result**

   The page is only displayed if all axes to be mastered had already been mastered before mastering is performed.

   (>>> *4.16.4 "Check result" Page 81*)

4. **Move to pose for mastering approval**

   In mastering confirmation, the correctness of the mastering is checked.

   - After mastering, the robot is generally already in the defined pose for mastering confirmation. The page is then skipped.
   - If the robot is not yet correctly positioned, the following options are available:
     - Option **Move to pose**

       If the option is activated, the robot can automatically move to the defined pose when an enabling switch and the Start key on the smartPAD are pressed.
     - Alternatively, each axis can be moved to the defined pose individually using the jog keys on the smartPAD.

5. **Execute mastering approval**

   Press and hold down the enabling switch and Start key on the smartPAD as long as mastering confirmation is in progress. Otherwise, mastering confirmation will be aborted.

4.16.4 Check result

Individual axes or all axes of a robot that has already been mastered can be remastered in order to check the mastering result.

Once mastering has been carried out, the difference from the last mastering procedure is displayed on the **Check result** page. It is possible to assess on the basis of the differences whether the previous mastering can be retained or the new mastering applied.

- **Discard** button

  Previous mastering is retained and wizard is closed.
- **Apply mastering**

  New mastering is applied and wizard switches to next page.

NOTICE
Damage to property due to modified mastering data Following a change to the mastering data, frames that have already been taught may no longer be addressed correctly. Damage to property may result. • Reteach frames that have already been taught.

4.17 Calibration of the joint torque sensors

Description

The robot is supplied with calibrated joint torque sensors and can generally be put into operation without recalibration. Calibration of the joint torque sensors is only necessary if the factory settings no longer match. This can be recognized as follows:

- Confirmation of the calibration of the joint torque sensors fails.

- The robot begins to drift during manual guidance. If the enabling signal for manual guidance has been issued, the robot does not remain stationary in its position. It drifts away, so slight counterpressure is needed to keep it in position.

> An inaccurate configuration of the load data or the installation direction of the robot can also lead to a failure of the joint torque sensor calibration confirmation or drifting during manual guidance. It is therefore advisable to check the correctness of these configuration data before recalibrating the joint torque sensors.

The following functions are available in the view for calibration of the joint torque sensors:

- **Adjust all sensors** button

  Opens a wizard for calibration of the joint torque sensors.
- **Factory reset** button

  Opens a dialog for resetting the joint torque sensors to the factory settings.

The view also shows the robot pose required for the calibration. Calibration is only available for floor-mounted robots.

Procedure

- To open the view, select **Setup** > **Service** > **Joint torque sensor** in the Feature menu.

4.17.1 Recalibrating all sensors

Description

The **Adjust all sensors** wizard guides the user through all the required steps.

Precondition

- Operating mode T1 or CRR
- No program is being executed.
- Manual guidance is not active.
- In order to open the wizard, a safety stop must additionally be active. Otherwise, the **Adjust all sensors** button is deactivated.

Procedure

1. Select the **Adjust all sensors** button. The wizard opens.
2. The following pages must be completed one after the other. Once a step has been successfully completed, it is possible to switch to the next page with **Next**.
   a. **Set preconditions**
      - **Visual inspections**

        In order to achieve the best possible result, the following requirements must be met:
        – The load mounted on the robot matches the configured load.
        – There are no supplementary loads, e.g. dress packages, mounted on the robot.

    - No external forces are applied to the robot during execution, e.g. by touching it.
  - **Move to pose for adjustment**

    The robot must be in a defined pose.

    - Option **Move to pose**
      If the option is activated, the robot can automatically move to the defined pose when an enabling switch and the Start key on the smartPAD are pressed.
    - Alternatively, each axis can be moved to the defined pose individually using the jog keys on the smartPAD.

b. **Execute adjustment**

   Press the enabling switch and Start key on the smartPAD and hold down until the process is completed.

   Once calibration has been carried out successfully, the system automatically switches to the next page.

c. **Move to pose for adjustment approval**

   - Option **Move to pose**

     If the option is activated, the robot can automatically move to the defined pose when an enabling switch and the Start key on the smartPAD are pressed.
   - Alternatively, each axis can be moved to the defined pose individually using the jog keys on the smartPAD.

d. **Execute adjustment approval**

   Press the enabling switch and Start key on the smartPAD and hold down until the process is completed.

   Once calibration has been successfully confirmed, the wizard is automatically closed.

4.17.2 Resetting the sensors to factory settings

Description

The **Factory reset** dialog makes it possible to reset the sensors to the factory settings.

Precondition

- Operating mode T1 or CRR
- No program is being executed.
- Manual guidance is not active.
- A safety stop is active.

Procedure

1. Select the **Factory reset** button. The dialog opens.
2. Select the **Reset** button. Once the sensors have been successfully reset, the dialog is automatically closed.

4.18 Confirmation of mastering and calibration of the joint torque sensors

Description

For start-up, it is necessary to check and confirm that the robot axes have been correctly mastered and that the joint torque sensors have been correctly calibrated:

- Confirmation of mastering

  The mastering of the axis position sensors of a kinematic system is checked. This means that a check is performed as to whether the actual mechanical axis position matches the measured axis position.
- Confirmation of calibration of the joint torque sensors

  The calibration of the joint torque sensors of a kinematic system is checked. For this purpose, checks are made at various measurement positions to determine whether the expected torques of the axes correspond to the actual axis torques. The expected axis torques are calculated on the basis of the robot model and the configured load data.

> Certain events result in a loss of confirmation, e.g. a reboot of the robot controller. The confirmation must then be performed again. Further information can be found in the help function under “Safety configuration”.

“Approval” view

The view shows the status of the mastering confirmation and the status of the calibration confirmation for each axis.

To open the view, select **Setup** > **Approval** in the Feature menu.

Approval settings

During execution of mastering confirmation, all axes are moved. Here it is possible to set whether all axes are to be moved simultaneously (default setting) or one after the other.

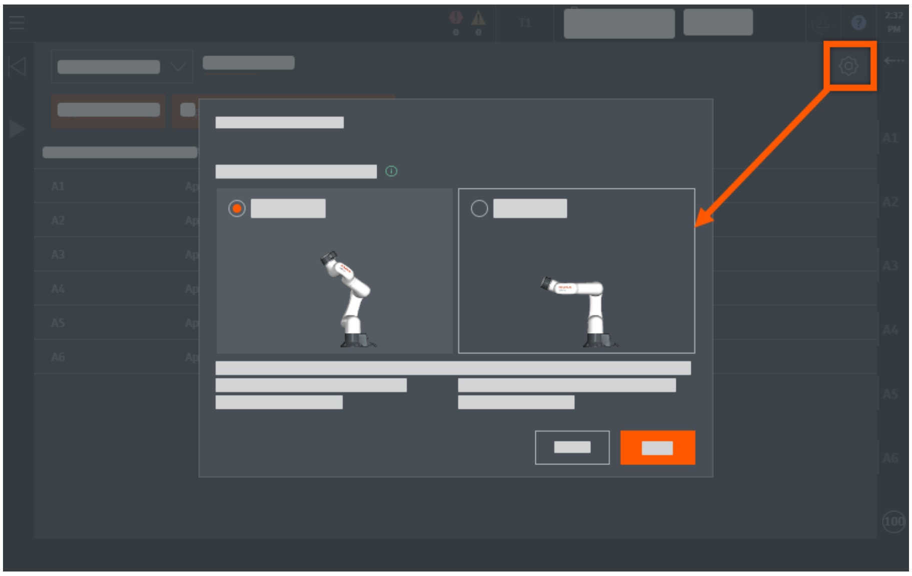


Fig. 4-14: Approval settings

Safety integrity of joint torque sensor calibration confirmation

The following points must be ensured before the confirmation is performed:

- The load data of the tool mounted on the robot flange match the load data with which the safety-oriented tool was configured.
- The tool has not picked up a workpiece.
- There are no supplementary loads, e.g. dress packages, mounted on the robot.

If any of these points are not met, the safety integrity of the confirmation is not given.

If the kinematic system to be checked is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), the following points must be ensured as well:

- The carrier kinematic system must not be moved while the confirmation is being performed.
- The mounting direction of the kinematic system to be checked may not differ from the configured mounting direction during confirmation (e.g. due to tilting of the mobile platform).

If any of these points are not met, the safety integrity of the confirmation is not given.

Procedure

1. In the Feature menu, select **Setup** > **Approval**.
2. Start the desired confirmation using the corresponding button:
   - **Approve mastering**
   - **Approve joint torque sensor adjustment**

   A wizard opens which guides the user through all the required steps.
3. Once mastering or calibration has been successfully confirmed, the wizard is automatically closed. The result of the confirmation is displayed in the main view.

5 General configuration

5.1 User roles and rights management

A user has certain rights depending on the role. Each user role is protected with an initial default password. The default password for all user roles is “kukakuka”. The password can be changed for each user role.

(>>> *5.2.4 "Changing a user password" Page 90*)

⚠ **Change default passwords**

If the default passwords are not changed, this enables unauthorized persons to log on.

- Before start-up, change the password for all user roles.
- Only communicate the passwords to authorized personnel.

⚠ **Keep the administrator password in a secure place**

The administrator password cannot be restored. If the password is forgotten, the System Software must be reinstalled.

- Keep the administrator password in a secure place.

The following user roles are available as standard:

- User

  The user is authorized to access all functions required for operation of the robot.

  The user is not authorized to make safety-relevant or administrative settings, but can view the safety-relevant settings.
- Safety Commissioning Engineer

  The user “Safety Commissioning Engineer” is responsible for starting up the safety equipment of the industrial robot. Only the Safety Commissioning Engineer is authorized to modify the safety configuration on the robot controller, to approve the safety configuration and to move the robot prior to approval of the safety configuration.
- Administrator

  The administrator is responsible for administrative tasks, e.g. user and password management or carrying out updates.

In addition to their role-specific rights, “Safety Commissioning Engineer” and “Administrator” have the rights of the user role “User”.

5.2 System settings

5.2.1 Network settings

Description

The network addresses for the following Ethernet interfaces of the robot controller can be configured in the system settings:

- KLI OT, interface XF5
- KLI IT, interface XF2
- KONI, interface XF7

The interfaces can be assigned either a static network address or a dynamic network address:

- **Automatic (DHCP)**

  If this option is selected, a DHCP server in the network automatically assigns all settings.
- **Manual (static)**

  If this option is selected, all settings can be entered manually.
- Optionally, a description or a comment can be entered for each interface.

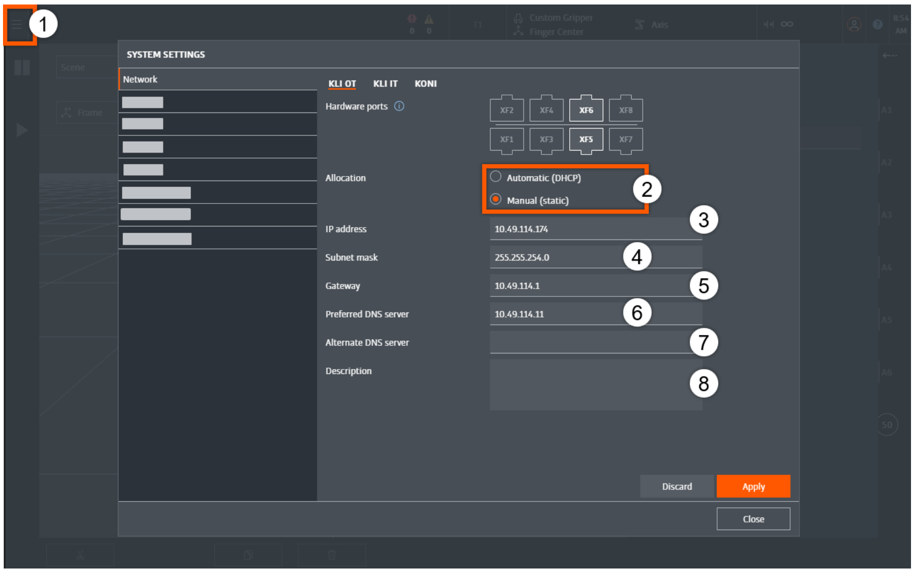


Fig. 5-1: Network settings, KLI OT

1	Main menu
2	Assignment options
3	IP Address
4	Subnet mask
5	Gateway
6	Preferred DNS server
7	Alternative DNS server
8	Description/comment (optional)

Precondition

- “Administrator” user role
- Operating mode T1 or CRR

Procedure

1. In the main menu, select **System Settings** > **Network**.
2. Select the interface and make the desired settings.
3. To save, select the **Apply** button.

5.2.2 Proxy network settings

Description

Communication with a proxy can be activated and configured in the system settings.

Precondition

- “Administrator” user role
- Operating mode T1 or CRR

Procedure

1. In the main menu, select **System Settings** > **Proxy**.
2. Activate proxy via the **Active** switch.
3. Enter a valid proxy address (URL or IP address) and the associated port.
4. To save, select the **Apply** button.

5.2.3 Firewall rules

Description

The firewall rules defined for the robot system can be displayed in the system settings.

- Each firewall rule includes the following information:
  - Network protocol, e.g. TCP or UDP
  - Port number
  - Status
  - Name and description
  - Origin, e.g. system or toolbox
  - Network interface, e.g. KLI IT, KLI OT, KONI or KSI
- Firewall rules can be sorted by name, protocol, port and status (in descending/ascending order).
- Each firewall rule opens a specific port via the defined network interface. To close a specific port, the corresponding rule can be deactivated.

> Deactivating a rule can limit the functionality of the system, toolbox, etc.

Fig. 5-2: Firewall rules

1	Main menu
2	Open/close all rules
3	Sorting options, descending/ascending
4	Rule open
5	**Status** switch activated

Precondition

- “Administrator” user role

Procedure

1. In the main menu, select **System Settings** > **Firewall**.
2. Open the firewall rule.
3. Activate or deactivate the firewall rule using the **Status** switch.

5.2.4 Changing a user password

Description

The password for each user role can be changed in the system settings.

Precondition

- “Administrator” user role

Procedure

1. In the main menu, select **System Settings** > **User roles**.
2. Select user role.
3. Enter a new password 2 times for the selected user role.
4. Select the **Change password** button.

5.2.5 Display settings

Description

The following display settings are possible:

- **Theme**
  Dark or light display mode can be set. The change is effective immediately.
- **Brightness**
  The change via the slider control is effective immediately.
- **Screensaver**
  Various screensavers and times for switching to the screensaver can be set.
  - The **Preview** button shows a preview of the screensaver.
  - The following setting deactivates the screensaver: **Show after** > **Never**

Procedure

1. In the main menu, select **System Settings** > **Display**.
2. Make the desired settings.

5.2.6 Date and time settings

Description

The time zone, date and time can be set in the system settings. Once the date and time have been changed, the controller is restarted.

Precondition

- “Administrator” user role

Procedure

1. In the main menu, select **System Settings** > **Date and Time**.
2. Make the desired settings.
3. To save, select the **Apply** or **Apply and restart** button.

5.2.7 Configuring the name of the robot controller

Description

The name of the robot controller can be configured in the system settings.

Precondition

- “Administrator” user role
- Operating mode T1 or CRR

Procedure

1. In the main menu, select **System Settings** > **Controller**.
2. Assign the desired name.
3. To save, select the **Apply** button.

5.2.8 Service Account

Description

The service account can be activated in the system settings. Activation of the account enables KUKA Customer Support to connect to the robot controller via SSH.

Precondition

- “Administrator” user role

Procedure

1. In the main menu, select **System Settings** > **Service Account**.
2. Activate the service account via the switch. The service account is automatically deactivated once the specified timeout has expired.
3. The access time can be extended using the **Timer reset** button. The timeout starts to run from the beginning.

6 I/O configuration

6.1 Physical inputs and outputs

Description

Physical inputs and outputs are made available by the devices connected to the bus. The system may contain multiple physical inputs and outputs that can be displayed, parameterized or mapped as required. Inputs are signals that the controller receives from an external source, e.g. the values of a sensor, while outputs are signals that the controller sends to external equipment, e.g. instructions to a gripper. The various inputs and outputs are managed on the main page of the **Physical I/O** interface.

Changes to physical inputs and outputs can only be carried out in T1 mode. In the case of safe physical inputs and outputs, changes are only possible with the **Safety Commissioning Engineer** role.

> It is advisable to make all desired changes before saving the changes via the **Apply** button.

Overview

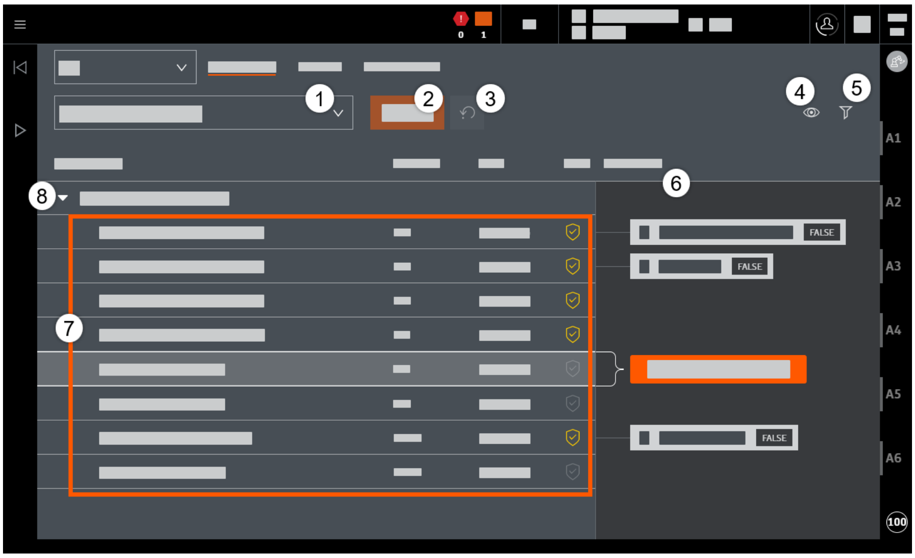


Fig. 6-1: Main page of the Physical I/O interface

Item	Description
1	Select the bus instance • **KUKA Controller Bus (KCB)** • **KUKA System Bus (SYS-X48)** • **KUKA Extension Bus (SYS-X44)** Only available if the bus is enabled in the **Bus Topology** in the I/O configuration settings. • **PROFINET** Only available if the bus is enabled in the **Bus Topology** in the I/O configuration settings.
2	Accept changes **Note:** The button is active if changes have been made in T1 mode and no program is running.
3	Discard changes

Item	Description
4	Show and hide columns **Note:** Hiding columns allows long I/O names to be displayed in full.
5	I/O filter The I/Os can be filtered by direction, safety and mapping.
6	Display of the mapped signals in the **Mapped To** area The following actions can be executed by touching a mapped signal: • Edit signal parameters • Cancel the mapping of signals • Edit scaling parameters
7	Physical I/Os of the selected device
8	Expand and collapse the device

6.1.1 Mapping physical inputs and outputs

Physical inputs and outputs can be mapped to an existing signal or a new signal.

Precondition

- When mapping the I/Os to the KUKA Extension Bus (SYS-X44) or PROFINET:

  The bus is enabled in the **Bus Topology** in the I/O configuration settings.

Procedure

1. Select the desired bus and expand the device.
2. Select a physical I/O or an individual bit of a physical I/O and then press the **Map** button in the **Mapped To** area. A dialog is opened.
3. Select a predefined bit length.

   Alternative: Enter the bit length manually in the input box.

   > Only bits with the same properties (direction, safety) can be mapped together.

4. Press **Continue** to switch to the **Map selected bits to...** page and select the desired mapping option:
   - Option **Map to existing signal**
   - Option **New signal**
5. Press **Continue** to switch to the mapping page.
6. If the **Map to existing signal** option is selected:

   a. Select the signal that is to be mapped.

      > All available signals are displayed. If necessary, filter the available signals.

   b. Press **Finish** to apply the mapping.
7. If the **New signal** option is selected:

   a. Set the signal parameters.

By default, the parameters (direction, safety, name) of the selected I/Os are applied for the new signal.

Only for signals of type NUMBER:

b. Switch to the next page by means of **Continue** and set the parameters for conversion.
c. Optional: Switch to the next page by means of **Continue** and set the parameters for scaling.
d. Press **Finish** to apply the mapping.

Detailed information can be found in the following section:
(>>> *6.2.2 "Creating and mapping a new signal" Page 96*)

6.2 Signals

Description

Signals are the interface on the controller to physical inputs and outputs. The system may contain multiple signals that can be displayed, parameterized or mapped as required. The different signals are managed on the main page of the signals interface. Signals can be set in different data types. The data types BOOL, Number and RAW are supported.

Changes to signals can only be made in T1 mode. In the case of safe signals, changes are only possible with the **Safety Commissioning Engineer** role.

It is advisable to make all desired changes before saving the changes via the **Apply** button.

Overview

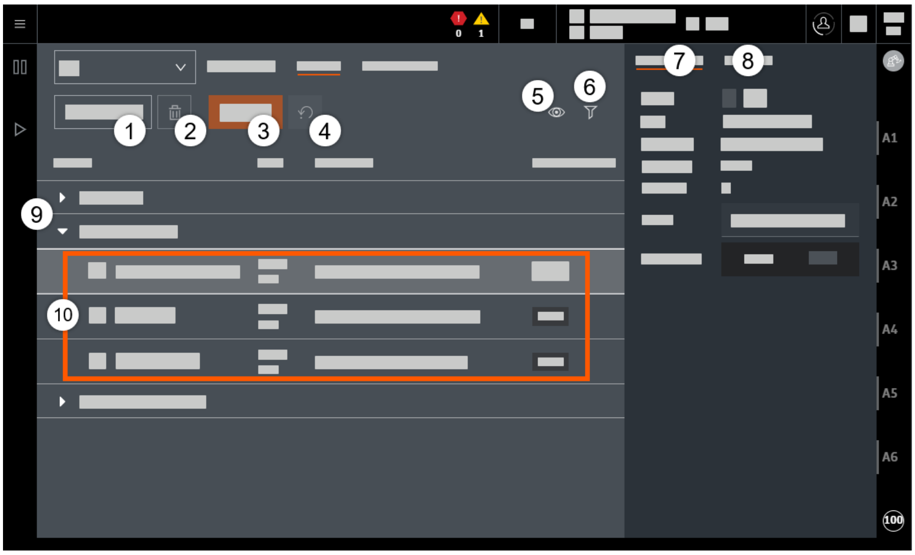


Fig. 6-2: Main page of the signals interface

Item	Description
1	Create new signal
2	Delete non-mapped signals
3	Accept changes **Note:** The button is active if changes have been made in T1 mode and no program is running.

Item	Description
4	Discard changes
5	Show and hide columns **Note:** Hiding columns allows long I/O names to be displayed in full.
6	I/O filter The I/Os can be filtered by direction, safety and mapping.
7	Detail view of the signal parameters
8	Detail view for signal mapping If an unmapped signal is selected, the **Map signal** button is displayed. If a mapped signal is selected, the **Unmap signal** button is displayed. The scaling parameters can be edited using the **Edit scaling** button.
9	Expand and collapse signal collection
10	Signals belonging to the selected signal collection

6.2.1 Signal collections

The following predefined signal collections are available:

User Signals

- On delivery, the collection contains predefined signals that are mapped to physical I/Os of the IFB-STD.
- The user can create new signals in the signal collection.
- The user can edit or delete the signals if they are not mapped.

User Safety Signals

- On delivery, the collection contains predefined signals that are mapped to physical I/Os of the KSP-300.
- The user can create new signals in the signal collection.
- The user can edit or delete the signals if they are not mapped.

SCHUNK Gripper Signals

- The signal collection is write-protected.
- On delivery, the collection contains predefined signals that are mapped to physical I/Os of the IFB-STD.
- The user cannot create new signals in the signal collection.
- The user cannot edit or delete the signals, but may change their mapping.

6.2.2 Creating and mapping a new signal

New signals can be created and mapped on the main page of the signals interface.

Procedure

1. Press the **New signal** button. A dialog is opened.

2. Set the signal parameters.
3. Press **Continue** to switch to the mapping page.

   Alternative: Press **Finish** to create the new signal without mapping. It can subsequently be mapped in the detail view of the signal.
4. On the mapping page, select the physical I/O that is to be mapped.

   If the list of I/Os displayed is too long, it is possible to filter for the bus and device.

> Multiple mapping is not possible.

Only for signals of type NUMBER:

5. Switch to the next page by means of **Continue** and set the parameters for conversion.
6. Defines the type of number:
   - Integer or floating-point number
   - Signed or unsigned
7. Optional: Switch to the next page by means of **Continue** and set the parameters for scaling.
8. Activate scaling to set parameters.
9. Select method:
   - **Min-Max**
   - **Factor-Offset**
10. If the **Min-Max** method is selected:
    a. Optional: Enter the unit.
    b. Define the input values (min and max).
    c. Define the process values (min and max).
       The scaling factor is determined.
11. If the **Factor-Offset** method is selected:
    a. Optional: Enter the unit.
    b. Enter the scaling factor and offset value.
       The process value is calculated.
    c. Add further calculations if necessary.
       The input value is added.
12. The new signal is created with **Finish** and the mapping is applied.

6.3 Bus Topology

Description

The bus topology defines the structure of the bus system with all connected devices and their connections to one another.

The various buses are displayed on the main page of the **Bus Topology** interface.

> As standard, the bus topology configured on the controller and the device parameters available offline are displayed. For comparison with the real bus structure – the display of the online parameters of the devices including diagnostic information – the bus system must be updated.

Overview

Fig. 6-3: Main page of the bus topology interface

Item	Description
1	Expand and collapse bus topology with device connections
2	Add device to KUKA Extension Bus (SYS-X44) or PROFINET
3	Delete device from KUKA Extension Bus (SYS-X44) or PROFI-NET
4	Accept changes **Note:** The button is active if changes have been made in T1 mode and no program is running.
5	Discard changes
6	Open I/O configuration settings The KUKA Extension Bus (SYS-X44) and the PROFINET bus instance can be enabled/disabled in the configuration settings. In this way, the activated bus instance is added to/removed from the bus topology.
7	Open **Device manager**
8	Parameter view of the selected device
9	Diagnostic data of the selected EtherCAT bus topology

6.3.1 Compare Online/Offline topology

Description

For the KUKA Extension Bus, it is possible to compare the online topology with the offline topology by means of a bus scan using the **Compare Online/Offline topology** button. In this way, the scanned devices are saved in the topology. If the KUKA Extension Bus is empty before the bus scan is performed, the scanned devices are automatically saved with the standard configuration from their device description file. Devices that have already been configured are retained.

The devices already configured are identified in the scanned topology by assigning numbers. The newly scanned devices are highlighted in color and are not assigned to any number.

It is possible to assign an existing configuration to another identical device. The default configuration is then automatically assigned to the original device.

Precondition

- The device description files of the connected devices have been imported.

6.3.2 Update PDOs

Description

In the parameter view of a device in the KUKA Extension Bus, the process data objects (PDOs) can be updated using the **Update PDOs** button. The process data objects of a device can be displayed using the **Open device configuration** button.

Precondition

- The device supports the **Update PDOs** function.
- The configured topology of the KUKA Extension Bus matches the topology of the connected device.

6.3.3 Device manager

The **Device manager** window contains the following areas:

- **Device overview**
- **Device description files**
- **Import**

Device overview

- List of available devices with the name of the vendor, the version of the device and the device description file
- Search box for quickly locating a device

Device description files

- List of devices already imported with the name of the vendor and the devices it contains
- Search box for quickly locating a file or device in a file
- Select a specific vendor
- Delete selected files
- Only EtherCAT device description files are supported (ESI files)

Import

The following steps are required in order to import device description files from a USB stick:

1. Prepare the USB stick with the **KUKA** folder at the top level.
2. Download the required device description files from the vendor and save them in the **KUKA** folder.
3. Plug the USB stick into the robot controller.
4. Press the **Refresh** button.

   A confirmation is displayed when the import has been successfully completed.

- Files with an error cannot be imported.
- Files with a warning can be imported.
- A file that has already been imported cannot be imported again.
- To update a file already imported, the existing version must first be deleted.

6.3.4 Configuration of EtherCAT devices

On the main page of the **Bus Topology**interface, the user can make the following changes to EtherCAT devices.

By means of the **Add device** button:

- Add a bus instance
- Add a device at the end of an EtherCAT branch
- **Continuous addition**: Add a device with the option of directly adding its children
- Add a device between two other devices

Only compatible devices are displayed for adding.

By means of the Delete button (recycle bin):

- Delete a bus instance
- Delete a device at the end of an EtherCAT branch
- Delete a device and its connected devices
- Delete a device but retain connected devices
- Delete an EK1100 and automatically also the configured EL devices that cannot remain in the topology without the EK1100 gateway

By means of the **Open device configuration** button:

- Define general parameters, process data objects, slave settings, distributed clocks and modules

6.3.5 Diagnosis

The current state of a device is displayed symbolically.

- To update the state, select the desired bus instance and then press **Apply**.

Icon	Status
	**OK** There are no error messages.
	**Solvable problem** The device is sending error messages, but the problem can be solved.
	**Device must be replaced** The device is defective and must be replaced.
	**Not available** The device has been configured but is not available in the network.
	**Need to refresh** An update is required to retrieve the current device status.

6.3.6 Updating MDPs

Description

In the parameter view of a device in the KUKA Extension Bus, the EtherCAT Modular Device Profiles (MDPs) can be updated using the **Update MDPs** button. The device’s added modules can be displayed using the **Open device configuration** button.

Precondition

- The device supports the **Update MDPs** function and is connected to the KUKA Extension Bus.
- The configured topology of the KUKA Extension Bus matches the physical structure on the controller.
- Manual configuration has been applied or a bus scan has been carried out.

Procedure

- Select the device and press the **Update MDPs** button.
  After successful updating, a message is displayed.

6.4 Configuring EtherCAT® Bridge FSoE M/M

Description

Safe and/or non-safe communication between a KR C5 robot controller and an external controller (e.g. PLC) can be established using “EtherCAT® Bridge FSoE M/M”.

Non-safe communication between 2 KR C5 controllers is also possible.

Communication

Robot controller – external controller (safe)

In the case of safe communication between a robot controller and an external controller, the robot controller is the FSoE slave and the external controller is the FSoE master.

> Safe communication is only possible with “EtherCAT-bridge-terminal EL6695” (= EL6695-1001).
> If the “EtherCAT-bridge-terminal EL6695” (= EL6695-0000) by Beckhoff is used, only non-safe I/O data can be exchanged.

Robot controller – external controller (not safe)

For the exchange of non-safe I/O data between a robot controller and an external controller, both controllers must be configured as the master in their bus line.

EtherCAT® Bridge FSoE M/M must be configured as a slave on both sides. EtherCAT® Bridge FSoE M/M forwards the received data from one line to the other. This enables the exchange of large amounts of data at the bus clock rate.

Robot controller – robot controller (not safe)

In the case of communication between 2 robot controllers, only non-safe I/O data can be exchanged.

Configuration

EtherCAT® Bridge FSoE M/M consists of a bus coupler and the Ether-CAT® bridge terminal.

Bus coupler: primary side

The KUKA robot controller connected to the bus coupler is connected to the primary side of the bridge terminal.

- A KUKA robot controller must always be connected to the primary side.

The primary side must be configured in iiQKA.OS.

Bridge terminal: secondary side

The controller that is connected to the bridge terminal itself is connected to the secondary side.

- An external controller (e.g. PLC) can be connected to the secondary side.
- Or a second KUKA robot controller.

The secondary side must be configured on the external controller or in iiQKA.OS (on the second robot controller).

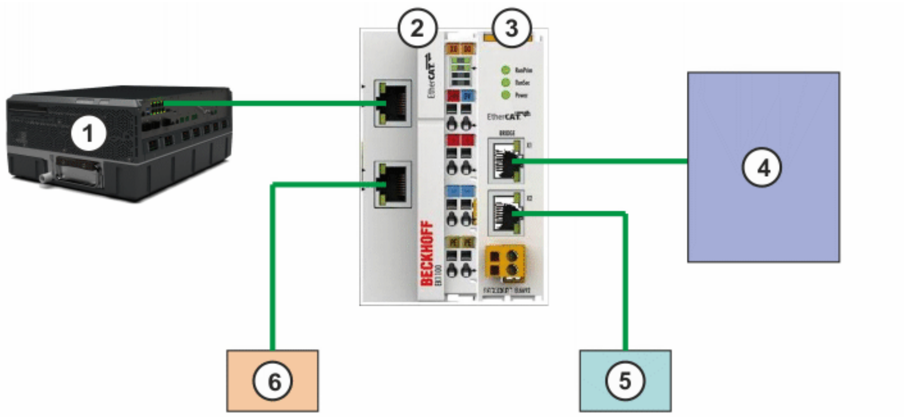


Fig. 6-4: KR C5 robot controller as primary controller

1	KR C5 on the primary side of the terminal
2	Bus coupler “EtherCAT® coupler EK1100”
3	Bridge terminal “EtherCAT® Bridge FSoE M/M” (= EL6695-1001)
4	Controller on the secondary side of the bridge terminal
5	EtherCAT device on the primary side
6	EtherCAT device on the secondary side

6.4.1 Configuring the primary side in iiQKA.OS

Description

This procedure must be carried out for all communication types:

- Robot controller – external controller (safe)
- Robot controller – external controller (not safe)
- Robot controller – robot controller (not safe)

Precondition

- KR C5 robot controller is connected to bus coupler.

- Device description file for bus coupler is available.

  The device description file can be obtained from the manufacturer of the bus coupler.
- Only if safe communication is to be set up:

  "Safety maintenance" user role

Procedure

1. Import the device description file of the bus coupler into iiQKA.OS.

   > Information about importing device description files can be found in the help function under "I/O configuration".

2. In iiQKA.OS in the Feature menu, select **Setup** > **I/O**.
3. Touch the cogwheel icon on the **Bus Topology** tab.

   The **I/O configuration settings** view opens.
4. Activate the bus instance **KUKA Extension Bus**: To do so, activate the check box in the corresponding line and touch the **Confirm** button.
5. On the **Bus Topology** tab, press the **Add device** button.

   Activate the **Continuous addition** option if not already active.
6. Add the following devices:

   a. **EK1100 EtherCAT Coupler (…)** or **EK1100 EtherCAT-Koppler (…)**

      (The name displayed depends on the selected interface language.)

      Select the version that corresponds to the specification on the bridge terminal.

   b. Add to port B of the bus coupler:

      KRC4 Primary EL6695-1001

      Select the version that corresponds to the specification on the bridge terminal.
7. Select the device **KRC4 Primary EL6695-1001** and click on the **Open device configuration** button.
8. Check and adapt the configuration: The configuration must match the controller on the other side of the bridge terminal.

   The main relevant settings are:

   - Process data objects, safe I/Os, synchronization bits, size of the non-safe I/Os

   Accept the changes with **Confirm changes**.
9. Select the **Physical I/O** tab and select the bus instance **KUKA Extension Bus**.
10. Open the device **KRC4 Primary EL6695-1001**.

    Map the inputs/outputs to safe signals.

    > Information about mapping can be found in the help function under "I/O configuration".

11. The remaining steps only need to be carried out in the following case:

    - The external controller is a PLC.
    - And: Safe communication is to be established.

    Steps:

    a. In the Feature menu, select **Setup** > **Safety** and switch to the **ENGINEERING** tab.

    b. Touch the cogwheel icon. The "**Safety Settings**" dialog opens.

Check the EtherCAT safety ID and adapt if necessary. The value must correspond to the safety ID of the PLC.

6.4.2 Configuring the secondary side on an external controller

Description

This procedure must be carried out for the following communication types:

- Robot controller – external controller (safe)
- Robot controller – external controller (not safe)

Precondition

- External controller is connected to bridge terminal (not to bus coupler).
- For downloading the device description file: Laptop/PC with Internet connection

Procedure

1. Call the KUKA Download Center on the laptop/PC.
   (www.kuka.com/en/downloads)
2. If required: Change the display language in the Download Center using the globe icon in the top right-hand corner.
3. Search for “EtherCAT”. (Upper/lower case not relevant)
4. Click on the following search result:
   KR C4 and KR C5 EtherCAT Master/Master Bridge ESI File
5. Download the following ZIP file:
   Kuka_EL6695sec.zip
6. Unzip file. It contains the following file:
   Kuka_EL6695sec.xml
7. Import the XML file into the configuration software of the external controller.
8. In the configuration software, configure the secondary side of the terminal “EtherCAT® Bridge FSoE M/M” in such a way that it corresponds to the configuration of the primary side.

Information about the procedures in the configuration software can be found in the documentation of the configuration software.

6.4.3 Configuring the safety interface

Description

This procedure must only be carried out for the following communication type:

- Robot controller – external controller (safe)

In order to be able to use terminal “EtherCAT® Bridge FSoE M/M” also for the safety interface, the described settings must be carried out in the project of the external controller.

Procedure

1. In the slot configuration:
   a. Select **Safety Process Data** in the left-hand area.

The following module is displayed in the right-hand area: **Safety Data (8 bytes)**, ID **0x00000102**

b. Add the module.

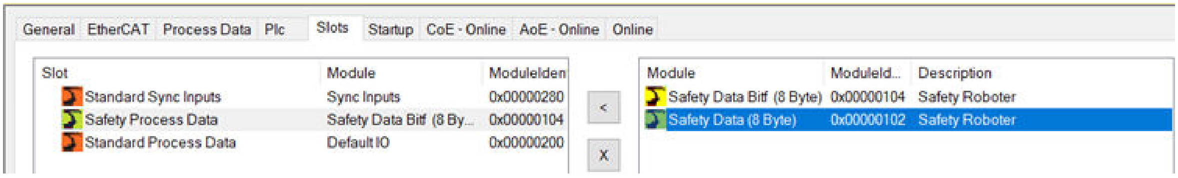


Fig. 6-5: Slot configuration

2. Insert the element **Custom FSoE Connection** in the safety program.

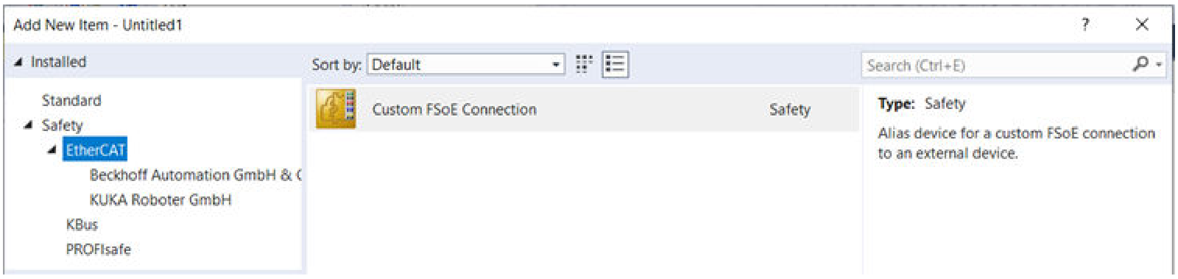


Fig. 6-6: Adding a custom FSoE connection

3. Select the following data structure:
   - **Inputs** > **Message Size**: 19 bytes (8 bytes of safe data)
   - **Output** > **Message Size**: 19 bytes (8 bytes of safe data)

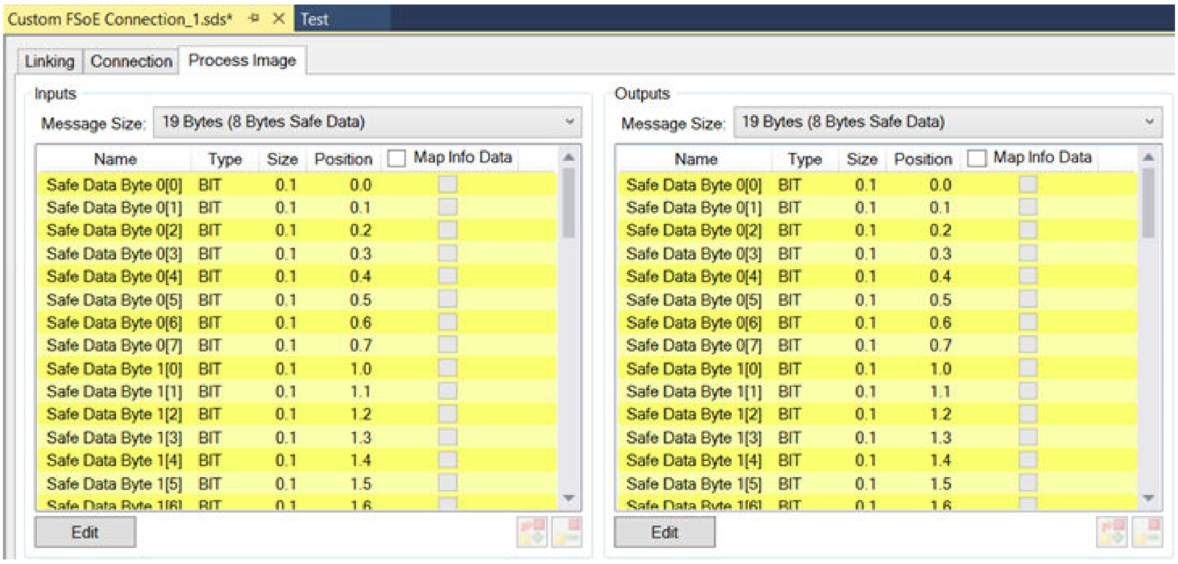


Fig. 6-7: Data structure for inputs/outputs

The FSoE address of the EtherCAT Bridge in the project of the external controller must correspond to the FSoE address in the safety configuration of the robot controller.

- The address must be in the range from 1 to 65 535.

  Default IP address: 999
- The watchdog times of the parameters for communication via the FSoE must be in the range from 64 to 32 767 ms.

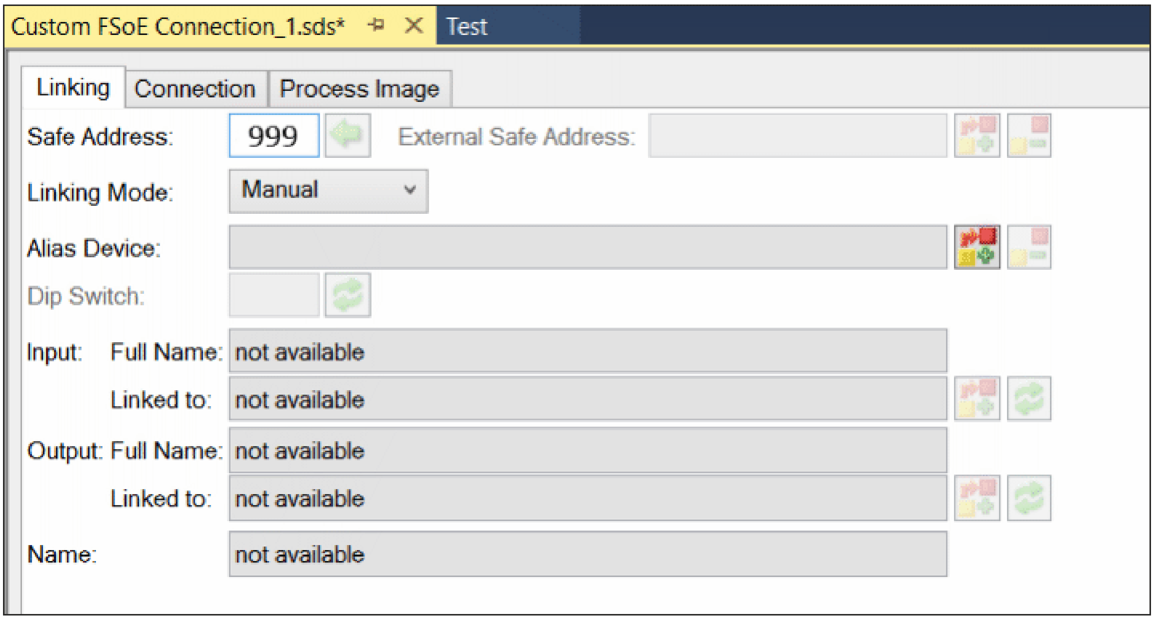


Fig. 6-8: FSoE address configuration

> Information about the procedures in the configuration software can be found in the documentation of the configuration software.

6.4.4 Configuring the secondary side in iiQKA.OS

Description

This procedure must only be carried out for the following communication type:

- Robot controller – robot controller (not safe)

Precondition

- KR C5 robot controller is connected to bridge terminal (not to bus coupler).

Procedure

1. In iiQKA.OS in the Feature menu, select **Setup** > **I/O**.
2. Touch the cogwheel icon on the **Bus Topology** tab.

   The **I/O configuration settings** view opens.
3. Activate the bus instance **KUKA Extension Bus**: To do so, activate the check box in the corresponding line and touch the **Confirm** button.
4. On the **Bus Topology** tab, press the **Add device** button.

   Add the following device:

   - **KRC4 Secondary EL6695-1001**

     Select the version that corresponds to the specification on the bridge terminal.
5. Select the device **KRC4 Secondary EL6695-1001** and click on the **Open device configuration** button.
6. Check and adapt the configuration: The configuration must match the controller on the other side of the bridge terminal.

   The main relevant settings are:

- Process data objects, synchronization bits, size of the non-safe I/Os

Accept the changes with **Confirm changes**.

7. Select the **Physical I/O** tab and select the bus instance **KUKA Extension Bus**.
8. Open the device **KRC4 Secondary EL6695-1001**.

   Map the inputs/outputs.

Information about mapping can be found in the help function under "I/O configuration".

7 Payload configuration

7.1 Payload configuration, general

Payloads are all the loads mounted on the robot flange. These include the following loads:

- Load of the tool mounted on the robot flange
- Load of the workpiece picked up by the tool

Check the safety configuration after any changes to the payload configuration
The payload configuration affects load-dependent monitoring functions, e.g. collision detection and maximum TCP force monitoring. After a change to the payload configuration, the safety integrity of these monitoring functions is no longer assured.

- If load-dependent monitoring functions are configured, the safety configuration must be checked and approved again after the payload configuration has been modified (carry out safety acceptance).

7.2 Tool configuration editor

Description

A tool can be added to the robot, configured and calibrated in the tool configuration editor. This tool is automatically connected to the robot flange.

- Only one tool can be configured in the tool configuration editor.
- Additional tools outside the robot can be added in the scene editor. This enables access to the capabilities of these tools.

  Tools outside the robot cannot be used for jogging or for program motions.

Procedure

- To access the editor, select the **Tool** tab under **Setup** > **Payload** in the Feature menu.

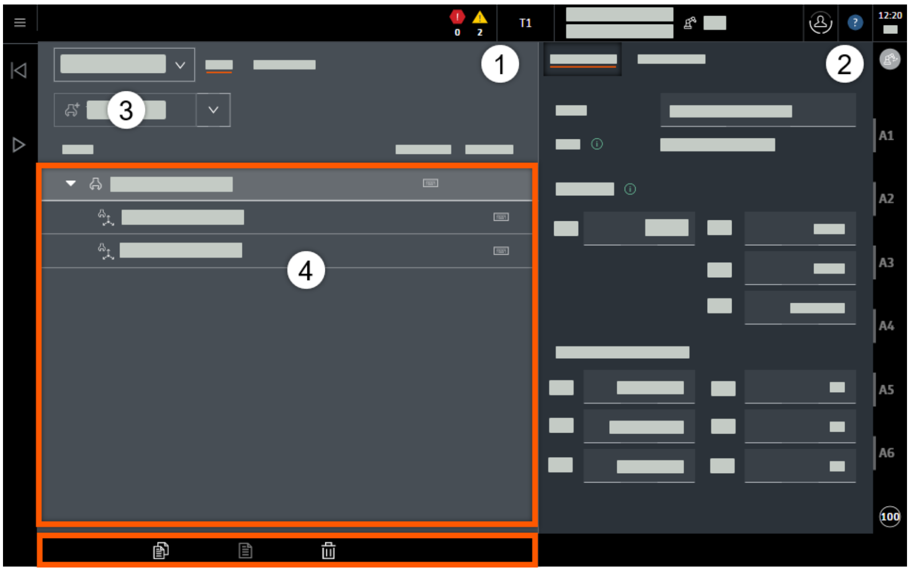


Fig. 7-1: Tool configuration editor

1	Main view
2	Detail view
3	Select and add tool/TCP
4	Configured tool (tree structure)

Main view

The main view shows the tool configuration as a tree structure and offers the following functions:

- Select and add **Tool**.
  - Generic tool
  - Or tool from one of the installed toolboxes
- Select and add **TCP**.
  Each tool includes at least one TCP. Further TCPs can be created.
- The toolbar at the bottom of the screen offers the following functions for modifying the tool configuration:
  - Delete selected element (recycle bin).
  - Copy selected element.
  - Paste copied element.

> During configuration of the **Tool Orientation Monitoring** Monitoring Block in the safety configuration editor, one of the available TCPs can be selected as a tool orientation frame. The following applies in this case:
> - Neither the tool nor the selected TCP can be deleted from the tool configuration editor.
> - To edit the TCP data, a Safety Commissioning Engineer must be logged on.

Detail view

The detail view displays the properties and parameters of the element selected in the configuration tree in the main view.

- **Parameters** tab

  The parameters of the selected tool or TCP can be entered manually. Or calibration data have been saved.
- **Capabilities** tab (if a tool from a toolbox is selected)
  - **Gripper Capability**

    It is possible to switch to the available gripper capabilities in order to configure the gripper functions.
  - **Actions**

    The gripper functions **Grip** and **Release** configured in the capabilities can be executed and tested.
  - **Signals**

    The current values of the configured gripper signals are displayed. It is possible to switch to the I/O configuration via the I/O names.
- **Calibration** tab (if a TCP is selected)

  The tool can be calibrated here.

Load data

Only a Safety Commissioning Engineer can enter and edit the load data of the tool.

- **M**

  Mass of the tool
- **Lx, Ly, Lz**

  Position of the center of mass in the FLANGE coordinate system
- **Ix, Iy, Iz**

  Mass moments of inertia about the principal inertia axes
- **Rx, Ry, Rz**

  Orientation of the principal inertia axes relative to the FLANGE coordinate system

TCP data

The TCP data can be entered manually or defined with the tool calibration. The following data are saved:

- **X, Y, Z**

  Origin of the TOOL coordinate system relative to the FLANGE coordinate system
- **Rx, Ry, Rz**

  Orientation of the TOOL coordinate system relative to the FLANGE coordinate system

7.2.1 Tool calibration

In tool calibration, a Cartesian coordinate system (TOOL coordinate system) is assigned to a tool installed on the mounting flange.

Advantages of tool calibration:

- The tool can be moved in a straight line in the tool direction.
- The tool can be rotated about the TCP without changing the position of the TCP.
- In program mode: The programmed velocity is maintained at the TCP along the path.

The TOOL coordinate system has its origin at a user-defined point. This point is called the TCP (Tool Center Point). A tool can have multiple TCPs.

The TCP of a tool can be calibrated in the parameter view of the TCP on the **Calibration** tab:

- The origin and orientation of the TOOL coordinate system are calibrated separately.
- It is possible to calibrate only the origin and enter the orientation manually or vice versa.
- To start the calibration, select **Calibrate**/**Recalibrate**.

  A wizard opens which guides you through all the required calibration steps.
- Calibration can also be carried out by means of manual guidance on the Commander. By turning the jog dial, the selection of the measurement point can be changed and by pressing the jog dial, a touch-up can be carried out.

7.2.1.1 Calibrating the origin

To calibrate the origin X, Y, Z, a reference point is addressed with the TCP of the tool from 4 different directions and the measurement pose is taught. The robot controller uses these 4 measurement poses to calculate the position of the TCP.

- The reference point can be freely selected.
- The flange positions in the 4 measurement poses must be as different as possible and maintain a certain minimum distance. If the points are too close together, the pose cannot be taught. A corresponding message is displayed in the wizard.
- Any measurement error is displayed in the parameter view of the TCP on the **Calibration** tab.

7.2.1.2 Calibrating the orientation

To calibrate the orientation Rx, Ry and Rz, the following points on the tool are moved to a reference point and the measurement pose is taught:

- Origin of the TOOL coordinate system
- Point in negative tool direction (in relation to the origin)
- Point on the XY plane of the TOOL coordinate system with a positive Y value

The robot controller uses these 3 measurement poses to calculate the orientation of the TCP.

7.3 Workpiece configuration editor

Description

In the workpiece configuration editor, workpieces picked up by a tool can be configured and calibrated.

Procedure

- To access the editor, select the **Workpiece** tab under **Setup** > **Payload** in the Feature menu.

Fig. 7-2: Workpiece configuration editor

1	Main view
2	Detail view
3	Add workpiece or open workpiece wizard
4	List of created workpieces

Main view

The main view displays the created workpieces and offers the following functions:

- Create a workpiece manually
  To do so, select **Add workpiece** in the Editor menu.
- Create a workpiece using a wizard
  The workpiece wizard can be started via the corresponding entry in the Editor menu. If no workpieces have been created yet, the work-piece wizard can also be started using the **Start workpiece wizard** button. The workpiece wizard guides you step by step through the configuration of the workpiece and provides additional written and graphical help.
- Delete a selected workpiece via the toolbar at the bottom of the screen (recycle bin)

Detail view

The detailed view shows the properties and parameters of the selected workpiece.

- **Parameters** tab
  The load data of the workpiece can be entered here and the motion frame can be selected.
- **Origin** tab
  The origin of the workpiece can be defined here.
- **Shape** tab
  A basic form for the workpiece in the 3D scene can be defined here (optional).

Parameters

Various parameters of the workpiece can be defined:

- **Name**
  Name of the workpiece
- **Mass**
  Mass of the workpiece
- **Motion Frame**
  A motion frame can be defined for each workpiece. Cartesian motions with the workpiece are executed with this frame by default. Besides the robot flange, all TCPs configured for a tool are available for selection.
- **Additional Load Data**
  The supplementary load data refer to the origin of the workpiece.
  - **Lx, Ly, Lz**
    Position of the center of mass relative to the origin of the workpiece
  - **Ix, Iy, Iz**
    Mass moments of inertia about the principal inertia axes of the workpiece
  - **Rx, Ry, Rz**
    Orientation of the principal inertia axes through the center of mass
- **Description**
  A description for the workpiece can be entered here. The description has no further effects.

Origin

The origin of the workpiece can be defined in various ways:

- **custom offset for workpiece origin**
  If this option is selected, the offset for the origin of the workpiece can be manually entered or calibrated. The offset is specified relative to the origin of the tool.
- **align workpiece origin to TCP**
  If this option is selected, the origin of the workpiece can be aligned with a TCP. All the TCPs configured for the tool are available for selection.

Calibration of the origin and its orientation is carried out using the same principle as tool calibration.

Shape

Optionally, a shape can be selected to represent the workpiece in the 3D scene. The following shapes are available:

- **Sphere**
- **Cuboid**
- **None** (default)

The dimensions and origin of the shape can be freely selected.

7.4 Gripper toolboxes

Overview

The following toolboxes are preinstalled on the robot controller:

- KUKA iiQKA.Gripper Toolbox

  The toolbox enables the configuration of a user-specific single gripper (Custom Gripper) or double gripper (Custom Dual Gripper).
- KUKA iiQKA.Gripper CoAct Toolbox

  The toolbox supports the SCHUNK Co-Act ESG 60 gripper.
  - The tool data are preset in accordance with the SCHUNK CoAct gripper specification.
  - The gripper signals are preconfigured in the I/O configuration.
  - The signals cannot be edited, deleted or their mapping modified.

Capabilities

The gripper capabilities are available as soon as the corresponding tool has been added to the robot in the tool configuration editor or in the scene editor outside the robot.

- The capabilities provide the functions for controlling the grippers.
- The gripper functions **Grip** and **Release** can be tested manually.

> Do not operate the gripper via the signals in the I/O configuration, but always by using the **Grip** and **Release** buttons in the capabilities.

- The gripper functions **Grip** and **Release** can be used as commands in programs.
- If multiple capabilities are configured, e.g. for a Custom Dual Gripper, the capability with which the command is to be executed must be specified when programming the gripper commands.
- In order to be able to test them, the gripper commands are available as buttons in the toolbar of the program view.
- If multiple capabilities are configured, e.g. for a Custom Dual Gripper, the capability to be operated can be assigned to the buttons by means of quick access.

> Further information about the gripper commands and the quick access buttons can be found in the help function under “Programming”.

7.4.1 Configuring gripper functions

Description

The gripper functions can be configured in the **Capabilities** view. Depending on the gripper type, the capability includes various configurable parameters.

Procedure

1. To open the view, select **Setup** > **Capabilities** in the Feature menu.
2. Select the desired gripper capability in the drop-down menu of the view.
   - Main view: Displays the capability as a tree structure.

- Parameter view: Displays the properties and parameters of the element selected in the configuration tree in the main view.

3. Set the gripper parameters and configure the required gripper signals.
    - If a required signal is already mapped, it can be selected via **Select signal ...**.
    - If a required signal has not yet been mapped, it can be created via **New signal ...**.

> Further information about mapping signals can be found in the help function under “I/O configuration”.

4. Save the configuration with **Apply**.

7.4.1.1 Custom Gripper Capability

A user-specific single gripper can be configured in the Custom Gripper Capability.

For a user-specific double gripper, a gripper capability must be configured for each gripper. The configuration corresponds analogously to configuration of the capability of the single gripper in each case.

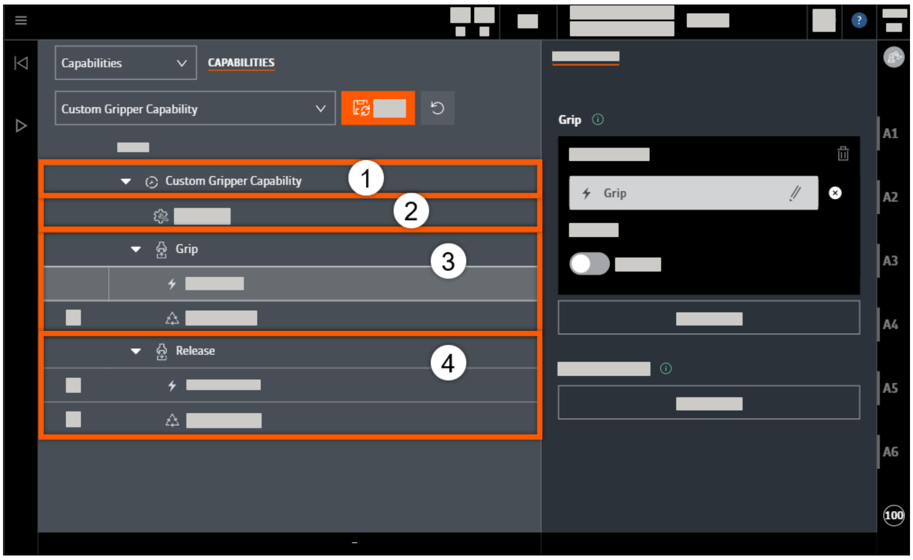


Fig. 7-3: Custom Gripper Capability

1	Gripper capability
2	General settings
3	Grip settings
4	Release settings

Gripper capability

Higher-level settings for the capability can be made here:

- **Details**
    - **Name**: The name of the capability can be changed here.
    - **Tool**: The name of the gripper is displayed.
- **Properties**

  A service runs in the background in the toolbox, which queries the status of the gripper every 300 ms. This status (e.g. **Gripped**) can be used as a return value in the programming. The querying of an individual status can be activated or deactivated using the **Refresh** switch. The status can also be opened in a separate window. All queries can be activated or deactivated simultaneously using the **Activate All** and **Deactivate All** buttons.

- **Actions**

  The gripper functions **Grip** and **Release** configured in the capabilities can be executed and tested.
- **Signals**

  The current values of the configured gripper signals are displayed. It is possible to switch to the I/O configuration via the I/O names.

General settings

A minimum pause time between output signal changes and a debounce time for input signals can be configured here:

- Option **Limit frequency of outputs**

  If the option is enabled, the output signals do not change faster than the specified delay.
- Option **Debounce inputs**

  If the option is enabled, only those input signal changes that are stably present at an input for at least the specified time are detected.

Grip settings

The grip function of the tool is configured here:

- Section **Grip action**
  - Configure output signals that are set during gripping.
  - Configure output signals that are set after gripping.
- Section **Gripped state**

  Configure the condition for detection of the **Gripped** state:
  - **Signal-based**

    The **Gripped** state is reached if input signals of a specific state are present. These sensor signals of the gripper must be configured.

    A timeout can also be configured if the **Gripped** state is not reached within a specified time.
  - **Time-based**

    The **Gripped** state is reached automatically when the time specified here has elapsed (e.g. 200 ms after the Close signal has been set).

Release settings

The release function of the tool is configured here. The configuration is analogous to that of the grip settings.

7.4.1.2 SCHUNK Gripper Capability

Gripper capability

Higher-level settings for the capability can be made here:

- **Details**
  - **Name**: The name of the capability can be changed here.
  - **Tool**: The name of the gripper is displayed.

- **Properties**

  A service runs in the background in the toolbox, which queries the status of the gripper every 300 ms. This status (e.g. **Gripped**) can be used as a return value in the programming. The querying of an individual status can be activated or deactivated using the **Refresh** switch. The status can also be opened in a separate window. All queries can be activated or deactivated simultaneously using the **Activate All** and **Deactivate All** buttons.
- **Actions**

  The gripper functions **Grip** and **Release** configured in the capabilities can be executed and tested.
- **Signals**

  The current values of the configured gripper signals are displayed. It is possible to switch to the I/O configuration via the I/O names.

Grip settings

The following grip settings can be configured in the capability of the SCHUNK gripper:

- **Grip type**
  - **Outer (close to grip)**

    Tool grips object from outside and closes during gripping
  - **Inner (open to grip)**

    Tool grips object from inside and opens during gripping
- **Gripped state**

  Condition for detecting the **Gripped** state:
  - **Signal-based**

    The **Gripped** state is reached when the associated sensor signals are active.
  - **Time-based**

    The **Gripped** state is reached automatically when the time specified here has elapsed (e.g. 200 ms after the Close signal has been set).
- **Released state**

  Condition for detection of the **Released** state is configured analogously to detection of the **Gripped** state.

7.4.2 Executing and testing gripper functions

Description

In the parameter view of the gripper capability, buttons are available for executing and testing the configured gripper functions:

- **Grip**
- **Release**

The buttons are also available under **Setup** > **Payload** in the parameter view of the tool (**Capabilities** tab).

Precondition

- Operating mode T1 or KRF
- Enabling switch is pressed.
- No program is being executed.

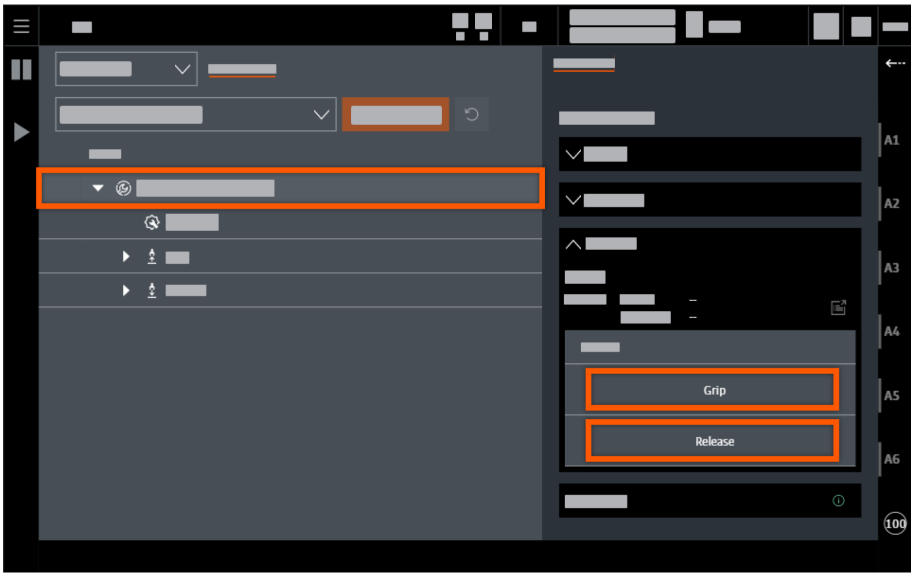


Fig. 7-4: Executing and testing gripper functions

8 3D scene

8.1 Overview of 3D scene

The scene view shows the 3D visualization of the scene. To display it, select **Scene** in the Feature menu.

The 3D scene shows the model of the objects that are present in the project. These include:

- Robot in the current pose
- All frames and bases
- All cuboids and prisms (monitoring spaces)
- Physical objects, e.g. SICK safety laser scanners
- Tool spheres and force interaction areas
- Workpiece with which the robot moves
- Safety spheres of the robot structure

> **i** Operation of the scene, e.g. creation and deletion of frames, is partly possible with the Commander on the robot. Further information can be found in the help function under “General operation”.

Operator control elements in the 3D scene

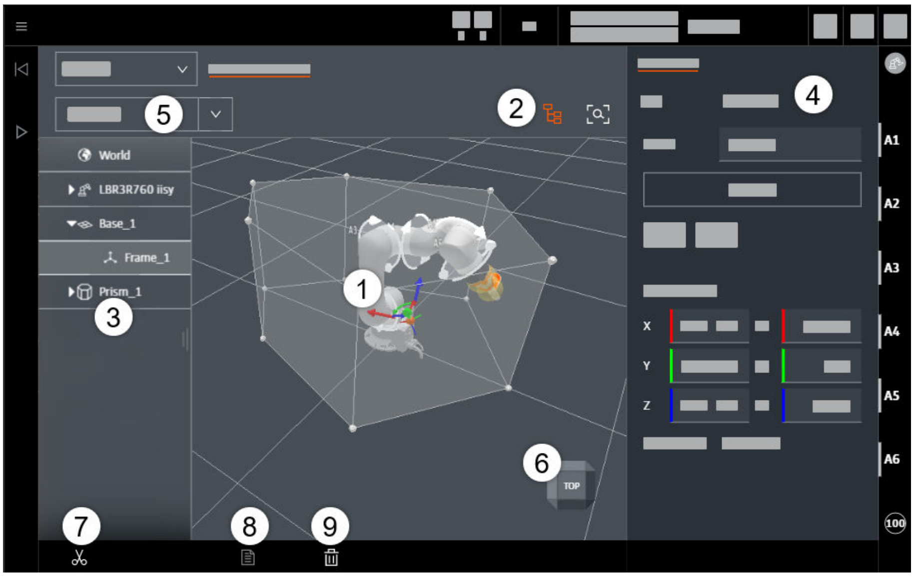


Fig. 8-1: Scene

1	3D view of the scene
2	Display and hide object tree
3	Object tree
4	Parameter view of the selected object
5	Create new object
6	Realign 3D view
7	Cut objects
8	Paste cut objects
9	Delete objects

Navigation in the 3D view

- Drag with one finger to rotate the 3D view.

- Drag with 2 fingers (panning) to move the 3D view.
- Make a pinch gesture with 2 fingers to zoom into the 3D view.
- Press the magnifying glass icon (**Zoom to fit**) to reset the view and align it centrally so that all objects in the scene are visible.
- Press the cuboid icon in the view to switch between predefined orientations and the Home view and to refresh the Home view with the currently selected orientation.
- All objects can be selected in the tree structure and in the 3D scene.
- Drag the object tree at the center of the edge to enlarge or reduce it.

Changing the scene

The scene editor can be used to change the scene itself.

- The robot visualization always represents the current pose.
- The object currently selected displays an auxiliary coordinate system with the orientation of the parent object.
- The properties of a selected object are displayed in the parameter view.
- Selected objects can be edited, cut or deleted.
- New objects can be added.

8.2 Managing frames

Frames

A frame is a 3-dimensional coordinate system that is described by its position and orientation relative to a reference system. Points in space can be defined easily using frames.

Each end point of a robot motion is defined by a frame. The target frame thus specifies not only the position in 3-dimensional space, but also the orientation of the TCP at this point.

If a frame is recorded by means of touch-up, the current robot pose is also saved in the frame in order to be able to address the frame exactly in a reproducible manner at all times.

Parameters of a frame

- 6D coordinates:
  - X, Y and Z coordinates: These 3 values determine the position of the frame in space
  - Rx, Ry, Rz: These 3 values specify the rotation angle about the X, Y and Z axes. They determine the orientation of the frame in space.
- **Parent**: Specifies the reference system for the frame.

  All coordinates and rotation angles are specified relative to this reference system. If the reference system is changed, the absolute position of the frame in space also changes. Further information about this can be found in the section on bases.

  If a frame is displayed under another object or frame in the object tree, this means that this other object is the **Parent** of the frame.

Shared and unshared frames

Frames can be either shared with all programs in the project or not shared.

Unshared frames

- Unshared frames are only visible in the robot program in which they were created.
- Unshared frames cannot be created or modified in the 3D scene, but only on the programming interface.
- Unshared frames are only visible in the 3D scene if the program to which they belong is open in the programming interface.
- The use of unshared frames within a program ensures that no other programs are affected if the unshared frame is modified or deleted.

Frames shared in the project

- Shared frames are visible for all robot programs in the current project.
- Shared frames can be created either in the programming interface or directly in the 3D scene.
- Shared frames are used, for example, for defined reference positions of the robot.

Shared and unshared frames can be converted from one to the other. If an unshared frame is to be split subsequently, either a new shared frame can be created for this, or an existing shared frame can be used.

Creating frames

Frames can be created and edited in several ways:

- The coordinates are entered manually in the parameter view.
- The robot is moved to the desired position by means of jogging or manual guidance and the frame is recorded by means of **Touch up**.
- A frame is first created with the current robot position. This can be changed subsequently.

Addressing frames with the robot

Fig. 8-2: Move to function

- In test mode (T1 mode), frames can be addressed independently of program execution using the **Move to** function.
- The mode is activated by pressing the **Move to** switch in the parameter view, changing the function of the Start key.
- The broken orange line indicates the connection between the TCP and the selected frame.

- The frame to be addressed is displayed in the status bar instead of the program name.
- In the status bar, the motion type can be changed from **P2P** to **LIN** via the drop-down menu.
- In order to address the frame, the enabling switch and the Start key must be held down.
- The mode can be terminated via **Exit move to** in the drop-down menu in the status bar or by deactivating the **Move to** switch in the parameter view. Changing the operating mode also terminates the mode.

8.3 Configuring, calibrating and managing tools

Description

The tool added to the robot in the payload configuration is displayed in the tree view of the scene editor. The tool can be configured and calibrated in the scene editor (or right in the payload configuration).

Exception: The following safety-oriented tool parameters can only be configured in the scene editor:

- Configuring tool spheres
  (>>> *8.3.1 "Configuring tool spheres" Page 125*)
- Configuring the force interaction area
  (>>> *8.3.2 "Configuring the force interaction area" Page 126*)

Tool configuration

To configure the tool, select the tool in the tree view:

- The tool has at least one TCP. Further TCPs can be created. For this, select **Tool** > **TCP** in the object selection menu.
- The load data can be edited in the detail view on the **Parameters** tab (precondition: “Safety maintenance” user role):
  - **M**
    Mass of the tool
  - **Lx, Ly, Lz**
    Position of the center of mass in the FLANGE coordinate system
  - **Ix, Iy, Iz**
    Mass moments of inertia about the principal inertia axes
  - **Rx, Ry, Rz**
    Orientation of the principal inertia axes relative to the FLANGE coordinate system
- If capabilities are available for the tool, the **Capabilities** tab is available in the detail view:
  - Link to the capability configuration
    It is possible to switch to the capability configuration.
  - **Actions**
    The functions configured in the capabilities can be executed and tested.
  - **Signals**
    The current values of the signals configured in the capabilities are displayed. The signals can be used to switch to the signal configuration in the I/O configuration.

> During configuration of the **Tool Orientation Monitoring** Monitoring Block in the safety configuration editor, one of the available TCPs can be selected as a tool orientation frame. The following applies in this case:
>
> - The selected TCP cannot be deleted from the scene editor.
> - To edit the TCP data, a Safety Commissioning Engineer must be logged on.

Tool calibration

For tool calibration, select a TCP in the tree view:

- The origin and orientation of a TCP can be entered manually in the detail view on the **Calibration** tab or calibrated on the **Calibration** tab.
- The procedure is identical to calibration in the payload configuration.

8.3.1 Configuring tool spheres

Description

Up to 6 spheres can be configured for a tool. The tool spheres are relevant for Cartesian velocity monitoring and space monitoring functions.

The tool spheres are monitored if the tool is selected as the structure to be monitored in the corresponding Monitoring Blocks in the safety configuration.

> Further information about the monitoring functions can be found in the help function under "Safety configuration".

Precondition

- "Safety maintenance" user role

Example

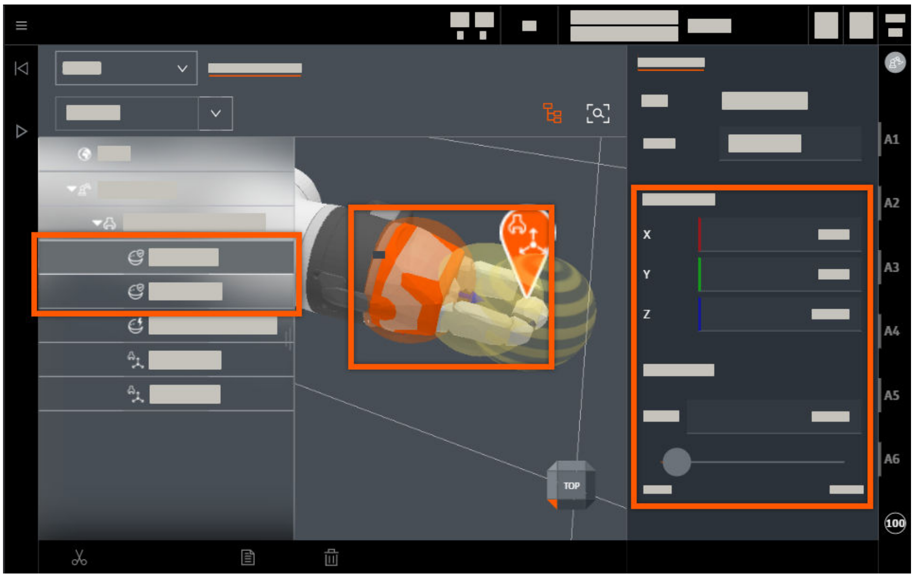


Fig. 8-3: Example of tool spheres

Configuration example for tool spheres for a SCHUNK Co-Act ESG 60 gripper:

Predefined position of the tool spheres		
Sphere	**Offset relative to the FLANGE coordinate system**	**Radius**
1	X = 0 mm, Y = 0 mm, Z = 20 mm	58 mm
2	X = 0 mm, Y = 0 mm, Z = 85 mm	50 mm

The tool spheres for other tools can be configured in analogously to this example.

- New tool spheres can be added if the tool is selected in the object tree.
- In the parameter view, the tool spheres can be shifted and the radius changed by entering coordinates.

8.3.2 Configuring the force interaction area

Description

The force interaction area is defined as a sphere that contains all the points of a safety-oriented tool where expected external forces can occur.

> Further information about the force interaction area can be found in the help function under “Safety configuration”, in the section “Monitoring Block Maximum TCP force”.

The more accurately the position of the force interaction point is defined (i.e. the smaller the radius of the force interaction area is configured), the better the Monitoring Block **Maximum TCP Force** can be used near singularities.

Precondition

- “Safety maintenance” user role

Example

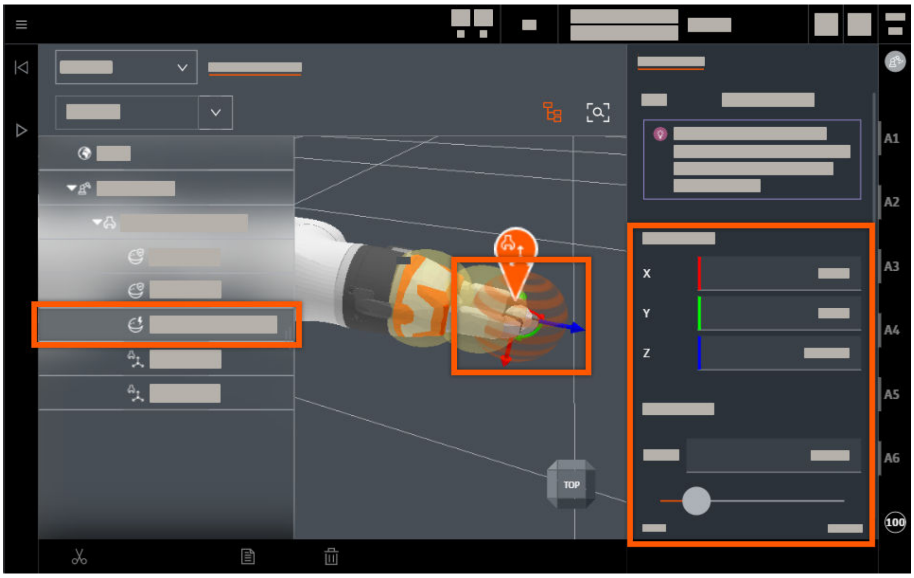


Fig. 8-4: Example of force interaction area

Configuration example for the force interaction area for a SCHUNK Co-Act ESG 60 gripper:

Predefined position of the force interaction area		
Sphere	**Offset relative to the FLANGE coordinate system**	**Radius**
1	X = 0 mm, Y = 0 mm, Z = 125 mm	50 mm

The force interaction area for other tools can be configured analogously to this example.

- In the parameter view, the force interaction area can be shifted and the radius changed by entering coordinates.
- The force interaction area should cover the collision area, but should be kept as small as possible to make efficient use of the workspace.

8.4 Adding tools outside the robot

Description

Additional tools outside the robot can be added in the scene editor. This enables access to the capabilities of these tools.

Tools outside the robot cannot be used for jogging or for program motions.

Procedure

1. In the **World** tree view and in the object selection menu, select **Tool**.
2. Select and add the desired tool.
3. To configure the tool, select the tool added in the tree view:
   - The name can be changed in the detail view on the **Parameters** tab. The load data for tools that are not connected to the robot flange are irrelevant and cannot be edited.
   - The capabilities can be configured as required in the detail view on the **Capabilities** tab.
     - Link to the capability configuration
       It is possible to switch to the capability configuration.
     - **Actions**
       The functions configured in the capabilities can be executed and tested.
     - **Signals**
       The current values of the signals configured in the capabilities are displayed. The signals can be used to switch to the signal configuration in the I/O configuration.

8.5 Managing workpieces

Description

The workpiece with which the robot is currently moving is displayed in the 3D scene and in the object tree.

Detail view

The detailed view shows the properties and parameters of the selected workpiece.

- **Parameters** tab
  The load data of the workpiece can be entered here and the motion frame can be selected.

- **Origin** tab
  The origin of the workpiece can be defined here.
- **Shape** tab
  A basic form for the workpiece in the 3D scene can be defined here (optional).

Parameters

Various parameters of the workpiece can be defined:

- **Name**
  Name of the workpiece
- **Mass**
  Mass of the workpiece
- **Motion Frame**
  A motion frame can be defined for each workpiece. Cartesian motions with the workpiece are executed with this frame by default. Besides the robot flange, all TCPs configured for a tool are available for selection.
- **Additional Load Data**
  The supplementary load data refer to the origin of the workpiece.
  - **Lx, Ly, Lz**
    Position of the center of mass relative to the origin of the workpiece
  - **Ix, Iy, Iz**
    Mass moments of inertia about the principal inertia axes of the workpiece
  - **Rx, Ry, Rz**
    Orientation of the principal inertia axes through the center of mass
- **Description**
  A description for the workpiece can be entered here. The description has no further effects.

Origin

The origin of the workpiece can be defined in various ways:

- **custom offset for workpiece origin**
  If this option is selected, the offset for the origin of the workpiece can be manually entered or calibrated. The offset is specified relative to the origin of the tool.
- **align workpiece origin to TCP**
  If this option is selected, the origin of the workpiece can be aligned with a TCP. All the TCPs configured for the tool are available for selection.

Calibration of the origin and its orientation is carried out using the same principle as tool calibration.

Shape

Optionally, a shape can be selected to represent the workpiece in the 3D scene. The following shapes are available:

- **Sphere**
- **Cuboid**
- **None** (default)

The dimensions and origin of the shape can be freely selected.

8.6 Calibrating and managing bases

A base is a 3-dimensional coordinate system, similar to a frame, which is defined by its position and orientation relative to a reference system. Furthermore, a base itself serves as a reference system for other objects, such as frames, other bases, prisms or cubes.

In base calibration, a Cartesian coordinate system (BASE coordinate system) is assigned to a work surface (or the workpiece on the work surface). The TCP can then be moved manually along the work surface/workpiece. Frames can be created with the base as a reference. If it is necessary to offset the base, e.g. because the work surface has been offset, the frames move with it and do not need to be retaught. Furthermore, the entry and checking of coordinates is intuitive, e.g. Z = 100 mm can always mean 100 mm above the work surface, irrespective of the angle by which the work surface is inclined.

Creating bases

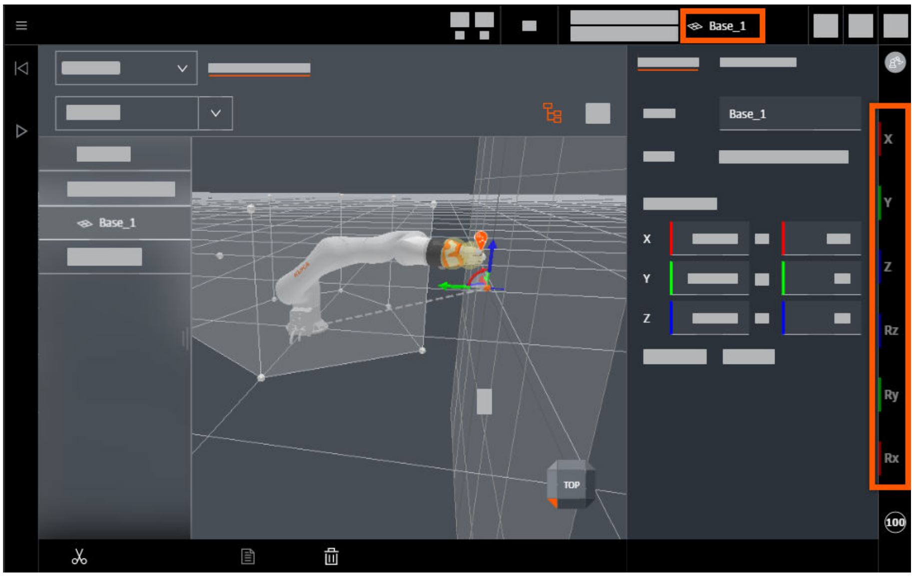


Fig. 8-5: Base in the 3D scene

- The BASE coordinate system can either be entered manually using the X, Y and Z coordinates and the rotation angles Rx, Ry and Rz, or the base can be calibrated.
- During base calibration, the robot moves to points on the XY plane of the desired BASE coordinate system and the position of the coordinate system is calculated from these points.
- To calibrate a base, first create a new base in the 3D scene and switch to the **Calibration** tab in the parameter view.
  - A wizard automatically performs base calibration and records the required points. Recalibration of an existing base can be carried out in the same way.
  - Calibration can also be carried out by means of manual guidance on the Commander. By turning the jog dial, the selection of the measurement point can be changed and by pressing the jog dial, a touch-up can be carried out.
- Bases are displayed as planes in the 3D scene. The origin of the base is additionally displayed.

- A base can be set to active in the status bar. Jogging can be carried out manually in the active base.
- Bases can be nested, i.e. a base can be created with another base as its reference, e.g. a workpiece on a work surface.

8.7 Managing monitoring spaces: prisms and cuboids

In the 3D scene, monitoring spaces can be defined that can be assigned to specific safety functions in the safety configuration.

There are two geometries for monitoring spaces:

- **Cuboid** with length, width, height and rotation angle about the Z axis
- **Prism** with 3 to 20 corners and a defined height

Spaces can only be created with the **WORLD** reference coordinate system or a base and cannot be nested in one another. Creating cuboids and prisms with a base enables the monitoring space to be rotated about the X and Y axes relative to WORLD.

Spaces are displayed transparently in the 3D scene. This allows easy checking of their position, shape and size. The corners of prisms can be individually edited, added or deleted.

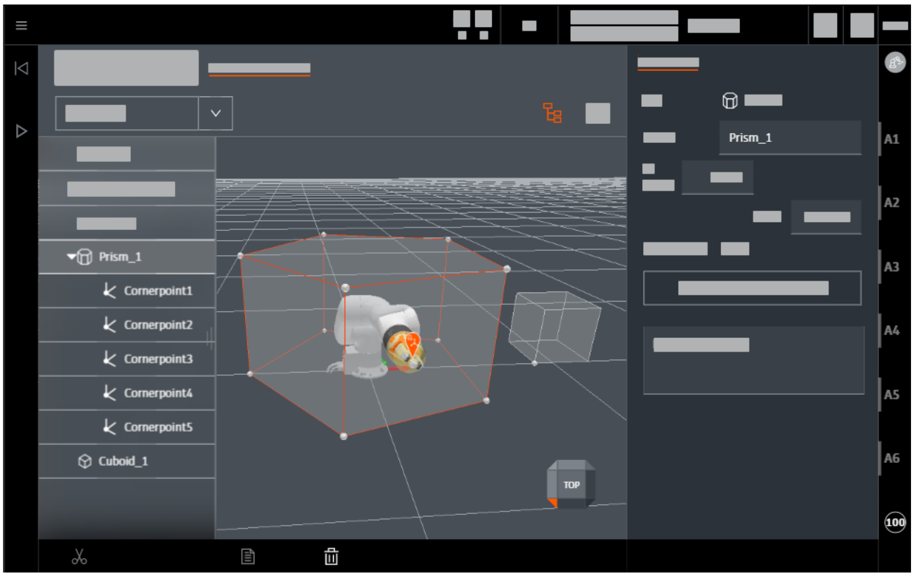


Fig. 8-6: Cuboid and Prism

Cuboids and prisms used in the safety configuration can only be edited in the **Safety Commissioning Engineer** user role. In order to be able to delete such spaces, they must first be removed in the safety configuration.

8.8 Configuring the Sick microScan3 laser scanner

In order to start up a SICK safety laser scanner, the laser scanner must be configured in the scene editor. For this, an object of type **SICK microScan3** is created in the scene editor.

In addition to the coordinates of the laser scanner in space, the checksum of the laser scanner must be entered. The checksum can be found in the scanner settings in the **Safety Designer** configuration tool under **Checksum of the configuration (function)**.

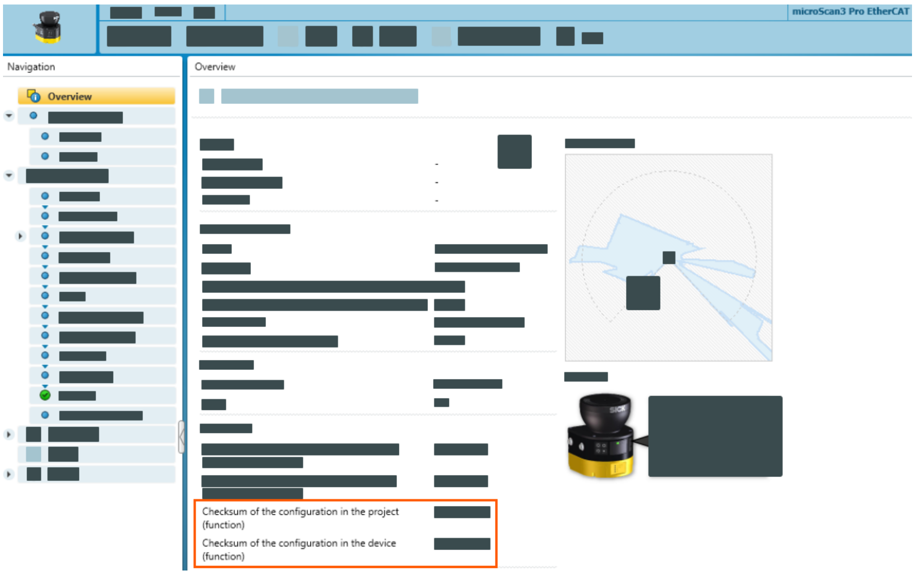


Fig. 8-7: Determining the checksum in Safety Designer

This checksum is automatically sent by the robot controller to the connected laser scanner. If the robot controller and laser scanner communicate correctly, the input and output signals of the laser scanner are displayed in the I/O configuration and can also be used in the safety configuration.

The laser scanner configured in the scene editor is automatically inserted into the bus topology of the I/O configuration as the first device on the KUKA Extension Bus. If the real laser scanner has been connected at a different position on the KUKA Extension Bus, proceed as follows:

- In the I/O configuration, start a bus scan on the KUKA Extension Bus (**Compare Online/Offline topology** button) and apply the result.

Further information about the bus scan can be found in the help function under “I/O configuration”.

8.9 Deleting objects from the 3D scene

- Objects can be deleted from the 3D scene using the recycle bin icon.
- Deleted objects cannot be restored.
- If an object that is selected for deleting has child objects assigned to it, there are various options:
  - Delete the object and all child objects.
  - Delete only the object itself. The child objects are automatically pushed up one level.

    The child objects maintain their absolute position in space. They can thus continue to be used in programs without restrictions.
- Objects that are used in the safety configuration (e.g. as a monitoring space) cannot be simply deleted. This applies to direct deletion and also if an object is to be deleted as a child object of a parent object.
  - The safety configuration must first be edited in such a way that the object is no longer used.
  - A dialog displays the relevant points in the safety configuration and it is possible to switch directly to the relevant point in the safety configuration.
  - The Safety Commissioning Engineer user role is required for this. Other user roles cannot delete or edit safety-relevant objects.

8.10 Cutting and pasting objects

- Frames, bases, cuboids and prisms can be cut from the object tree using the scissors icon.
- Cut objects are saved to a clipboard.
- Cut objects can be pasted back into the object tree from the clipboard.
- If an object has been cut unintentionally, there are several ways to undo the cut action:
  - Press the **Cancel** button in the pop-up message.
  - Press the scissors icon again.
  - Paste the cut object back in the same place.
- Objects that are used in the safety configuration (e.g. as a monitoring space) cannot be simply cut.
- The object tree can be restructured by cutting and pasting objects.
- A cut frame that is pasted under another **Parent** remains in the identical location, but the coordinate values change, as they refer to the **Parent**.
- If a **Parent** is cut, the child objects are also cut.

9 Safety configuration

The safety configuration defines the safety-oriented functions in order to integrate the industrial robot safely into the system. Safety-oriented functions serve to protect human operators when they work with the robot.

The system integrator determines the required safety functions using the risk assessment as a basis. The Safety Commissioning Engineer implements the safety specifications.

Verification of safety in the case of HRC
The safety configuration must sufficiently reduce the risks during collaborative operation (HRC). Death, severe injuries or damage to property may otherwise result.

- The system integrator must verify that the safety configuration meets the safety requirements for HRC systems.
- It is advisable to perform this verification in accordance with the information and instructions for operating collaborative robots in ISO/TS 15066.

Tasks of the Safety Commissioning Engineer:

- The Safety Commissioning Engineer configures the safety functions.
- The Safety Commissioning Engineer carries out safety acceptance and checks the safety functions for correct operation.
- The Safety Commissioning Engineer approves the safety configuration on the robot controller.
- The Safety Commissioning Engineer is responsible for ensuring that the safety configuration is only applied and approved on robots for which it is intended.

Qualification of the Safety Commissioning Engineer
The tasks of the Safety Commissioning Engineer may only be performed by personnel able to assess the work to be carried out and detect potential hazards. Death, severe injuries or damage to property may otherwise result. The following qualifications are required:

- Adequate specialist training, knowledge and experience
- Knowledge of the relevant operating or assembly instructions, knowledge of the relevant standards
- All persons working with the industrial robot must have read and understood the industrial robot documentation, including the safety chapter.

9.1 Safety configuration, general

On delivery, a safety configuration is preinstalled on the robot controller as standard. If this standard safety configuration is not sufficient for the planned applications, it can be removed and newly created, or edited and expanded.

The following basic configuration elements are available for creating the safety configuration:

- **Safety Rule Set**
- **Safety Rule**
- **Monitoring Block**

9.1.1 Safety Rule Set

Safety Rule Sets are higher-level structure elements of the safety configuration. They group together one or more Safety Rules that jointly implement a specific safety function or support a device. All Safety Rules contained in the Safety Rule Sets are processed in parallel by the safety system. The grouping of various Safety Rules into Safety Rule Sets thus has no effect on the execution of the configured safety monitoring functions.

One example is the triggering of several different safety reactions if a certain combination of Monitoring Blocks is violated, e.g. a safety stop and a safe output. For this purpose, 2 Safety Rules with identical Monitoring Block combinations can be included in the same Safety Rule Set.

9.1.2 Safety Rule

A Safety Rule links up to 6 Monitoring Blocks logically to one another. This makes it possible to implement complex safety monitoring functions.

An appropriate safety reaction must be configured for each Safety Rule:

- Stop, Brake or output signal

A Safety Rule is considered to be violated if all incorporated Monitoring Blocks are violated or invalid. The configured safety reaction is then triggered.

The violation status of a Safety Rule is displayed on the **RUNTIME** tab of the safety configuration editor.

(>>> *9.3 "Status of the current safety configuration" Page 139*)

9.1.3 Monitoring Block

Each Monitoring Block monitors an elementary, safety-relevant aspect of the system state, e.g. whether a safety-oriented input is set, automatic mode is active or the velocity of a specific robot axis exceeds a defined threshold.

A Monitoring Block is the smallest unit of monitoring in the safety system. Within a Safety Rule, several Monitoring Blocks can be combined to form more complex safety monitoring functions.

The violation status of a monitoring block is displayed on the **RUNTIME** tab of the safety configuration editor.

(>>> *9.3 "Status of the current safety configuration" Page 139*)

9.2 Safety configuration editor

To access the editor, select **Setup** > **Safety** in the Feature menu and switch to the **ENGINEERING** tab.

On the tab, the Safety Commissioning Engineer can edit and approve the safety configuration.

Fig. 9-1: Safety configuration editor

1	Feature menu
2	Add configuration element
3	Apply modified safety configuration
4	Approve safety configuration
5	Open safety settings
6	Display of grace period (safety stop canceled)
7	Cancel safety stop if safety configuration not approved
8	Main view
9	Parameter view

The editor contains the following elements:

- Main view: Shows the safety configuration as a tree structure.
- Parameter view: Displays the properties and parameters of the element selected in the configuration tree in the main view. The parameters can be edited.
  (>>> 9.2.1 "Editing parameters" Page 136)
- Buttons with the following functions (log-on as Safety Commissioning Engineer required):
  - Add configuration element to the safety configuration:
    - **Safety Rule Set**
    - **Safety Rule** (below the selected **Safety Rule Set**)
    - **Monitoring Block** (below the selected **Safety Rule**)
  - Select and remove configuration element from the tree (recycle bin).
  - Apply modified safety configuration (**Apply** button).
    (>>> 9.2.2 "Applying the safety configuration" Page 136)
  - Cancel safety stop if safety configuration not approved (**Unblock** button).
    The button is only available after a modified safety configuration has been applied. As soon as the safety configuration has been approved, the button is no longer displayed.
    (>>> 9.2.3 "Canceling the safety stop if the safety configuration is not approved" Page 137)

- Approve safety configuration (**Start Approval** button).
  (>>> *9.2.4 "Approving the safety configuration" Page 138*)
- Open safety settings (cogwheel).
  (>>> *9.2.6 "Safety Settings" Page 139*)

9.2.1 Editing parameters

Description

In the parameter view, the parameters of an element selected in the configuration tree can be edited:

- **Safety Rule Set**
  - Safety Rule Sets can be named and provided with a description.
- **Safety Rule**
  - Safety Rules can be named and provided with a description.
  - Safety Rules can be enabled or disabled using the **Status** button.
    This is a simple way to test different configuration variants during start-up.
  - An appropriate safety reaction must be configured for each Safety Rule.
    - Stop, Brake or output signal
- **Monitoring Block**
  - The definable monitoring parameters depend on the type of Monitoring Block.
  - Monitoring Blocks can be named.
    Exceptions:
    - Monitoring Blocks with only one available instance have a predefined name that cannot be changed.
    - Monitoring Block “**Input Signal**”: The localized name of the selected signal is used as the name of the Monitoring Block.
    - Monitoring Block “**Input Signal with Acknowledgement**”: The name of the Monitoring Block is composed of the localized name of the selected signal and the acknowledgement signal. First the input signal is named, then the acknowledgement signal, separated by a comma.
    - Monitoring Block “**Cartesian Monitoring Space**”: The localized name of the selected space shape is used as the name of the Monitoring Block.

Precondition

- “Safety maintenance” user role

9.2.2 Applying the safety configuration

Description

Each safety configuration has a unique activation ID. With this ID, the Safety Commissioning Engineer can unambiguously identify the safety configuration on the robot controller.

- If changes are made to the safety configuration on the **ENGINEERING** tab, the activation ID also changes.

- The modified safety configuration is no longer identical to the safety configuration currently running on the robot controller and displayed on the **RUNTIME** tab. This is indicated on the **RUNTIME** tab by a crossed-out activation ID.
- If the modified safety configuration is applied, the safety configuration on the **RUNTIME** tab is updated and the new activation ID is displayed.

> Any modification of the activation ID requires a complete check of all configuration parameters. It is not sufficient to check the modified parameters only.

- The safety configuration is not yet enabled when the changes have been applied.

  The robot cannot be moved. A safety stop 1 (path-maintaining) is active and all safe output signals are set to “0” (LOW level).

Precondition

- “Safety maintenance” user role

Procedure

1. Select the **Apply** button. A dialog is opened.
2. The following actions are available:
   - **Cancel**

     Closes the dialog without applying the changes.
   - **Apply**

     The validity of the modified safety configuration is checked.
     - If the safety configuration is valid, the safety controller restarts and the changes are applied.
     - If the safety configuration is invalid, the dialog is closed without the changes being applied. A pop-up message displays a corresponding error message.

9.2.3 Canceling the safety stop if the safety configuration is not approved

Description

The safety stop activated after a modified safety configuration has been applied can be canceled for a grace period of 4 hours. The deactivation of the safe output signals is also canceled during the grace period.

During the grace period, the robot can be moved in order to check the safety configuration.

Precondition

- “Safety maintenance” user role

Procedure

1. Select the **Unblock** button. A dialog is opened.
2. The following actions are available:
   - **Cancel**

     Closes the dialog without canceling the safety stop.
   - **Unblock**

     Starts the grace period and closes the dialog.

3. As long as the started grace period has not yet elapsed, a message with the remaining grace period is displayed in the safety configuration editor.
4. The grace period that is already running can be extended. To do so, select the **Unblock** button again and start the grace period from the beginning.

9.2.4 Approving the safety configuration

Description

The safety configuration must not be approved until the correctness of all configuration parameters has been successfully verified (safety acceptance).

Precondition

- “Safety maintenance” user role

Procedure

1. Select the **Start Approval** button. A dialog opens displaying the safety configuration report.

   The report contains all data that the Safety Commissioning Engineer must check before the safety configuration is approved.
2. The following actions are available:
   - **Download to USB**

     The safety configuration report can be downloaded.

     The button is active if a USB stick is connected to the smartPAD.
   - **Approve safety configuration**

     Approves the safety configuration.

     Before approval, the activation ID in the safety configuration report must be compared with the activation ID displayed on the **RUNTIME** tab. The IDs must match.
   - **Close**

     Closes the dialog.

9.2.5 Creating and downloading a safety configuration report

Description

The report can only be created for the safety configuration that is currently running on the robot controller. The report can also be downloaded to a USB stick and used, for example, to document the successful verification and validation of the safety configuration.

The report can be created from both tabs of the safety configuration editor. On the **ENGINEERING** tab, however, only in the context of enabling a safety configuration after any changes in the safety configuration have been applied.

Precondition

- USB stick is connected to the smartPAD.
- Report on the approval of a modified safety configuration on the **ENGINEERING** tab:
  - “Safety maintenance” user role

– Changes have been saved.
(>>> 9.2.2 "Applying the safety configuration" Page 136)

Procedure

1. In the Feature menu, select **Setup** > **Safety**.
2. On the **RUNTIME** tab, press the **Open Report** button.
   Or: On the **ENGINEERING** tab, press the **Start Approval** button.
   A dialog opens displaying the safety configuration report.
3. To download, select the **Download to USB** button.

9.2.6 Safety Settings

The Safety Commissioning Engineer can configure the following settings in the **Safety Settings** dialog:

- **Bus settings** tab: EtherCAT safety ID (or FSoE slave address) of the robot controller
  The current value of the EtherCAT safety ID is displayed. The value can be changed.
- **Workpieces** tab: Mass of the heaviest workpiece
  The mass of the heaviest workpiece that the robot might pick up must be configured if load-dependent Monitoring Blocks are used. The following Monitoring Blocks are load-dependent:
  – **Collision**
  – **Maximum TCP Force**

  Each of the load-dependent Monitoring Blocks checks whether the workpiece mass transferred to the safety controller with the load data exceeds the configured mass of the heaviest workpiece. If the mass of the heaviest workpiece is not configured, it is initialized with the default value (= 0.0 kg) and the Monitoring Block is violated when the workpiece load data are used in the safety controller.
  The current value of the heaviest workpiece is displayed on the **Workpieces** tab. The value can be changed by entering the desired value or using the **Apply from heaviest workpiece** button.
  The button sets the value to the maximum of all masses of the workpieces currently configured.

Further information about configuring workpieces can be found in the help function under “Payload configuration”.

The following actions can be selected in the **Safety Settings** dialog:

- **Cancel**
  Closes the dialog without applying the changes.
- **Apply**
  Accepts the changed settings.

9.3 Status of the current safety configuration

Description

The **RUNTIME** tab of the safety configuration editor shows the safety configuration currently running on the robot controller as a tree structure. The activation ID of the safety configuration and diagnostic states for Safety Rules and Monitoring Blocks are also displayed.

Procedure

- To access the tab, select **Setup** > **Safety** in the Feature menu.

Activation ID

If changes have been made to the safety configuration on the **ENGINEERING** tab, but have not yet been applied, the activation ID is crossed out.

Status of Safety Rules

The status is displayed in the line with the Safety Rule. Safety Rules can have the following statuses:

- Violated
  - Red icon with exclamation mark at the beginning of the line
  - Highlighted line with red background color

  A safety rule is violated if all of the contained monitoring blocks are violated or invalid. The configured safety reaction is then triggered.
- Muted
  - Gray icon with **Reaction Muted** display at the end of the line

  A Safety Rule is triggered if the safety reaction has been canceled through CRR mode.
- Not violated
  - No icon

  A Safety Rule is not violated if at least one of the contained monitoring blocks is not violated.

When a Safety Rule Set is collapsed in the tree view, the aggregated violation status of the Safety Rules contained in it is displayed.

Status of Monitoring Blocks

The status is displayed on the Monitoring Block. Monitoring Blocks can have the following statuses:

- Violated
  - Red icon with exclamation mark
- Invalid
  - Yellow icon with exclamation mark

  There is an error or the desired aspect of the system state cannot be monitored. A sensor error, for example, may be the cause.
- Not violated
  - No icon

The status of all Monitoring Blocks for a safety rule is also displayed in the line with the safety rule. Red/yellow dots indicate the number and sequence of the violated/invalid Monitoring Blocks.

9.4 Safety reactions

An appropriate safety reaction is defined for each Safety Rule. This reaction must take place in the event of an error and switch the system to a safe state.

The following safety reactions can be configured:

- Safety stop 1 (path-maintaining) is triggered.

  The manipulator is braked on the programmed path. At standstill, the drives are switched off and the mechanical brakes are applied.

  The safety controller monitors the braking process. After a duration of 1.5 s at the latest, or less depending on the robot type, the brakes are applied and the drives are switched off. In the event of an error, the drives are switched off and the mechanical brakes are applied immediately (safety stop 0).

WARNING

Risk of injury due to safety stop 1 (path-maintaining) in safety functions for detecting crushing situations

In crushing situations, safety stop 1 (path-maintaining) can lead to higher crushing forces due to the controlled stopping on a planned braking path. For this reason, safety stop 1 (path-maintaining) is not suitable for safety functions for detecting crushing situations, e.g. by means of the Monitoring Block **Maximum TCP Force**.

- Use safety stop 1 (HRC) for safety functions for detecting crushing situations.

- Safety stop 1 (HRC) is triggered.

  The manipulator switches to compliance control with increased damping in order to reduce the acting external forces and to come to a standstill. The manipulator leaves the programmed path in this case. At standstill, the drives are switched off and the mechanical brakes are applied.

  The safety controller monitors the braking process. Specifically, the Cartesian velocity and the external axis torques are monitored. In the event of an error, the drives are switched off and the mechanical brakes are applied immediately (safety stop 0).

  Conditions for use of the “Safety stop 1 (HRC)” reaction:

  - Only compatible with Safety Rules that contain at least one of the following Monitoring Blocks:
    - **Collision**
    - **Maximum TCP Force**

- Brake is triggered.

  The manipulator is braked on the programmed path as long as the Safety Rule is violated. The safety controller monitors the braking process. In the event of an error, the drives are switched off and the mechanical brakes are applied immediately (safety stop 0).

  Unlike a safety stop 1, the braking process does not lead to a complete standstill or deactivation of the drives. The velocity reduction and safety-oriented monitoring of the braking process are only carried out until the Safety Rule is no longer violated.

  Conditions for use of the “Brake” reaction:

  - Only compatible with Safety Rules that contain a Monitoring Block **Maximum Cartesian Velocity**
  - Not compatible with Safety Rules that contain a Monitoring Block **Timer Expired**
  - Not compatible with jogging

If the “Brake” reaction is triggered during jogging, no automatic braking with the drives occurs. If the velocity does not decrease, the safety controller detects an error and triggers a safety stop 0.

- Safety-oriented output is set to “0” (LOW level).

The safety reactions can be used for any number of Safety Rules. The safety system concurrently executes all the Safety Rules contained in the safety configuration.

A safety reaction is triggered as soon as one of the Safety Rules using this reaction is violated. This makes it possible, for example, to inform a higher-level controller about a safety-oriented output if specific errors occur.

It is possible to trigger different safety reactions if a specific combination of Monitoring Blocks is violated. For example, both a safety stop and an output signal can be triggered. For this, 2 Safety Rules must be configured with an identical combination of Monitoring Blocks.

9.4.1 Behavior of safety-oriented outputs

The following points must be observed when using Safety Rules with a safety-oriented output as a reaction:

- All the safety-oriented outputs use LOW as the safe state.
- If a Safety Rule is violated that uses a safety-oriented output as a reaction, the output is immediately set to LOW.
- Once the violation state has been resolved, the output is not reset to HIGH until the following conditions are met:
  - The Safety Rule is not violated for at least 24 ms. The reaction to resolution of the violation state is always delayed.
  - If the discrete safety interface is used:

    The output has the LOW level for at least 200 ms beforehand. If the LOW level has not yet been active for this time, the level is not changed to HIGH until the period of 200 ms has elapsed.
  - If the Ethernet safety interface is used:

    The output has the LOW level for at least 500 ms beforehand. If the LOW level has not yet been active for this time, the level is not changed to HIGH until the period of 500 ms has elapsed.
- The level change from LOW to HIGH does not have to be acknowledged.
- Connection errors are automatically acknowledged by the safety controller at safety-oriented inputs/outputs once the connection has been restored. The output level can therefore switch from LOW to HIGH after restoration of the connection.

WARNING

Danger to life and limb due to automatic restart of peripheral devices

Using Safety Rules with a safety-oriented output as a reaction may result in an automatic restart of peripheral devices connected to this output. Death, severe injuries or damage to property may result.

- The Safety Commissioning Engineer must take appropriate measures to ensure that no automatic restart is possible.

9.5 Configuration of safety-oriented tools

The following safety-oriented tool parameters are not configured in the safety configuration editor, but in other editors:

- Load data

  The load data can be configured both in the tool configuration editor and in the scene editor. The load data are taken into consideration when the following Monitoring Blocks are used:

  - **Collision**
  - **Maximum TCP Force**
- TCP for monitoring the tool orientation

  The TCP can be configured both in the tool configuration editor and in the scene editor. The TCP can be selected as a tool orientation frame when configuring the following Monitoring Block:

  - **Tool Orientation Monitoring**

  The same TCP is monitored in all Monitoring Blocks of the type **Tool Orientation Monitoring**.
- Safety spheres

  Up to 6 spheres can be configured in the scene editor for modeling the tool geometry. The spheres are taken into consideration when the following Monitoring Blocks are used, provided they are configured as a structure to be monitored:

  - **Maximum Cartesian Velocity**
  - **Cartesian Monitoring Space**
- Force interaction area

  A force interaction area can be configured in the scene editor. The area is defined as a sphere that contains all the points of a safety-oriented tool where expected external forces can occur. The area is used by the following Monitoring Block:

  - **Maximum TCP Force**

> Further information can be found in the help function under “3D scene” or under “Payload configuration”.

9.6 Configuration of further safety parameters in scene

The following additional safety parameters can be configured in the scene editor:

- Monitoring spaces

  Monitoring spaces can be created and configured as cuboids or prisms in the scene editor. All created cuboids and prisms can be selected as the space to be monitored when the following Monitoring Blocks are used:

  - **Cartesian Monitoring Space**
- Installation position and orientation of the robot

  Relevant for the monitoring behavior of the following Monitoring Blocks:

  - **Cartesian Monitoring Space**
  - **Tool Orientation Monitoring**
  - **Collision**
  - **Maximum TCP Force**

  If the robot is selected in the 3D or tree view of the scene editor, the position and alignment of the robot can be edited in the parameter editor.

Further information about the configuration of these parameters can be found in the help function under “3D scene”.

9.7 Safety interfaces

Various safety interfaces are available for exchanging safe signals between a higher-level controller and a robot controller.

- The safety-oriented inputs of these interfaces can be used for connecting safety devices, e.g. external EMERGENCY STOP devices or safety gates, and for evaluating the corresponding input signals.
- The safety-oriented outputs of these interfaces can be used to signal the violation of Safety Rules.

9.7.1 Discrete safety interfaces

The robot controller provides the following discrete safety interfaces:

- XG11.1 (KSP-300)
  - 2 safety-oriented inputs
  - 1 safety-oriented output
- XG58 (KSP-300)
  - 2 safety-oriented inputs

Use

- In the standard safety configuration, interface XG11.1 is used for connecting an external EMERGENCY STOP device and a safety gate. Output XG11.1 is used to communicate the state of the EMERGENCY STOP device on the smartPAD to the robot controller.
- Interface XG58 is not used in the standard safety configuration.

Further information about the safety interfaces is contained in the assembly instructions of the robot controller in the “Planning” chapter.

9.7.2 Ethernet safety interfaces

The robot controller provides the following Ethernet safety interface:

- EtherCAT/FSoE

Use

The interface can be used for connecting the EL6695-1001 EtherCAT bridge terminal. The terminal is connected to the KEI interface of the robot controller:

- “Performance” system board: interface XF8

Configuration

In order to start up the EtherCAT bridge terminal, the EtherCAT safety ID for establishing the FSoE communication with this device must be set in the safety settings of the safety configuration.
(>>> *9.2.6 "Safety Settings" Page 139*)

Further information about the start-up and configuration of the EtherCAT bridge terminal can be found in the help function under “I/O configuration”.

9.7.3 Safety interface for external laser scanner

A laser scanner of type **SICK microScan3 Pro** can be connected to the robot controller via the EtherCAT/FSoE Ethernet safety interface.

The SICK safety laser scanner is connected to the KEI EtherCAT interface of the robot controller:

- “Performance” system board: interface XF8

Configuration

The following settings in the configuration of the laser scanner are required for use with the system software iiQKA.OS:

- Set the FSoE address of the laser scanner to 777. The system software only supports this FSoE address.
- Select the small process data object (PDO) for the FSoE PDO that is used. The system software supports the module “Small process data set”.
- It is recommended not to use the internal restart interlock of the laser scanner. The system software does not support the resetting of the lock via a network input signal from the scanner.
- Configure the response to a loss of connection as “Automatic start after reconnection”. The system software does not support a commanded restart via the network.

> For start-up, the laser scanner must be integrated into the 3D scene. Further information can be found in the help function under “3D scene”.

Restart interlock

A restart interlock, e.g. to prevent the robot from restarting when a protective field is entered, can be implemented using the Monitoring Block **Input Signal with Acknowledgement**. After an interruption of the protective field, this monitoring function remains violated until this interruption has been eliminated and a separate safe acknowledgement signal is set. For example, the acknowledgement signal can be set by means of a connected pushbutton outside the danger zone.

No support for multiple monitoring functions

The system software iiQKA.OS does not support the internal function of the Sick safety laser scanner to switch between multiple monitoring cases. It only supports monitoring case 1, which is permanently active.

As an alternative to the monitoring cases, the system software offers the Safety Rule mechanism. A Safety Rule can be used to change the system reaction to interruption of a protective field.

9.8 Configuration of safe signals

Description

The safe signals are configured in the I/O configuration editor. The available physical I/Os, the signal mapping and the bus topology are specified there.

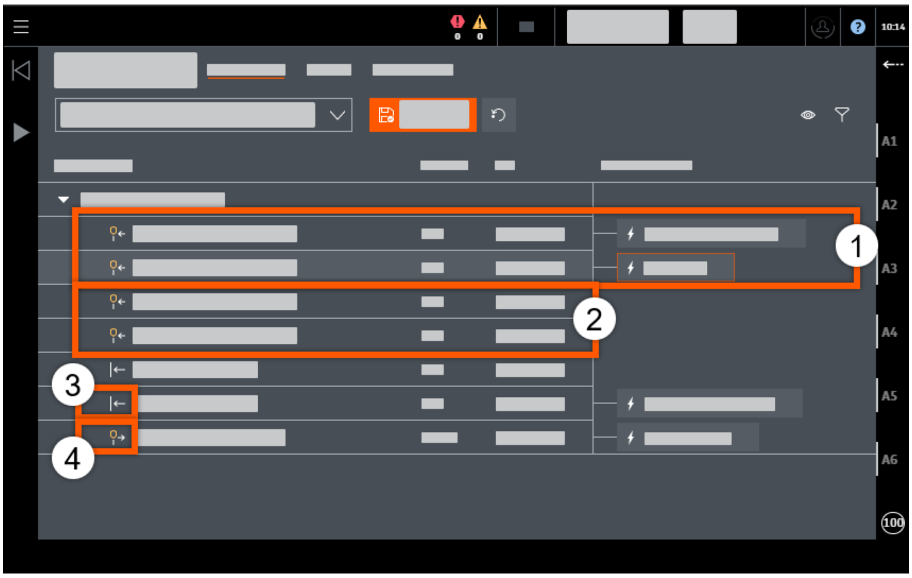


Fig. 9-2: List of available physical I/Os

1 Mapped safety-oriented I/Os
2 Non-mapped safety-oriented I/Os
3 Icon for non-safety-oriented I/Os
4 Icon for safety-oriented I/Os

As soon as safety-oriented I/Os have been mapped to a signal, they can be used in the safety configuration. This only applies to I/Os that can be used for connecting external devices to the robot controller.

> **i** Further information about the mappable safety-oriented I/Os can be found in the assembly instructions of the robot controller.

There are also internal safe signals of the KUKA smartPAD pro and the LBR iisy Commander (if present). These signals are not displayed in the I/O configuration editor. They are predefined and can be selected directly in the safety configuration.

Procedure

- To open the editor, select **Setup** > **I/O** from the Feature menu.

> **i** Further information about mapping the signals in the I/O configuration editor can be found in the help function under “I/O configuration”.

9.9 Use of safe signals in the safety configuration

Description

Signals can be used in the safety configuration as follows:

- As parameters of a Safety Rule with an output as a safety reaction
  If the Safety Rule is violated, the signal for the output is set to LOW.
- As parameters of a Monitoring Block
  The LOW state is interpreted as a triggering state.

Monitoring of multiple enabling devices

The following Monitoring Blocks can be used to monitor 3-step enabling devices of up to 3 devices in each case:

- **Enabling Inactive**
- **Manual Guidance Inactive**

2 safe input signals must be configured per enabling device (device). One of the safe input signals supplies the signal from the enabling switches and the other safe input signal supplies the signal from the panic switches.

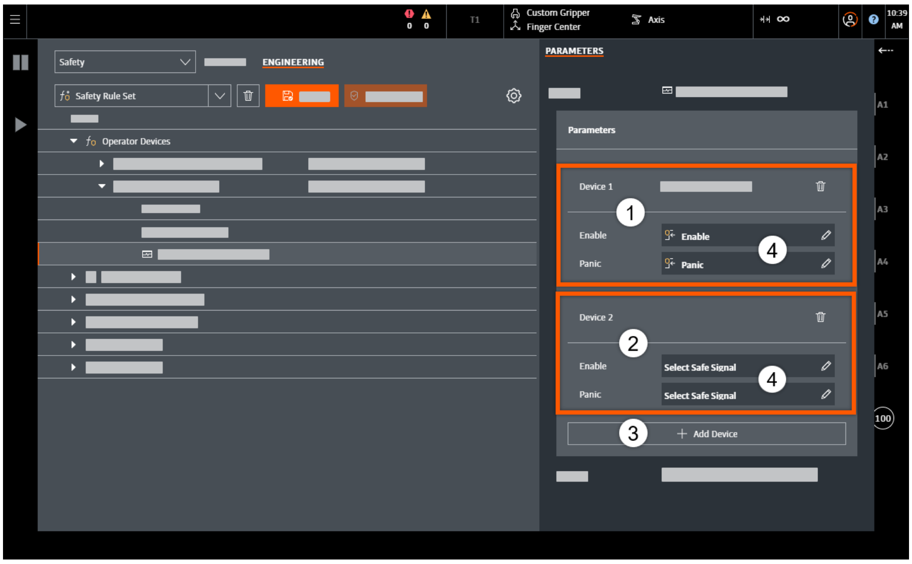


Fig. 9-3: Monitoring of multiple enabling devices

1	Device 1 (safe signals selected)
2	Device 2 (no safe signals selected)
3	**Add Device** button
4	Buttons for opening/editing the signal selection

Signal selection

Only signals that are assigned to a safety-oriented I/O can be selected. No signal is preselected.

- The **Select Safe Signal** button opens the signal selection. All available signals are displayed.
- After successful selection, the signal name is displayed on the button.
- The selection can be changed. The signal selection is opened again by tapping on the signal name or on the pencil icon.

9.10 Overview of Monitoring Blocks

Monitoring Blocks for evaluating the operating mode

Monitoring Block	Description
Test Mode	Checks whether a test mode (T1, CRR) is active
Automatic Mode	Checks whether an automatic mode (AUT) is active
Reduced Speed Mode	Checks whether an operating mode with reduced velocity (T1, CRR) is active
High Speed Mode	Checks whether an operating mode with high velocity (AUT) is active.

(>>> *9.12 "Evaluating the operating mode" Page 150*)

Monitoring Block for evaluating active safety stops

Monitoring Block	Description
Safety Stop	Checks whether a safety stop is active

(>>> *9.13 "Monitoring Block “Safety Stop”" Page 151*)

Monitoring Blocks for monitoring enabling devices

Monitoring Block	Description
Enabling Inactive	Checks whether the enabling signal has not been issued on a teach pendant
Manual Guidance Inactive	Checks whether the enabling signal has not been issued on a hand guiding device
Manual Guidance Active	Checks whether the enabling signal has been issued on a hand guiding device

(>>> *9.15 "Monitoring of enabling devices" Page 153*)

Monitoring Blocks for evaluating the confirmation status of mastering and joint torque sensor calibration

Monitoring Block	Description
Mastering Not Approved	Checks whether the mastering of the axis position sensors of a kinematic system is confirmed
JTS Adjustment Not Approved	Checks whether the calibration of the joint torque sensors of a kinematic system is confirmed

(>>> *9.16 "Evaluation of the confirmation status of mastering and joint torque sensor calibration" Page 155*)

Monitoring Blocks for monitoring safety-oriented inputs

Monitoring Block	Description
Input Signal	Monitors the signal at a safety-oriented input (e.g. on an EMERGENCY STOP device)
Input Signal with Acknowledgement	Monitors the signal at a safety-oriented input (e.g. on a safety gate) which has to be acknowledged via a second input signal.

(>>> *9.17 "Monitoring of safety-oriented inputs" Page 156*)

Monitoring Blocks for velocity monitoring

Monitoring Block	Description
Maximum Axis Velocity	Monitors the velocity of an axis
Maximum Cartesian Velocity	Monitors the Cartesian translational velocity at defined points of a kinematic system

(>>> *9.18 "Velocity monitoring functions" Page 158*)

Monitoring Blocks for space monitoring

Monitoring Block	Description
Axis Work Range	Checks whether the position of one of the rotational axes of a kinematic system is within a permissible axis range
Axis Protection Range	Checks whether the position of one of the rotational axes of a kinematic system is within a non-permissible axis range

Monitoring Block	Description
Cartesian Monitoring Space	Checks whether a part of the monitored structure of a kinematic system is located inside or outside of a Cartesian monitoring space • A Cartesian monitoring space can be configured as a cuboid or prism. • A Cartesian monitoring space can be defined as a workspace in which the robot must be located, or as a protected space that it must not enter.

(>>> *9.19 "Space monitoring functions" Page 160*)

Monitoring Block for monitoring the tool orientation

Monitoring Block	Description
Tool Orientation Monitoring	Checks whether the orientation of the tool of a kinematic system is inside a permissible space

(>>> *9.20 "Monitoring of tool orientation" Page 165*)

Monitoring Blocks for monitoring forces and axis torques (HRC)

Monitoring Block	Description
Collision	Monitors the external axis torques of all axes of a kinematic system **Note:** The external axis torque is defined as that part of the torque on an axis which is generated by the forces/torques occurring as the robot (and/or the tools) interact(s) with its environment.
Maximum TCP Force	Monitors the external force acting on the tool or the robot flange of a kinematic system (on a point within the configured force interaction area)

(>>> *9.21 "Monitoring of forces and axis torques" Page 168*)

Monitoring Block for switching a delay

Monitoring Block	Description
Timer Expired	Delays the triggering of the reaction of a Safety Rule by a specified time

(>>> *9.22 "Monitoring Block “Timer Expired”" Page 172*)

9.11 Confirmation of mastering and calibration of the joint torque sensors

The confirmation checks and confirms the mastering of the axis position sensors and the calibration of the joint torque sensors of a kinematic system.

> Further information about performing the confirmation can be found in the help function under “General operation”.

The safety integrity of the following Monitoring Blocks is only assured if the mastering and/or joint torque sensor calibration have been confirmed successfully.

Monitoring Block	Confirmation of mastering	Confirmation of joint torque sensor calibration
Axis Work Range	✓	✗
Axis Protection Range	✓	✗
Maximum Cartesian Velocity	✓	✗
Cartesian Monitoring Space	✓	✗
Tool Orientation Monitoring	✓	✗
Collision	✓	✓
Maximum TCP Force	✓	✓

The following events cause confirmation to be lost. The safety integrity of the above-mentioned Monitoring Blocks is thus no longer assured. Confirmation of the mastering and/or confirmation of the calibration of the joint torque sensors must be performed again:

- Robot controller is rebooted.
- New/modified safety configuration is applied.
- Confirmation of the mastering of an axis has failed.
- Confirmation of the joint torque sensor calibration of an axis has failed.
- Maximum torque of a joint torque sensor is exceeded.
- Only confirmation of mastering: the axis position is remastered.
- Only confirmation of joint torque sensor calibration: sensors are recalibrated or reset to the factory settings.

The loss of confirmation does not result in a violation of the Monitoring Blocks. The kinematic system can still be moved.

After these events, the Monitoring Blocks are only violated if the mastering confirmation for an axis or the confirmation of calibration of a joint torque sensor fails.

The following Monitoring Blocks can be used to evaluate the status of the confirmation:

- **Mastering Not Approved**
- **JTS Adjustment Not Approved**

If mastering or joint torque sensor calibration is not confirmed, the safe state can be initiated as a reaction.

(>>> *9.16 "Evaluation of the confirmation status of mastering and joint torque sensor calibration" Page 155*)

9.12 Evaluating the operating mode

9.12.1 Monitoring Block “Test Mode”

The Monitoring Block **Test Mode** can be used to check whether a test mode (T1, CRR) is active.

The Monitoring Block is required for safety monitoring functions that are dependent on the operating mode, e.g. operator safety.

The Monitoring Block is violated if a test mode (T1, CRR) is active.

9.12.2 Monitoring Block “Automatic Mode”

The Monitoring Block **Automatic Mode** can be used to check whether an automatic mode (AUT) is active.

The Monitoring Block is required for safety monitoring functions that depend on the operating mode.

The Monitoring Block is violated if an automatic mode (AUT) is active.

9.12.3 Monitoring Block “Reduced Speed Mode”

Description

The Monitoring Block **Reduced Speed Mode** can be used to check whether an operating mode with reduced velocity (T1, CRR) is active.

In combination with other Monitoring Blocks, the Monitoring Block can be used to disable the reaction of a Safety Rule in the case of an operating mode with high velocity.

The Monitoring Block is violated if an operating mode with reduced velocity (T1, CRR) is active.

Example

(>>> *9.18.3 "Velocity monitoring in T1 and CRR" Page 159*)

9.12.4 Monitoring Block “High Speed Mode”

The Monitoring Block **High Speed Mode** can be used to check whether an operating mode with high velocity (AUT) is active.

In combination with other Monitoring Blocks, the Monitoring Block can be used to disable the reaction of a Safety Rule in the case of an operating mode with reduced velocity.

The Monitoring Block is violated if an operating mode with high velocity (AUT) is active.

9.13 Monitoring Block “Safety Stop”

Description

The Monitoring Block **Safety Stop** checks whether a safety stop is active.

The Monitoring Block is required, for example, in the case of a safety stop to set an output that affects the connected peripheral equipment.

The Monitoring Block is violated if a safety stop is active.

> ℹ The “Brake” safety reaction is not a safety stop and does not cause a violation.

Example

Safety Rule for switching off a tool

A tool (e.g. a laser) is switched off via a safety-oriented output if the following conditions are met:

- Robot stops with a safety stop.
- At the same time, the operator safety is violated (e.g. with the safety gate open).

Safety Rule		
Monitoring Block 1	**Monitoring Block 2**	**Reaction**
Safety Stop	**Input Signal** (safety gate)	**Safe Output**

9.14 Monitoring of operator devices

The KUKA smartPAD pro and the LBR iisy Commander are used as standard for operator control of the robot.

The preconfigured Safety Rule Set “Operator Devices” is essential for the integration of operator devices. It contains the following Safety Rules:

- “Emergency Stop Operator Device”
  (>>> *9.14.1 "Monitoring of the EMERGENCY STOP device on the smartPAD pro" Page 152*)
- “Enabling in Test Mode”
  (>>> *9.14.2 "Monitoring of enabling in T1/CRR" Page 152*)

9.14.1 Monitoring of the EMERGENCY STOP device on the smartPAD pro

The Safety Rule “Emergency Stop Operator Device” is used to monitor the EMERGENCY STOP device on the smartPAD pro. If the EMERGENCY STOP is pressed, a safety stop 1 (path-maintaining) is triggered.

Safety Rule Set “Operator Devices”	
Safety Rule “Emergency Stop Operator Device”	
Monitoring Block 1	**Reaction**
Input Signal	**Stop 1 on Path**

9.14.2 Monitoring of enabling in T1/CRR

The enabling devices on the smartPAD and LBR iisy Commander are monitored using the Safety Rule “Enabling in Test Mode”. In the following cases, a safety stop 1 (path-maintaining) is triggered in T1 and CRR modes:

- All enabling switches of both operator devices are released or one of their enabling switches is fully pressed (panic position).
- An enabling switch on the Commander and an enabling switch on the smartPAD are simultaneously held in the center position.

Safety Rule Set “Operator Devices”			
Safety Rule “Enabling in Test Mode”			
Monitoring Block 1	**Monitoring Block 2**	**Monitoring Block 3**	**Reaction**
Test Mode	**Enabling Inactive**	**Manual Guidance Inactive**	**Stop 1 on Path**

9.15 Monitoring of enabling devices

9.15.1 Monitoring Block "Enabling Inactive"

Description

The Monitoring Block **Enabling Inactive** can be used to monitor 3-step enabling devices of up to 3 teach pendants. For each enabling device, 2 safe input signals must be configured, one of which supplies the signal of the enabling switches and one the signal of the panic switches.

The Monitoring Block implements the following normative requirements and measures against foreseeable misuse:

- After an enabling switch has been pressed down fully, the signal will not be issued if the switch is released to the center position.
- The signal is canceled in case of a stop request. To issue the signal again, the enabling switch must be released and pressed again.
- The signal is only issued 100 ms after the enabling switch has been pressed.

The following must be taken into consideration when using multiple enabling switches of one or more enabling devices:

- If multiple enabling switches of an enabling device are held simultaneously in the center position, it is not possible to distinguish whether one of them is intentionally released or unintentionally released as the result of an accident. The enabling signal is not canceled until all enabling switches have been released or one of the enabling switches is fully pressed.
- If the enabling switches of different enabling devices are pressed simultaneously, e.g. an enabling switch on the smartPAD and an enabling switch on the hand guiding device, a safety stop 1 (path-maintaining) is triggered.
- If the enabling switches of the enabling devices of different teach pendants configured in the Monitoring Block **Enabling Inactive** are pressed simultaneously, a safety stop 1 (path-maintaining) will be triggered.

The Monitoring Block is violated in the following cases:

- The input signal that supplies the signal of the enabling switches is LOW (state "0"). This means that no enabling switch is pressed on the teach pendant.
- The input signal that supplies the signal of the panic switches is LOW (state "0"). This means that an enabling switch is fully pressed on the teach pendant.

Parameter

Parameter	Description
Enable	Safe input signal used for the enabling switches of the enabling device A predefined input signal is available for the KUKA smartPAD.
Panic	Safe input signal used for the panic switches of the enabling device A predefined input signal is available for the KUKA smartPAD.

9.15.2 Monitoring Block “Manual Guidance Inactive”

Description

The Monitoring Block **Manual Guidance Inactive** can be used to monitor 3-step enabling devices of up to 3 hand guiding devices. For each enabling device, 2 safe input signals must be configured, one of which supplies the signal of the enabling switches and one the signal of the panic switches.

The Monitoring Block implements the following normative requirements and measures against foreseeable misuse:

- After an enabling switch has been pressed down fully, the signal will not be issued if the switch is released to the center position.
- The signal is canceled in case of a stop request. To issue the signal again, the enabling switch must be released and pressed again.
- The signal is only issued 100 ms after the enabling switch has been pressed.

The following must be taken into consideration when using multiple enabling switches of one or more enabling devices:

- If multiple enabling switches of an enabling device are held simultaneously in the center position, it is not possible to distinguish whether one of them is intentionally released or unintentionally released as the result of an accident. The enabling signal is not canceled until all enabling switches have been released or one of the enabling switches is fully pressed.
- If the enabling switches of different enabling devices are pressed simultaneously, e.g. an enabling switch on the smartPAD and an enabling switch on the hand guiding device, a safety stop 1 (path-maintaining) is triggered.
- If the enabling switches of the enabling devices of different hand guiding devices configured in the Monitoring Block **Manual Guidance Inactive** are pressed simultaneously, a safety stop 1 (path-maintaining) will be triggered.

The Monitoring Block is violated in the following cases:

- The input signal that supplies the signal of the enabling switches is LOW (state “0”). This means that no enabling switch is pressed on the hand guiding device.
- The input signal that supplies the signal of the panic switches is LOW (state “0”). This means that an enabling switch is fully pressed on the hand guiding device.

Parameter

Parameter	Description
Enable	Safe input signal used for the enabling switches of the enabling device For robots equipped with a hand guiding device, e.g. LBR iisy Commander, a predefined input signal is available.
Panic	Safe input signal used for the panic switches of the enabling device For robots equipped with a hand guiding device, e.g. LBR iisy Commander, a predefined input signal is available.

9.15.3 Monitoring Block “Manual Guidance Active”

Description

The Monitoring Block **Manual Guidance Active** checks whether the enabling signal has been issued on a hand guiding device.

The Monitoring Block can be used in a Safety Rule to activate another Monitoring Block. This can be a Cartesian velocity monitoring function, for example, which is then active during manual guidance.

The Monitoring Block is violated if the enabling signal for manual guidance has been issued:

- The configured input signals of the Monitoring Block **Manual Guidance Inactive** are used for evaluating the Monitoring Block.
- The Monitoring Block constitutes an inversion of the Monitoring Block **Manual Guidance Inactive**:
  - The Monitoring Block **Manual Guidance Active** is violated if the Monitoring Block **Manual Guidance Inactive** is not violated.
  - If the Monitoring Block **Manual Guidance Active** is invalid, the Monitoring Block **Manual Guidance Inactive** is also invalid.

Example

(>>> *9.18.4 "Velocity monitoring during manual guidance" Page 159*)

9.16 Evaluation of the confirmation status of mastering and joint torque sensor calibration

9.16.1 Monitoring Block “Mastering Not Approved”

Description

The Monitoring Block **Mastering Not Approved** can be used to check whether the mastering of all axis position sensors of a monitored kinematic system has been confirmed.

The Monitoring Block is violated if the mastering of one or more axes of the monitored kinematic system is not confirmed.

Example

Safety Rule for monitoring the confirmation status of the mastering

The confirmation status of the mastering is monitored in the operating modes with high velocity. This ensures that the robot cannot be moved in the operating modes with high velocity if mastering is not confirmed.

If the following condition is met, a safety stop 1 (path-maintaining) is executed:

- Mastering of at least one axis has not been confirmed and an operating mode with high velocity is active.

Safety Rule		
Monitoring Block 1	**Monitoring Block 2**	**Reaction**
High Speed Mode	**Mastering Not Approved**	**Stop 1 on Path**

9.16.2 Monitoring Block “JTS Adjustment Not Approved”

Description

The Monitoring Block **JTS Adjustment Not Approved** can be used to check whether the calibration of all joint torque sensors of a monitored kinematic system has been confirmed.

The Monitoring Block is violated if the calibration of one or more joint torque sensors of the monitored kinematic system is not confirmed.

9.17 Monitoring of safety-oriented inputs

Safety equipment, such as local and external EMERGENCY STOP devices, light curtains and safety gates, can be connected to safety-oriented inputs.

The following Monitoring Blocks are available for monitoring the associated input signals:

- **Input Signal**
  (>>> *9.17.1 "Monitoring Block “Input Signal”" Page 156*)
- **Input Signal with Acknowledgement**
  (>>> *9.17.2 "Monitoring Block “Input Signal with Acknowledgement”" Page 157*)

9.17.1 Monitoring Block “Input Signal”

Description

The Monitoring Block **Input Signal** can be used to monitor the status of an input signal.

The Monitoring Block can be implemented as follows, for example:

- Monitor safety equipment that is connected via a safety-oriented input.
- Deactivate monitoring via a safety-oriented input.
- Trigger a stop via a safety-oriented input.

Parameter	Description
Input Signal	Input signal to be monitored

The Monitoring Block is violated if the input signal is LOW (state “0”).

Example 1

Predefined Safety Rule “Safety Door” in the Safety Rule Set “Standard Safety Interface” (standard safety configuration)

If the following conditions apply, a safety stop 1 (path-maintaining) is executed:

- Operating mode is AUT.
- Safety gate connected via XG11.1 is open.
- Enabling switches on the Commander are not actuated.

Safety Rule Set "Standard Safety Interface"			
Safety Rule "Safety Door"			
Monitoring Block 1	**Monitoring Block 2**	**Monitoring Block 3**	**Reaction**
Automatic Mode	**Input Signal** (safety gate)	**Manual Guidance Inactive**	**Stop 1 on Path**

Example 2

Predefined Safety Rule "Emergency Stop External" in the Safety Rule Set "Standard Safety Interface" (standard safety configuration)

If the following condition is met, a safety stop 1 (path-maintaining) is executed:

- External EMERGENCY STOP device connected via XG11.1 is pressed.

The Safety Rule is disabled by default. In order to be able to use the functionality, the Safety Rule must be enabled.

Safety Rule Set "Standard Safety Interface"	
Safety Rule "Emergency Stop External"	
Monitoring Block 1	**Reaction**
Input Signal (EMERGENCY STOP)	**Stop 1 on Path**

9.17.2 Monitoring Block "Input Signal with Acknowledgement"

Description

The Monitoring Block **Input Signal with Acknowledgement** can be used to monitor the state of an input signal which has to be acknowledged via a second input signal. The Monitoring Block can be implemented as follows, for example:

- Monitoring of a safety device with acknowledgement, e.g. safety gate/light curtain with acknowledgement via a pushbutton

Parameter	Description
Input Signal	Input signal to be monitored
Ack. Signal	Input signal to be used for acknowledgement

The Monitoring Block is violated in the following cases:

- Input signal is LOW (state "0").
- Input signal is HIGH (state "1") but has not yet been confirmed by the acknowledgement signal.

Example

Safety Rule for monitoring a safety gate with acknowledgement

If the following condition is met, a safety stop 1 (path-maintaining) is executed:

- Safety gate is open while an operating mode with high velocity is active.

The safety stop is not canceled until closing of the safety gate has been confirmed via the acknowledgement signal.

Safety Rule		
Monitoring Block 1	**Monitoring Block 2**	**Reaction**
Input Signal with Acknowledgement	**High Speed Mode**	**Stop 1 on Path**

9.18 Velocity monitoring functions

9.18.1 Monitoring Block “Maximum Axis Velocity”

The Monitoring Block **Maximum Axis Velocity** can be used to monitor the velocity of an axis.

The Monitoring Block is violated if the absolute velocity of the monitored axis exceeds the configured limit value.

Parameter	Description
Monitored Axis	Axis to be monitored
Maximum Velocity	Maximum velocity at which the monitored axis may move in the positive and negative direction of rotation

9.18.2 Monitoring Block “Maximum Cartesian Velocity”

The Monitoring Block **Maximum Cartesian Velocity** can be used to monitor the Cartesian velocity at defined points of a kinematic system.

The Monitoring Block is violated in the following cases:

- Cartesian velocity exceeds the configured limit value at one or more points of the monitored kinematic system.

The Monitoring Block becomes invalid in the following cases:

- The position of one or more axes is unmastered.
- Confirmation of mastering of one or more axes has failed.

> **i** If the Monitoring Block is violated due to loss of mastering, it is necessary to switch to CRR mode in order to be able to move the robot again and master it.

Parameter	Description
Structure	Structure to be monitored • **Robot and Tool**: The center points of the robot axes and the safety spheres on the tool are monitored. • **Robot**: The center points of the robot axes are monitored. • **Tool**: The center points of the safety spheres on the tool are monitored.
Maximum Velocity	Maximum Cartesian velocity that must not be exceeded at any of the monitored points

The following points must be observed when using the Monitoring Block **Maximum Cartesian Velocity**:

- The system does not monitor the entire structure of the robot and tool for violation of a velocity limit, but only defined points of the robot structure and the center points of the safety spheres of the tool.

  A total of up to 6 safety spheres can be configured for a tool in the scene editor.

> Further information about the configuration of the safety spheres of the tool can be found in the help function under “3D scene”.

In particular with projecting tools and workpieces, the safety spheres of the safety-oriented tool must be planned and configured in such a way as to assure the safety integrity of the velocity monitoring.

> Tools from toolboxes may have preconfigured safety spheres. For example, the first two tool spheres of a SCHUNK gripper are preconfigured.

- If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), the following applies:
  - The Cartesian velocity of the monitored kinematic system is monitored relative to the carrier kinematic system and not its absolute velocity in space.

9.18.3 Velocity monitoring in T1 and CRR

In the Safety Rule “Velocity Limit T1” in the Safety Rule Set “Velocity Monitoring” of the standard safety configuration, a safety-oriented velocity monitoring function for the T1 and CRR operating modes is predefined:

- If the maximum Cartesian velocity of 250 mm/s is exceeded in the T1 or CRR operating mode and no enabling switch is pressed on the Commander, a safety stop 1 (path-maintaining) is triggered.
- It is necessary for the Monitoring Block **Maximum Cartesian Velocity** to be linked to the Monitoring Block **Manual Guidance Inactive** in order to enable manual guidance at a velocity of more than 250 mm/s.

Safety Rule Set “Velocity Monitoring”			
Safety Rule “Velocity Limit T1”			
Monitoring Block 1	**Monitoring Block 2**	**Monitoring Block 3**	**Reaction**
Reduced Speed Mode	**Manual Guidance Inactive**	**Maximum Cartesian Velocity**	**Stop 1 on Path**

9.18.4 Velocity monitoring during manual guidance

For manual guidance, a maximum velocity must be defined that may not be exceeded during manual guidance. The value for this velocity limit must be defined in a risk assessment.

In the Safety Rule “Velocity Limit Manual Guidance” in the Safety Rule Set “Velocity Monitoring” of the standard safety configuration, a safety-oriented velocity monitoring function for manual guidance is predefined:

- If an enabling switch on the Commander is pressed and the Cartesian velocity of 500 mm/s is exceeded, a safety stop 1 (path-maintaining) is triggered.
- The configured maximum Cartesian velocity is valid in all operating modes. In other words, also for manual guidance in T1/CRR.
- If required by the risk assessment, the value for the maximum Cartesian velocity must be reduced.

Safety Rule Set "Velocity Monitoring"		
Safety Rule "Velocity Limit Manual Guidance"		
Monitoring Block 1	**Monitoring Block 2**	**Reaction**
Manual Guidance Active	**Maximum Cartesian Velocity**	**Stop 1 on Path**

9.19 Space monitoring functions

The robot environment can be divided into areas in which it must be located for execution of the application (workspace) and areas which it must not enter or may only enter under certain conditions (protected space). The system must then continuously monitor whether the robot is inside or outside such a monitoring space.

The following Monitoring Blocks are available for this purpose:

- **Axis Work Range**
- **Axis Protection Range**
- **Cartesian Monitoring Space**

By linking these to other Monitoring Blocks, it is possible to define further conditions that must be met if a monitoring space is violated. A monitoring space can be activated via a safe input, for example, or may be applicable in automatic mode only.

> If the robot has violated a monitoring space and been stopped by the safety controller, the robot can be moved out of the violated area in CRR mode.

Stopping distance

If the robot is stopped by a monitoring function, it requires a certain stopping distance before coming to a standstill.

The stopping distance depends primarily on the following factors:

- Robot type
- Velocity of the robot
- Position of the robot axes
- Payload

> **Include stopping distances in the risk assessment**
> The stopping distance when the safety reaction is triggered varies according to the specific robot type. Failure to take this into consideration when dimensioning a monitoring space may result in death, severe injuries or damage to property.
> - The system integrator must include the stopping distances in the risk assessment and design the monitoring spaces accordingly.

> Further information about the stopping distances and stopping times can be found in the assembly instructions of the relevant robot.

9.19.1 Monitoring Block "Axis Work Range"

Description

The Monitoring Block **Axis Work Range** can be used to define for each axis a permissible axis range that the axis must not leave.

The Monitoring Block is violated in the following cases:

- Monitored axis is located outside the permissible axis range.

The Monitoring Block becomes invalid in the following cases:

- The position of one or more axes is unmastered.
- Confirmation of mastering of the monitored axis has failed.

> **i** If the Monitoring Block is violated due to loss of mastering, it is necessary to switch to CRR mode in order to be able to move the robot again and master it.

Parameter	Description
Monitored Axis	Axis to be monitored
Lower Limit	Lower limit of the permissible axis range in which the monitored axis may move
Upper Limit	Upper limit of the permissible axis range in which the monitored axis may move

The following points must be observed when using the Monitoring Block **Axis Work Range**:

- The value for the lower limit must be less than the value for the upper limit.
- For personnel protection, only the axis position is relevant. For this reason, the positions are converted to the axis range -180° … +180°, even for axes which can rotate more than 360°.
- The limited range of values for the lower and upper limits does not allow the Monitoring Block to be used if the axis position at ±180° lies within the permissible axis range. In this case, the Monitoring Block **Axis Protection Range** must be used instead.

  The diagram (>>> *Fig. 9-4*) shows an axis-specific work range from 90° to 360°. Since the axis position at 180° is located in this work range, the Monitoring Block **Axis Work Range** cannot be used to monitor whether the axis is within this range. Instead, the Monitoring Block **Axis Protection Range** can be used to define a protected axis range from 0° to 90°.

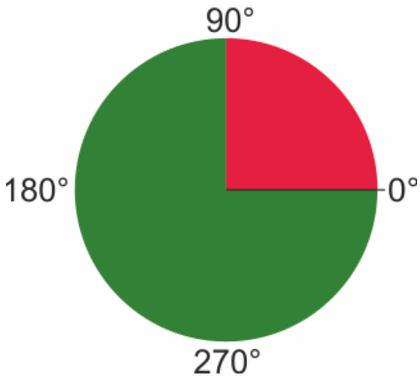


Fig. 9-4: Axis range monitoring example

9.19.2 Monitoring Block “Axis Protection Range”

Description

The Monitoring Block **Axis Protection Range** can be used to define for each axis a protected axis range that the axis must not enter.

The Monitoring Block is violated in the following cases:

- Monitored axis is located within the protected axis range.

The Monitoring Block becomes invalid in the following cases:

- The position of one or more axes is unmastered.
- Confirmation of mastering of the monitored axis has failed.

Parameter	Description
Monitored Axis	Axis to be monitored
Lower Limit	Lower limit of the protected axis range in which the monitored axis must not move
Upper Limit	Upper limit of the protected axis range in which the monitored axis must not move

The following points must be observed when using the Monitoring Block **Axis Protection Range**:

- The value for the lower limit must be less than the value for the upper limit.
- For personnel protection, only the axis position is relevant. For this reason, the positions are converted to the axis range -180° … +180°, even for axes which can rotate more than 360°.
- The limited range of values for the lower and upper limits does not allow the Monitoring Block to be used if the axis position at ±180° lies within the protected axis range. In this case, the Monitoring Block **Axis Work Range** must be used instead.

  The diagram (>>> *Fig. 9-5*) shows an axis-specific protection range from 90° to 270°. Since the axis position at 180° is located in this protection range, the Monitoring Block **Axis Protection Range** cannot be used to monitor whether the axis is within this range. Instead, the Monitoring Block **Axis Work Range** can be used to define a permissible axis range from -90° to 90°.

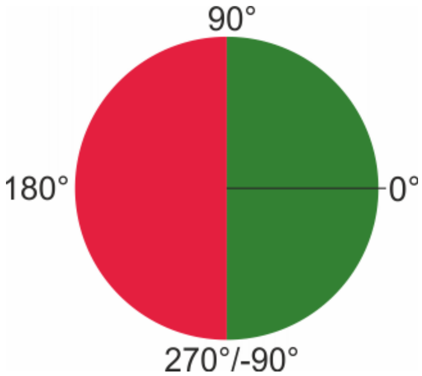


Fig. 9-5: Axis range monitoring example

9.19.3 Monitoring Block “Cartesian Monitoring Space”

Description

The Monitoring Block **Cartesian Monitoring Space** can be used to monitor whether a part of the monitored structure of a kinematic system is inside or outside a Cartesian monitoring space.

- A Cartesian monitoring space can be configured as a cuboid or prism. The space and its shape are created and managed in the scene editor.

> Further information about managing Cartesian monitoring spaces can be found in the help function under “3D scene”.

- A Cartesian monitoring space can be defined as a workspace in which the robot must be located, or as a protected space that it must not enter. The space type is set in the Monitoring Block.

The Monitoring Block is violated in the following cases:

- Workspace: Part of the monitored structure is located outside the workspace.
- Protected space: Part of the monitored structure is located inside the protected space.

The Monitoring Block becomes invalid in the following cases:

- The position of one or more axes is unmastered.
- Confirmation of mastering of one or more axes has failed.

> If the Monitoring Block is violated due to loss of mastering, it is necessary to switch to CRR mode in order to be able to move the robot again and master it.

Parameter

Parameter	Description
Workspace|Protected Space (Depending on selection **Space Type**)	**Select Space Shape** The spaces created in the scene editor can be selected using the button.
Space Type	Space type • **Workspace** • **Protected Space**
Structure	Structure to be monitored • **Robot and Tool**: The safety spheres on the robot and tool are monitored. • **Robot**: The safety spheres on the robot are monitored. • **Tool**: The safety spheres on the tool are monitored.

The following points must be observed when using the Monitoring Block **Cartesian Monitoring Space**:

- The system does not monitor the entire structure of the robot and tool for violation of a space, but only the safety spheres. The position of the safety spheres of the robot and the tool is visualized in the 3D scene.

  A total of up to 6 safety spheres can be configured for a tool in the scene editor.

> Further information about the configuration of the safety spheres of the tool can be found in the help function under “3D scene”.

  In particular with projecting tools and workpieces, the safety spheres of the safety-oriented tool must be planned and configured in such a way as to assure the safety integrity of workspaces and protected spaces.

> Tools from toolboxes may have preconfigured safety spheres. For example, the first two tool spheres of a SCHUNK gripper are preconfigured.

- The definition of the Cartesian monitoring spaces in the WORLD coordinate system is based on the assumption that the installation position and orientation of the monitored kinematic system in WORLD do not change. This means that the position of the monitoring space does not change relative to the base of the monitored kinematic system.
  - If the monitored kinematic system is mounted on a carrier kinematic system (e.g. mobile platform, linear unit), it must be taken into consideration that the safety monitoring is based on a fixed position of the monitoring space relative to the carrier kinematic system. For this reason, the monitoring space, too, is moved in the event of a change in position or inclination of the carrier kinematic system.
- With very narrow protected spaces, there is a risk that the robot may enter the protected space and leave it again without the space violation being detected. Possible cause: Due to a very high tool velocity, the protected space is only violated during a very short interval.

  Example:

  The following minimum values are configured in the scene editor:

  - Minimum radius of the tool sphere: 25 mm
  - Minimum size of the protected space: 0 mm

  With this minimum configuration, tool velocities of over 4 m/s are required to allow the robot to pass through the protected space without being detected.

  The following measures are recommended to prevent the robot from moving through protected spaces without being detected:

  - Configure a maximum Cartesian velocity that does not allow a value greater than 4 m/s.
  - Alternatively: When configuring the protected space, select sufficiently large values for the length, width and height.
  - Alternatively: When configuring the tool spheres, select sufficiently large values for the radius.

9.19.3.1 Unexpected protected space violation at corners and edges

When monitoring a protected space using the Monitoring Block **Cartesian Monitoring Space**, violations of the protected space may occur in the area of the corners and edges of the cuboid or prism, even though no safety sphere enters the protected space.

- **Cuboid as protected space:**

  Each safety sphere is replaced by a cube for calculation of the monitoring. The cube is just large enough to completely enclose the safety sphere. The cube is aligned parallel to the cuboid. The cube cannot be moved as close to the edges and corners of the cuboid as the safety sphere could. This can result in unexpected violation of the protected space.
- **Prism as protected space:**

  Each safety sphere is replaced by a cylinder for calculation of the monitoring. The cylinder is just large enough to completely enclose the safety sphere. The rotational axis of the cylinder is aligned parallel to the Z axis of the base frame. The cylinder cannot be moved as close to the lower and upper edges and corners of the prism as the safety sphere could. This can result in unexpected violation of the protected space.

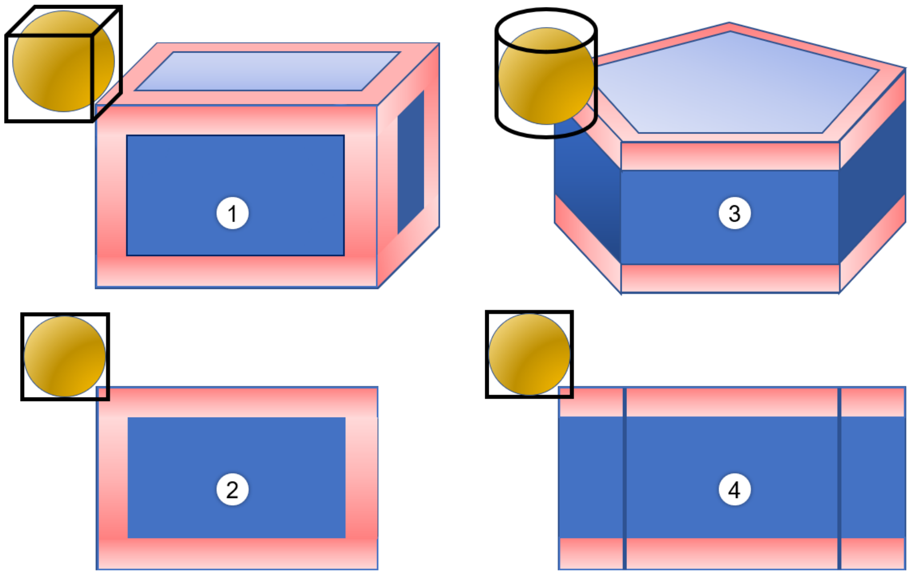


Fig. 9-6: Unexpected protected space violation at corners and edges

1 3D view of cuboid
2 Side view of cuboid
3 3D view of prism
4 Side view of prism

9.20 Monitoring of tool orientation

Description

The Monitoring Block **Tool Orientation Monitoring** can be used to monitor the orientation of the tool of a kinematic system. The Monitoring Block can, for example, be used in HRC applications in order to prevent dangerous parts of the mounted tool, e.g. sharp edges, from pointing towards humans.

Here, the TCP of the tool (= tool orientation frame) whose orientation is to be monitored must first be determined:

- The Z axis of the TCP is always monitored.
- In all instances of the Monitoring Block **Tool Orientation Monitoring**, the same TCP is monitored.
- The permissible range for the tool orientation can be different in the Monitoring Blocks.
- The permissible range for the tool orientation is defined by a reference vector with a fixed orientation relative to the WORLD coordinate system and by a deviation angle of this reference vector.
- The reference vector is defined by the rotation of the unit vector of the Z axis of the WORLD coordinate system about the 3 angles Rz, Ry and Rx relative to the WORLD coordinate system.

The Monitoring Block is violated in the following cases:

- The angle between the Z axis of the monitored TCP (tool orientation frame) and the reference vector is greater than the configured deviation angle.

The Monitoring Block becomes invalid in the following cases:

- The position of one or more axes is unmastered.
- Confirmation of mastering of one or more axes has failed.

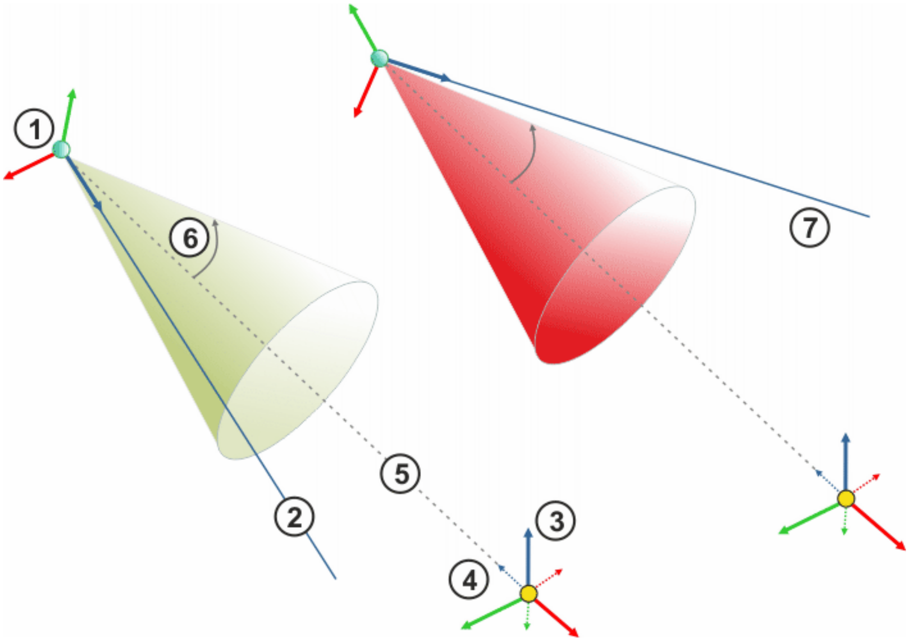


Fig. 9-7: Monitoring of tool orientation

1	Monitored TCP (tool orientation frame)
2	Monitored axis (Z axis)
3	WORLD coordinate system
4	Reference coordinate system (rotates about Rx, Ry and Rz relative to WORLD)
5	Reference vector (Z axis of the reference coordinate system)
6	Deviation angle
7	Permitted deviation exceeded

Parameter

Parameter	Description
Monitored TCP	Selection of the TCP whose orientation is to be monitored (tool orientation frame) The robot flange and all TCPs created in the tool configuration editor or in the scene editor for the tool used are available for selection. The monitored TCP that is configured is jointly used by all instances of the **Tool Orientation Monitoring** Monitoring Block in the safety configuration. If the monitored TCP that is configured is edited, it is changed for all instances of the **Tool Orientation Monitoring** Monitoring Block. **Note:** As soon as a TCP is configured as a monitored TCP, the tool and the TCP can no longer be deleted. To edit the TCP data, a Safety Commissioning Engineer must be logged on.
Reference Vector (relative to World)	Reference vector with fixed orientation relative to the WORLD coordinate system • **Rx** Rotation about the X axis of the WORLD coordinate system • **Ry** Rotation about the Y axis of the WORLD coordinate system • **Rz** Rotation about the Z axis of the WORLD coordinate system The orientation can be entered manually or taught.
Allowed Deviation	Permissible deviation relative to the reference vector The specified angle defines a monitoring cone. The Z axis of the monitored TCP may move within this cone.

⚠ **WARNING**

Risk of injury due to moving carrier kinematic system during monitoring of the tool orientation
If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), it must be taken into consideration that the orientation of the reference vector is relative to the coordinate system of the carrier kinematic system. This means that the reference orientation – for example, in the case of a change in inclination of the carrier kinematic system – is moved along to a ramp.

- The carrier kinematic system must come to a standstill during monitoring and must not move.

9.21 Monitoring of forces and axis torques

Forces and axis torques can only be monitored on robots equipped with position and joint torque sensors.

The accuracy of the monitoring of forces and axis torques depends on the dynamics of the robot motion. If these monitoring functions are triggered incorrectly, it is advisable to reduce the dynamics of the robot motion in programs. This can be achieved by reducing the parameters “Velocity” and “Acceleration” of the **Motion group** commands.

> Further information about reducing the dynamics of the robot motion in programs can be found in the help function under “Programming”.

> If the permissible forces or torques are continuously exceeded due to jamming, the robot can be retracted by switching to CRR mode.

> **WARNING**
>
> **Risk of injury due to incorrectly configured workpiece pick-up**
> How workpiece load data affect the load-dependent Monitoring Blocks **Collision** and **Maximum TCP Force** depends on how the workpiece is picked up.
>
> - The pick-up point of the workpiece and the resulting center of mass must match the pick-up point and center of mass configured for the workpiece in the payload configuration.

9.21.1 Monitoring Block “Collision”

Description

The Monitoring Block **Collision** can be used to monitor the external axis torques of all axes of a kinematic system.

The Monitoring Block is violated in the following cases:

- The external torque exceeds the configured limit on at least one axis of the monitored kinematic system.

The Monitoring Block becomes invalid in the following cases:

- Confirmation of the calibration of one or more joint torque sensors has failed.

Parameter

Parameter	Description
External Torque Limit	Maximum external axis torque

The external axis torque is defined as that part of the torque on an axis which is generated by the forces/torques occurring as the robot (and/or the tools) interact(s) with its environment.

The external axis torque is not measured directly but is rather calculated using the dynamic robot model. The accuracy of the calculated values depends, among other things, on the dynamics of the robot motion and of the interaction forces of the robot with its environment.

WARNING

Risk of injury due to incorrect use of the Monitoring Block "Collision"
The Monitoring Block **Collision** serves exclusively to reduce the risk of transient collisions. A transient collision is the momentary impact of the robot with an obstacle, e.g. if the obstacle can retract after the collision.

- Do not use the Monitoring Block to reduce pinching and crushing hazards.
- Avoid pinching and crushing hazards through other measures, e.g.:
  - Appropriate design of the robotic cell
  - Cartesian or axis-specific workspace/protected space monitoring functions
  - Maximum TCP force monitoring
  - Tool orientation monitoring

WARNING

Risk of injury due to errors in the workpiece load data
The Monitoring Block **Collision** does not automatically allow for possible errors in the load data of the workpiece. Errors in the load data lead to incorrectly determined external axis torques. Severe injuries or damage to property may result.

- Configure the lowest possible values for the maximum external axis torques for collision detection.

  In this way, significant deviations in the load data are interpreted as a collision and cause a violation of the Monitoring Block.

WARNING

Risk of injury due to loss of workpiece during collision monitoring
If workpieces that have been picked up are inadvertently released and fall off while collision monitoring is active, this results in an error in determining the external axis torques. Severe injuries or damage to property may result.

- If the Monitoring Block **Collision** is used, test the gripper with the workpiece in the application. It must be ensured that the workpiece cannot be released, fall off or break during collision monitoring.

WARNING

Risk of injury due to non-reduced velocity during collision monitoring
If violation of the Monitoring Block **Collision** triggers a safety stop in a Safety Rule, the interaction forces may increase due to the stopping distance of the robot. A reduction of the velocity compensates for the possible increase of the interaction forces.

- Only use the Monitoring Block **Collision** at reduced velocity.
- To reduce the velocity using safe technology, the Monitoring Block **Collision** must be combined with one of the following Monitoring Blocks:
  - **Maximum Cartesian Velocity**
  - **Maximum Axis Velocity**

WARNING

Risk of injury due to moving carrier kinematic system during collision monitoring

If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), the following applies:

- The carrier kinematic system must come to a standstill during monitoring and must not move.

The safety integrity of the Monitoring Block **Collision** is not assured when the carrier kinematic system is moving.

WARNING

Risk of injury due to deviation from the installation position

If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), the following applies:

- The installation position of the monitored kinematic system must not deviate from the configured installation position.

  A deviation is given, for example, if the “floor” installation position is configured, but the mobile platform moves onto a ramp and is thus in an inclined position.

The safety integrity of the Monitoring Block **Collision** is otherwise not assured.

9.21.2 Monitoring Block “Maximum TCP Force”

Description

The Monitoring Block **Maximum TCP Force** can be used to monitor the external force acting on the tool or the robot flange of a kinematic system (on a point within the configured force interaction area).

The force interaction area for a tool can be configured in the scene editor.

Further information about tool management and the force interaction area can be found in the help function under “3D scene”:

The Monitoring Block is violated in the following cases:

- The external force acting on the tool or the robot flange of the monitored kinematic system exceeds the configured limit.

The Monitoring Block becomes invalid in the following cases:

- Confirmation of the calibration of one or more joint torque sensors has failed.

Parameter

Parameter	Description
Force Interaction Area	**Open in Scene** The link can be used to open the configuration of the force interaction area in the scene.
Max TCP force	Maximum external force on the TCP

The force interaction area is defined as a sphere that contains all the points of a safety-oriented tool where expected external forces can occur. It is used by the Monitoring Block **Maximum TCP Force** to determine the safe external TCP forces.

The size of the force interaction area affects the accuracy of the TCP force calculation in robot poses near singularities. The more accurately the position of the force interaction point is defined (i.e. the smaller the radius of the force interaction area is configured), the better the Monitoring Block **Maximum TCP Force** can be used near singularities.

Furthermore, the accuracy of the TCP force calculation depends on the dynamics of the robot motion and of the interaction forces of the robot with its environment.

WARNING

Risk of injury due to incorrect configuration of the force interaction area
Incorrect configuration of the force interaction area may result in a loss of the safety integrity when using the Monitoring Block **Maximum TCP Force**.

- Select the interaction area so that all expected forces acting on the tool lie within the configured area.
- If the TCP force monitoring is active, no forces may be applied outside the configured area, e.g. by pulling or pushing the robot structure.

WARNING

Risk of injury due to incorrectly configured mass of the heaviest workpiece
Incorrect configuration of the mass of the heaviest workpiece may result in a loss of the safety integrity when using the Monitoring Block **Maximum TCP Force**.

- The configuration must be verified when approving the safety configuration (safety acceptance).

  (>>> *9.23.6.1 "Mass of the heaviest workpiece" Page 188*)

WARNING

Risk of injury due to loss of workpiece during monitoring of the maximum TCP force
If workpieces that have been picked up are inadvertently released and fall off while TCP force monitoring is active, this results in an error in determining the external force on the TCP. Severe injuries or damage to property may result.

- If the Monitoring Block **Maximum TCP Force** is used, test the gripper with the workpiece in the application. It must be ensured that the workpiece cannot be released, fall off or break during TCP force monitoring.

WARNING

Risk of injury due to non-reduced velocity during monitoring of the maximum TCP force

If violation of the Monitoring Block **Maximum TCP Force** triggers a safety stop in a Safety Rule, the interaction forces may increase due to the stopping distance of the robot. A reduction of the velocity compensates for the possible increase of the interaction forces.

- Only use the Monitoring Block **Maximum TCP Force** at reduced velocity.
- To reduce the velocity using safe technology, the Monitoring Block **Maximum TCP Force** must be combined with one of the following Monitoring Blocks:
  - **Maximum Cartesian Velocity**
  - **Maximum Axis Velocity**

WARNING

Risk of injury due to moving carrier kinematic system during monitoring of the maximum TCP force

If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), the following applies:

- The carrier kinematic system must come to a standstill during monitoring and must not move.

The safety integrity of the Monitoring Block **Maximum TCP Force** is not assured when the carrier kinematic system is moving.

WARNING

Risk of injury due to deviation from the installation position

If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit), the following applies:

- The installation position of the monitored kinematic system must not deviate from the configured installation position.

  A deviation is given, for example, if the “floor” installation position is configured, but the mobile platform moves onto a ramp and is thus in an inclined position.

The safety integrity of the Monitoring Block **Maximum TCP Force** is otherwise not assured.

9.22 Monitoring Block “Timer Expired”

Description

The Monitoring Block **Timer Expired** can be used to delay triggering of the reaction of a Safety Rule by a certain time.

- The Monitoring Block is violated if the timer has expired.
- The timer does not start running until all other Monitoring Blocks of the Safety Rule have been violated.
- If a specific instance of the Monitoring Block is used in different Safety Rules, the timer starts to run from the first activation.

Parameter	Description
Timer Expired	Delay time Each delay is a multiple of 12 ms. In other words, each delay is rounded up to the next multiple of 12, e.g.: • A setting of 0 ms results in a delay of 12 ms • A setting of 18 ms results in a delay of 24 ms

Example

The application requires that the robot can still be moved in automatic mode for a limited time, e.g. 2 hours, if mastering is not confirmed. Once this time has elapsed, a safety stop 1 (path-maintaining) is triggered.

Safety Rule			
Monitoring Block 1	**Monitoring Block 2**	**Monitoring Block 3**	**Reaction**
Automatic Mode	**Mastering Not Approved**	**Timer Expired**	**Stop 1 on Path**

9.23 Safety acceptance

Description

The system must not be put into operation until the safety acceptance procedure has been completed successfully. Checklists must be used to check and demonstrate that all monitoring functions are correctly configured and work correctly.

Safety acceptance must be carried out in the following cases:

- For initial start-up and recommissioning of the industrial robot

  If the preinstalled safety configuration is adopted without any changes, it is sufficient to check its suitability on the basis of a risk assessment.
- After a change to the industrial robot
- After exchanging the robot controller

  It is sufficient to check whether the activation ID of the loaded safety configuration matches the activation ID of the desired safety configuration.
- After a change to the safety configuration/activation ID

  Any modification of the activation ID requires a complete check of all configuration parameters. It is not sufficient to check the modified parameters only.
- After a software update, e.g. of the system software

  Safety acceptance after a software update is only necessary if the activation ID changes as a result of the update.

Checklists

The safety acceptance procedure can be carried out and documented using the following checklists or using your own checklists.

- The items in the checklist must be completed fully and confirmed in writing.
- The checklists confirmed in writing are to be kept as documentary evidence.

9.23.1 Basic properties of the safety configuration

No.	Task	Yes	Not relevant
1	Operator safety: is all operator safety equipment configured, properly connected and tested for correct function?		
2	Operator safety: a stop is triggered if AUT mode is active and the operator safety (e.g. safety gate) is open.		
3	Operator safety: is a manual acknowledgement function present and is it activated to prevent resumption of automatic operation by closing the operator safety alone?		
4	Brake test: is a mandatory cyclical brake test planned and configured?		
5	Enabling on teach pendant: have all enabling devices that were configured in the Monitoring Block **Enabling Inactive** been properly connected and tested for correct function?		
6	Enabling on hand guiding device: have all enabling devices that were configured in the Monitoring Block **Manual Guidance Inactive** been properly connected and tested for correct function?		
7	Local EMERGENCY STOP: are all local EMERGENCY STOP devices configured, properly connected and tested for correct function?		
8	External EMERGENCY STOP: are all external EMERGENCY STOP devices configured, properly connected and tested for correct function?		
9	Local and external EMERGENCY STOP: are the local and external EMERGENCY STOP devices each configured as an individual Monitoring Block in a Safety Rule?		
10	Safety stop: is all safety stop equipment configured, properly connected and tested for correct function?		
11	If position-specific Monitoring Blocks are used: is the limited safety integrity of the position-specific Monitoring Blocks taken into consideration if mastering has not been approved? **Note:** Initiation of the safe state if mastering has not been confirmed can be configured using the Monitoring Block **Mastering Not Approved**.		
12	If position-specific Monitoring Blocks are used: has the mastering of all axis positions been successfully confirmed?		
13	Velocity monitoring: have all necessary velocity monitoring tests been configured and tested?		
14	Manual guidance: has it been configured in such a way that appropriate velocity monitoring is active for manual guidance in every operating mode?		
15	Workspace monitoring: have all required workspace monitoring functions been configured and tested?		
16	Cartesian workspace/protected space monitoring: has it been taken into consideration that the system does not monitor the entire structure of the robot, tool and workpiece for space violation, but only the safety spheres on the robot and on the tool?		
17	Collision detection: have all required HRC functionalities been configured and tested?		

No.	Task	Yes	Not relevant
18	Collision detection: has it been taken into consideration that the Monitoring Block **Collision** is only approved for the reduction of hazards associated with transient contact (free collisions), but not for crushing situations?		
19	Collision detection: has it been configured in such a way that velocity monitoring is always active when the Monitoring Block **Collision** is active?		
20	TCP force monitoring: has it been configured in such a way that velocity monitoring is always active when the Monitoring Block **Maximum TCP Force** is active?		
21	TCP force monitoring: has a force interaction area been configured?		
22	If axis torque-specific Monitoring Blocks are used: is the limited safety integrity of the axis torque-specific Monitoring Blocks taken into consideration when mastering and/or joint torque sensor calibration has not been confirmed? **Note:** Initiation of the safe state when mastering and/or joint torque sensor calibration has not been confirmed can be configured using the Monitoring Block **Mastering Not Approved** and/or **JTS Adjustment Not Approved**.		
23	If axis torque-specific Monitoring Blocks are used: have the mastering of all axis positions and the calibration of all joint torque sensors been successfully confirmed?		
24	Safety Rules: has it been taken into consideration that the safe state of the Monitoring Blocks is the “violated” state (state “0”)? **Note:** In the event of an error, a Monitoring Block switches to the safe state.		
25	Safety Rules: in the configuration of the output signals for the safety reaction, has it been taken into consideration that an output is LOW (state “0”) in the safe state?		
26	If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit): has it been taken into consideration that in the case of the Monitoring Block **Cartesian Monitoring Space** the safety monitoring is based on a fixed position of the monitoring space relative to the carrier kinematic system? For this reason, the monitoring space is also moved in the event of a change in position or inclination of the carrier kinematic system.		
27	If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit): has it been taken into consideration that the Monitoring Block **Maximum Cartesian Velocity** does not monitor the absolute velocity in space, but the velocity of the monitored kinematic system relative to the carrier kinematic system?		
28	If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit): has the fact been taken into consideration that, with the **Tool Orientation Monitoring** Monitoring Block, the reference orientation is defined relative to the carrier kinematic system and moves with the carrier kinematic system?		

No.	Task	Yes	Not relevant
29	If the monitored kinematic system is fastened to a carrier kinematic system (e.g. mobile platform, linear unit): has it been taken into consideration that the safety integrity of the Monitoring Blocks **Collision** and **Maximum TCP Force** is only assured as long as the carrier kinematic system is stationary?		

9.23.2 Safety-oriented tools

9.23.2.1 Geometry data of the tool

If one of the following Monitoring Blocks is used in the safety configuration, it is necessary to check that the geometric tool data have been configured correctly:

- **Maximum Cartesian Velocity**
  Only if the safety spheres on the tool are configured as a structure to be monitored.
- **Cartesian Monitoring Space**
  Only if the safety spheres on the tool are configured as a structure to be monitored.

The geometric tool data can be tested by deliberately violating one of the configured monitoring spaces with each tool sphere and checking the reaction. If no space monitoring functions are used, only the position of the sphere center points is relevant.

The configured Cartesian velocity limit can be tested by deliberately exceeding this velocity for each tool sphere and checking the reaction.

Precondition

- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes	Not relevant
1	Have the radius and position of all tool spheres been correctly configured and checked?		

Configuration
Tool name: _______________ Tool sphere data: • Sphere name: _______, X: _______, Y: _______, Z: _______, Radius: _______ • Sphere name: _______, X: _______, Y: _______, Z: _______, Radius: _______ • Sphere name: _______, X: _______, Y: _______, Z: _______, Radius: _______ • Sphere name: _______, X: _______, Y: _______, Z: _______, Radius: _______ • Sphere name: _______, X: _______, Y: _______, Z: _______, Radius: _______ • Sphere name: _______, X: _______, Y: _______, Z: _______, Radius: _______

9.23.2.2 Tool load data

Configuration of the tool load data has an effect on the monitoring behavior of the following Monitoring Blocks:

- **Collision**

- **Maximum TCP Force**

Explicit verification of the tool load data is not required, as it is implicitly included in the test procedures of the aforementioned Monitoring Blocks.

9.23.2.3 Tool orientation

A TCP selected as a tool orientation frame affects the monitoring behavior of the Monitoring Block **Tool Orientation Monitoring**. It is not necessary to explicitly check the configuration of the tool orientation, as it is implicitly contained in the test procedures of the Monitoring Block **Tool Orientation Monitoring**.

9.23.3 Installation position and orientation of the robot

The installation position and orientation of the robot have an effect on the monitoring behavior of the following Monitoring Blocks:

- **Cartesian Monitoring Space**
- **Tool Orientation Monitoring**
- **Collision**
- **Maximum TCP Force**

Explicit verification of the installation position and orientation of the robot is not required, as it is implicitly included in the test procedures of the aforementioned Monitoring Blocks.

9.23.4 Safety Rules

Description

A Safety Rule can be tested by violating all but one of the contained Monitoring Blocks simultaneously. The remaining Monitoring Block can then be tested separately in a targeted manner.

Each Safety Rule must then be tested to determine whether the configured safety reaction is triggered. If the reaction is to switch off an output, the test must also ensure that the output is correctly connected.

Safety Rules with the Monitoring Block **Maximum Cartesian Velocity** and a Stop or Brake as a reaction can be tested as follows:

1. Move the robot at a velocity exceeding the limit value of the Monitoring Block involved **Maximum Cartesian Velocity**.
2. Once all other Monitoring Blocks of the Safety Rule have been violated, reduce the velocity to a value below this limit value.
   - Stop as reaction: Stop until complete standstill
   - Brake as reaction: No stop until complete standstill

No.	Task	Yes	Not relevant
1	Monitoring Block 1 has been tested successfully. Precondition: Monitoring Blocks 2, 3, 4, 5 and 6 (if configured) are violated. Monitoring Block 1: ______________________		
2	Monitoring Block 2 has been tested successfully. Precondition: Monitoring Blocks 1, 3, 4, 5 and 6 (if configured) are violated. Monitoring Block 2: ______________________		
3	Monitoring Block 3 has been tested successfully. Precondition: Monitoring Blocks 1, 2, 4, 5 and 6 (if configured) are violated. Monitoring Block 3: ______________________		
4	Monitoring Block 4 has been tested successfully. Precondition: Monitoring Blocks 1, 2, 3, 5 and 6 (if configured) are violated. Monitoring Block 4: ______________________		
5	Monitoring Block 5 has been tested successfully. Precondition: Monitoring Blocks 1, 2, 3, 4 and 6 (if configured) are violated. Monitoring Block 5: ______________________		
6	Monitoring Block 6 has been tested successfully. Precondition: Monitoring Blocks 1, 2, 3, 4 and 5 (if configured) are violated. Monitoring Block 6: ______________________		

Configuration
Safety Rule Set name: _____________
Safety Rule name: _____________
Safety Rule ID: _____________

9.23.5 Monitoring Blocks

Checking the Monitoring Blocks within a Safety Rule necessitates checking the violation status of the Monitoring Blocks. The violation status can be checked in 2 different ways:

- Via the status visualization of the Monitoring Block
  (>>> *9.3 "Status of the current safety configuration" Page 139*)
- Check whether the configured safety reaction of the Safety Rule is triggered. Precondition:
  - All other Monitoring Blocks within the Safety Rule are violated.

9.23.5.1 Monitoring Block “Enabling Inactive”

No.	Activity	Yes	Not relevant
1	The Monitoring Block is violated if all enabling switches of enabling device 1 have been released.		
2	The Monitoring Block is violated if any enabling switch of enabling device 1 is fully pressed (panic position).		
3	The Monitoring Block is violated if all enabling switches of enabling device 2 have been released.		
4	The Monitoring Block is violated if any enabling switch of enabling device 2 is fully pressed (panic position).		
5	The Monitoring Block is violated if all enabling switches of enabling device 3 have been released.		
6	The Monitoring Block is violated if any enabling switch of enabling device 3 is fully pressed (panic position).		

Configuration
Signal for the enabling switch(es) of enabling device 1: _______________ Signal for the panic switch(es) of enabling device 1: _______________
Signal for the enabling switch(es) of enabling device 2: _______________ Signal for the panic switch(es) of enabling device 2: _______________
Signal for the enabling switch(es) of enabling device 3: _______________ Signal for the panic switch(es) of enabling device 3: _______________

9.23.5.2 Monitoring Block “Manual Guidance Inactive”

No.	Activity	Yes	Not relevant
1	The Monitoring Block is violated if all enabling switches of hand guiding device 1 have been released.		
2	The Monitoring Block is violated if any enabling switch of hand guiding device 1 is fully pressed (panic position).		
3	The Monitoring Block is violated if all enabling switches of hand guiding device 2 have been released.		
4	The Monitoring Block is violated if any enabling switch of hand guiding device 2 is fully pressed (panic position).		
5	The Monitoring Block is violated if all enabling switches of hand guiding device 3 have been released.		
6	The Monitoring Block is violated if any enabling switch of hand guiding device 3 is fully pressed (panic position).		

Configuration
Signal for the enabling switch(es) of hand guiding device 1: _____________ Signal for the panic switch(es) of hand guiding device 1: ______________
Signal for the enabling switch(es) of hand guiding device 2: _____________ Signal for the panic switch(es) of hand guiding device 2: _____________
Signal for the enabling switch(es) of hand guiding device 3: _____________ Signal for the panic switch(es) of hand guiding device 3: _____________

9.23.5.3 Monitoring Block “Manual Guidance Active”

No.	Activity	Yes	Not relevant
1	The Monitoring Block is violated if any enabling switch of hand guiding device 1 is pressed.		
2	The Monitoring Block is violated if any enabling switch of hand guiding device 2 is pressed.		
3	The Monitoring Block is violated if any enabling switch of hand guiding device 3 is pressed.		

9.23.5.4 Monitoring Block “Reduced Speed Mode”

No.	Activity	Yes
1	The Monitoring Block is violated in T1.	
2	The Monitoring Block is violated in CRR.	

9.23.5.5 Monitoring Block “High Speed Mode”

No.	Activity	Yes
1	The Monitoring Block is violated in AUT.	

9.23.5.6 Monitoring Block “Test Mode”

No.	Activity	Yes
1	The Monitoring Block is violated in T1.	
2	The Monitoring Block is violated in CRR.	

9.23.5.7 Monitoring Block “Automatic Mode”

No.	Activity	Yes
1	The Monitoring Block is violated in AUT.	

9.23.5.8 Monitoring Block “Safety Stop”

No.	Activity	Yes
1	The Monitoring Block is violated if a safety stop is active (e.g. if an EMERGENCY STOP device is pressed).	

9.23.5.9 Monitoring Block “Input Signal”

No.	Activity	Yes
1	The Monitoring Block is violated if the input signal is LOW (state “0”).	

Configuration
Monitoring Block name: _______________
Monitoring Block ID: _______________
Input signal: _______________

9.23.5.10 Monitoring Block “Input Signal with Acknowledgement”

No.	Activity	Yes
1	The Monitoring Block is violated if the input signal is LOW (state “0”) or if the input signal is HIGH (state “1”) but has not yet been acknowledged.	

Configuration
Monitoring Block name: _______________ Monitoring Block ID: _______________ Input signal: _______________ Acknowledgement signal: _______________

9.23.5.11 Monitoring Block “Mastering Not Approved”

No.	Task	Yes
1	The Monitoring Block is violated if the mastering of one or more axes of the monitored kinematic system is not confirmed.	

Configuration
Monitoring Block name: _______________ Monitoring Block ID: _______________

9.23.5.12 Monitoring Block “JTS Adjustment Not Approved”

No.	Task	Yes
1	The Monitoring Block is violated if the calibration of one or more joint torque sensors of the monitored kinematic system is not confirmed.	

Configuration
Monitoring Block name: _______________ Monitoring Block ID: _______________

9.23.5.13 Monitoring Block “Maximum Axis Velocity”

The Monitoring Block can be tested by moving the monitored axis at a velocity of approx. 10% above the configured velocity limit.

No.	Task	Yes
1	The Monitoring Block is violated if the maximum permissible axis velocity is exceeded.	

Configuration
Monitoring Block name: _______________ Monitoring Block ID: _______________ Monitored axis: _______________ Maximum velocity: _______________

9.23.5.14 Monitoring Block “Axis Work Range/Axis Protection Range”

Precondition

- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes
1	The Monitoring Block is violated if the lower limit of the monitored axis range is violated.	
2	The Monitoring Block is violated if the upper limit of the monitored axis range is violated.	

Configuration
Monitoring Block name: _______________
Monitoring Block ID: _______________
Monitoring range type (work range or protection range): _______________
Monitored axis: _______________
Lower limit: _______________
Upper limit: _______________

9.23.5.15 Monitoring Block “Maximum Cartesian Velocity”

In order to test the configured velocity limit of the Monitoring Block, the monitored kinematic system must be moved in such a way that the monitored point that moves fastest is moved at a velocity of approx. 10% above the configured limit value.

- If the safety reaction of the Safety Rule is a safety stop or a Brake, this requires violation of another Monitoring Block of the Safety Rule, as the controller would otherwise avoid violating the velocity limit.
- If the Safety Rule does not contain a second Monitoring Block, the velocity limit can be checked by observing the automatic velocity limitation of the controller. The controller reduces the programmed velocity to a value below the velocity limit of the Monitoring Block.

It must also be checked whether the structure to be monitored is configured correctly:

- If both structures (robot and tool) are monitored, the velocity monitoring must be violated both by the monitoring points on the robot and by the monitoring points on the tool.
- If only one of the two structures (robot or tool) is monitored, the velocity monitoring must be violated either by the monitoring points on the robot or by the monitoring points on the tool.

Precondition

- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes	Not relevant
1	The Monitoring Block is violated if the maximum Cartesian velocity at the monitoring point that moves fastest is exceeded.		
2	The Monitoring Block is violated if the velocity monitoring is violated exclusively by monitoring points on the robot.		

No.	Task	Yes	Not relevant
3	The Monitoring Block is violated if the velocity monitoring is violated exclusively by monitoring points on the tool.		

Configuration
Monitoring Block name: _______________
Monitoring Block ID: _______________
Monitored structure: _______________
Maximum velocity: _______________

9.23.5.16 Monitoring Block "Cartesian Monitoring Space" (cuboid)

Description

It must be checked whether the orientation and size of the cuboid have been correctly configured:

- In order to check the orientation, a first cuboid surface must be violated at 3 or more different points and an adjacent cuboid surface at 2 or more different points.
- In order to check the size, the other space surfaces must be violated at 1 point in each case.
- In total, at least 9 points must be addressed.

It must also be checked whether the structure to be monitored is configured correctly:

- If both structures (robot and tool) are monitored, the space monitoring must be violated both by the safety spheres on the robot and by the safety spheres on the tool.
- If only one of the two structures (robot or tool) is monitored, the space monitoring must be violated either by the safety spheres on the robot or by the safety spheres on the tool.

Precondition

- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes	Not relevant
1	The correct configuration of the cuboid orientation has been checked as described above. The Monitoring Block is violated every time a monitoring space is violated.		
2	The correct configuration of the cuboid size has been checked as described above. The Monitoring Block is violated every time a monitoring space is violated.		
3	The Monitoring Block is violated if the space monitoring is violated by the safety spheres on the robot.		
4	The Monitoring Block is violated if the space monitoring is violated by the safety spheres on the tool.		

Configuration
Monitoring Block name: ______________ Monitoring Block ID: ______________ Monitored structure: ______________ Monitoring space type (workspace or protected space): ______________ Cuboid parameters: • Origin frame coordinates (relative to World): – X: _________, Y: _________, Z: _________ – Rz: _________, Ry: _________, Rx: _________ • Dimensions: – Length: _________, Width: _________, Height: _________

9.23.5.17 Monitoring Block “Cartesian Monitoring Space” (prism)

Description

It must be checked whether all corners, the Z coordinate and the orientation of the prism base and the height of the prism have been configured correctly:

- In order to check the correct position of all corners, 2 different points on each side surface of the prism must be violated. These 2 points must differ in each case in the X or Y coordinate relative to the base frame.
- In order to check the Z coordinate and the orientation of the prism base, the monitoring function must be violated at 3 points of the prism base in each case.
- In order to check the height of the prism, the monitoring function must be violated at a point on the cover of the prism.
- In total, at least 4 + 2*(number of corners) points must be addressed.

It must also be checked whether the structure to be monitored is configured correctly:

- If both structures (robot and tool) are monitored, the space monitoring must be violated both by the safety spheres on the robot and by the safety spheres on the tool.
- If only one of the two structures (robot or tool) is monitored, the space monitoring must be violated either by the safety spheres on the robot or by the safety spheres on the tool.

Precondition

- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes	Not relevant
1	The correct configuration of the corners has been checked as described above. The Monitoring Block is violated every time a monitoring space is violated.		
2	The correct configuration of the Z coordinate and the orientation of the base have been checked as described above. The Monitoring Block is violated every time a monitoring space is violated.		

No.	Task	Yes	Not relevant
3	The correct configuration of the prism height has been checked as described above. The Monitoring Block is violated every time a monitoring space is violated.		
4	The Monitoring Block is violated if the space monitoring is violated by the safety spheres on the robot.		
5	The Monitoring Block is violated if the space monitoring is violated by the safety spheres on the tool.		

Configuration
Monitoring Block name: ______________
Monitoring Block ID: ______________
Monitored structure: ______________
Monitoring space type (workspace or protected space): ______________
Prism parameters:
• Origin frame coordinates (relative to World): – X: _________, Y: _________, Z: _________ – Rz: _________, Ry: _________, Rx: _________
• Height: ______________
• Number of corners: ______________
• Coordinates of corners (relative to prism origin frame): – Corner 1: X: _________, Y: _________ – Corner 2: X: _________, Y: _________ – Corner 3: X: _________, Y: _________ – Corner 4: X: _________, Y: _________ – Corner 5: X: _________, Y: _________ – Corner 6: X: _________, Y: _________ – Corner 7: X: _________, Y: _________ – Corner 8: X: _________, Y: _________ – Corner 9: X: _________, Y: _________ – Corner 10: X: _________, Y: _________ – Corner 11: X: _________, Y: _________ – Corner 12: X: _________, Y: _________ – Corner 13: X: _________, Y: _________ – Corner 14: X: _________, Y: _________ – Corner 15: X: _________, Y: _________ – Corner 16: X: _________, Y: _________ – Corner 17: X: _________, Y: _________ – Corner 18: X: _________, Y: _________ – Corner 19: X: _________, Y: _________ – Corner 20: X: _________, Y: _________

9.23.5.18 Monitoring Block “Tool Orientation Monitoring”

Description

In order to test the Monitoring Block, the permissible workspace (monitoring cone) must be violated at 3 straight lines offset by approx. 120° to one another. This ensures that the orientation of the reference vector, the permissible deviation angle and the tool orientation frame are correctly configured.

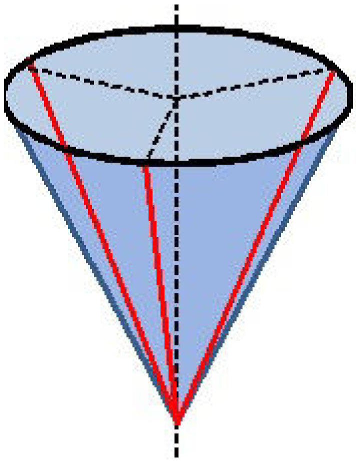


Fig. 9-8: Position of the straight lines on the monitoring cone

The orientation angles of the Z axis of the tool orientation frame (monitored TCP) are defined using 3 straight lines situated on the edge of the monitoring cone and offset at 120° to one another. These orientation angles must be set in order to test the Monitoring Block **Tool Orientation Monitoring**. The Monitoring Block must be violated if all 3 orientation angles are exceeded.

Precondition

- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes
1	The correct configuration of the monitoring cone has been checked and the configured reaction was triggered when the permissible deviation angle for all 3 straight lines was exceeded.	

Configuration
Monitoring Block name: ______________
Monitoring Block ID: ______________
Rotation of the reference vector (relative to WORLD):
• Rz: _________, Ry: _________, Rx: _________
Permissible workspace (deviation angle): ______________

9.23.5.19 Monitoring Block “Collision”

The Monitoring Block can be tested by applying forces to the robot at standstill. The sensitivity of the collision detection function must be suitable for the intended use or application.

The test must be repeated in 3 different robot positions. In each position, several different directions of force application must be tested.

Precondition

- Calibration of all joint torque sensors has been successfully confirmed.
- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes
1	Robot position 1: The Monitoring Block is violated if collision forces are exerted on the monitored kinematic system. The test is successful for several different directions in which the force is applied.	
2	Robot position 2: The Monitoring Block is violated if collision forces are exerted on the monitored kinematic system. The test is successful for several different directions in which the force is applied.	
3	Robot position 3: The Monitoring Block is violated if collision forces are exerted on the monitored kinematic system. The test is successful for several different directions in which the force is applied.	

Configuration
Monitoring Block name: _______________ Monitoring Block ID: _______________ Maximum external axis torque: _______________

9.23.5.20 Monitoring Block “Maximum TCP Force”

In order to test the Monitoring Block, a suitable measuring instrument is required, e.g. a spring balance.

During the test, it must be noted that the monitoring function automatically takes into consideration possible errors in the workpiece load data. For this reason, it is possible that the reaction will already be triggered at lower TCP forces. To avoid this, proceed as follows:

- Do not pick up a workpiece during the test.
- Apply the TCP force in the direction of gravity (i.e. downwards).

Precondition

- Calibration of all joint torque sensors has been successfully confirmed.
- Mastering of all axis positions has been successfully confirmed.

No.	Task	Yes	Not relevant
1	The Monitoring Block is violated if the external force acting on the TCP of the monitored kinematic system exceeds the maximum permissible force.		

Configuration
Monitoring Block name: _______________ Monitoring Block ID: _______________ Maximum TCP force: _______________

9.23.5.21 Monitoring Block “Timer Expired”

No.	Activity	Yes
1	The Monitoring Block is violated if the configured delay time has expired.	

Configuration
Monitoring Block name: _______________
Monitoring Block ID: _______________
Delay time: _______________

9.23.6 General safety-oriented parameters

9.23.6.1 Mass of the heaviest workpiece

If workpieces are picked up by a kinematic system in an application and, at the same time, one of the following Monitoring Blocks is used in the safety configuration, it is necessary to check whether the mass of the heaviest workpiece is configured correctly:

- **Collision**
- **Maximum TCP Force**

No.	Task	Yes
1	Under **Setup** > **Payload** on the **Workpiece** tab, configure a workpiece with a mass that is 10 g greater than the mass of the heaviest work-piece configured in the safety settings. Select the configured workpiece in the status bar and jog the robot with the workpiece in Cartesian mode. A message must be displayed on the smartPAD indicating that the load data of the workpiece used are invalid.	
2	Under **Setup** > **Payload** on the **Workpiece** tab, configure a workpiece with a mass that is 10 g less than the mass of the heaviest workpiece configured in the safety settings. Select the configured workpiece in the status bar and jog the robot with the workpiece in Cartesian mode. No message may be displayed on the smartPAD indicating that the load data of the workpiece used are invalid.	

Configuration
Mass of the heaviest workpiece: _______________

10 Programming

10.1 Creating and managing programs

The system can contain multiple programs that can be opened, edited or executed if required. The various programs are managed in the Feature menu **Program**.

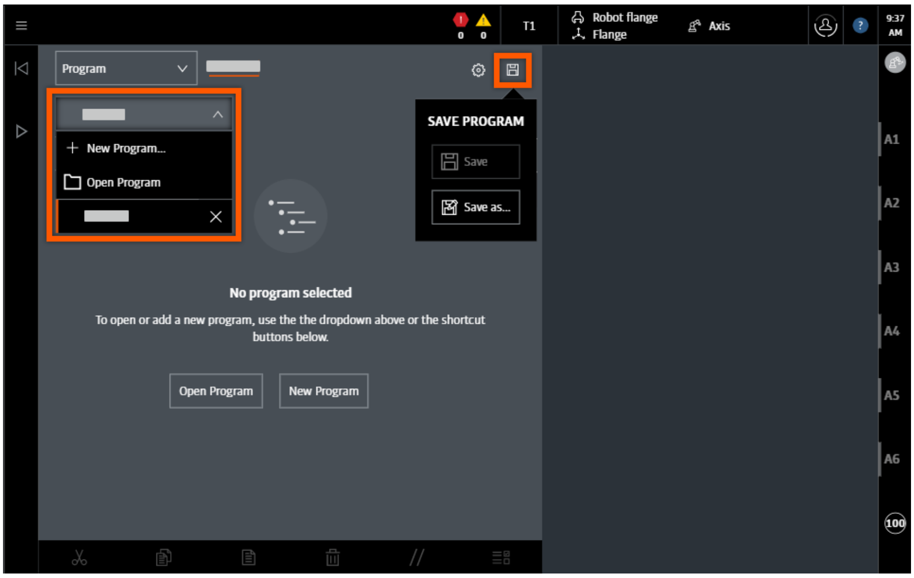


Fig. 10-1: Managing programs

These functions are available:

- Create a new program
- Manage existing programs in the **OPEN PROGRAM** dialog:
  - Open an existing program
  - Duplicate an existing program
  - Delete an existing program

> Recently opened programs are displayed directly in the program menu and can be opened from there.

- In the **Save** dialog:
  - Save the program currently open
  - Save a copy of the current program under a new name

10.2 Node Palette: inserting nodes (program elements)

A program consists of multiple program elements or program lines, so-called nodes. Nodes have a hierarchical structure and can be nested in each other. New nodes are inserted into the program via the **Node Palette**.

> It is advisable to start an application from a defined position. The command for addressing this position should be an **Axis (PTP)** motion that is inserted into the new program as the first motion command.

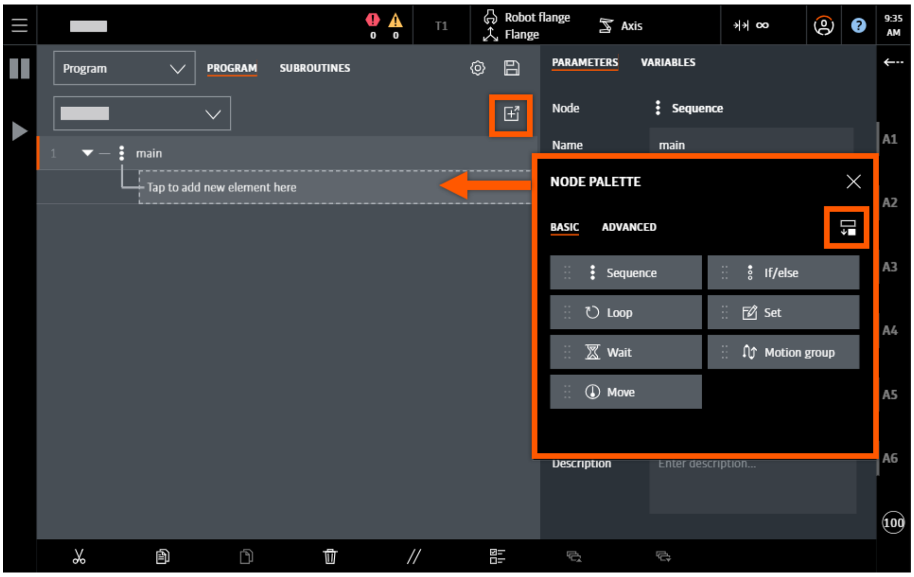


Fig. 10-2: Node Palette

- The node palette can be moved freely on the interface so that it does not conceal any currently required content.
- The nodes in the pallet are divided into the categories **BASIC** and **ADVANCED**.
- Press a node to insert it below the node selected in the program.

> New nodes can be inserted as the last element below the current node (**Last child**), or at the same hierarchy level behind the current node (**Sibling after**).
> The insertion position is indicated in the program tree structure.

- Alternatively, press a node and drag it to the desired position in the program to place it there.

> If a program line is marked in yellow after insertion, the hierarchy is invalid or there are still entries missing in the command that are required to ensure that it is complete.

10.2.1 Basic nodes

10.2.1.1 Sequence

The **Sequence** node is used to structure the program, similar to files in a folder system. The **Sequence** node only calls all child nodes one after the other. Several nodes of the type **Sequence** can be nested in each other.

Each program contains a **Sequence** node named **main** at the highest level. This node can be renamed but not deleted.

10.2.1.2 Motion group

Description

The node can be used to program a motion group. A motion group always consists of the node **Motion group** and one or more nodes of type **Move** (motion).

Parameters

The following parameters can be defined on the **Parameters** tab:

- **Motion type**: Motion type with which the motions of the group are carried out
  - **Toolpath (Cartesian)**
    Cartesian motion in which the tool is moved along a defined path
  - **Axis (PTP)**
    Axis motion of the robot
- **TCP**: TCP with which the motions of the group are carried out
  The TCP that is currently selected in the status bar is preselected by default.
- **Speed**: Velocity at which the motions of the group are carried out
- **Acceleration**: Acceleration at which the motions of the group are carried out

The parameters set here are automatically applied to all motions below the **Motion group** node. Other values for velocity and acceleration can be programmed for individual motions (node **Move**).

> When teaching frames within a motion group, the parameters (TCP, velocity and acceleration) set in the **Motion group** node are used and not the TCP selected in the status bar.

> It is advisable to start an application from a defined position. The command for addressing this position should be an **Axis (PTP)** motion that is inserted into the new program as the first motion command.

> **CAUTION**
>
> **Risk of injury and damage to property due to subsequent modification of the payload**
> If the payload (and thus also the TCP) is modified after motion segments have already been inserted, all motion segments use the new payload. This results in a different robot pose and the robot may execute unexpected motions. Injuries or damage to property may result.
>
> - Always test new or modified programs in operating mode T1 first.

Sensitivity

Settings to move the robot under impedance control can be made on the **Sensitivity** tab.

(>>> *10.7 "Programming of a compliant robot" Page 209*)

Triggers

A trigger can be programmed on the **Triggers** tab.

(>>> *10.8 "Trigger programming" Page 216*)

Error executing a Motion group

When executing a **Motion group**, it is possible that the program will be stopped with the following error message: **Motion command execution did not succeed. State: {motionState}.**

To remedy this, it is advisable to check the programming as follows:

- Check whether all end frames in the affected **Motion group** are accessible, for example by manually addressing the frames with **Move to**

- Check whether the frame coordinates are located in the workspace of the robot, for example via the scene
- Check whether the correct payload has been selected
- Check whether the correct base has been selected

If the **Toolpath (Cartesian)** motion type has been selected:

- Check whether adding one or more intermediate frames changes the behavior
- Check whether the motion type can be changed to **Axis (PTP)** (it is possible that the path will change!)

10.2.1.3 Move (motion)

Description

The **Move** node is always part of a motion group (**Motion group**). The node can be used to program the following motions:

- Absolute motion

  By default, absolute motion is preselected.
- Relative motion

Absolute Motion

If absolute motion is selected, the **Move** node defines the motion type and the target frame of the motion:

- The motion type must conform to the motion type of the motion group (**Motion group** node):
  - A Cartesian motion group can contain linear, circular and spline motions.
  - An axis-specific motion group can only contain Axis (PTP) motions.
- Target frames are the coordinates of the target position relative to the TCP. The frame coordinates can be entered manually or taught. When adding a new **Move** node, an unshared frame is automatically created.

  The functional principle of frames is described in the 3D scene.
- Unshared frames can subsequently be converted to project frames and vice versa. To do so, change the selection in **Target Type**. Project frames are known in the entire project on the robot controller and can be used in every program.

NOTICE
Unexpected robot motion due to retaught frames If a frame is retaught, the change affects all motions that move to this frame. – If **Move** nodes with frames that have already been taught are copied in order to use them for new motions, make sure to create and teach new frames in the respective segments. – To create a new frame, select **Select or add frame** and then **New project frame** or **New unshared frame** in the **Frame** menu. Do not press the **Touch up** button. This button does not create a new frame, but overwrites the existing frame with new coordinates. If it is a global frame, it is modified in all programs that use it.

- The link **Open in scene** can be used to display the current frame in the 3D scene in order to be able to visualize its position better.

  In the scene, press the program name in the status bar at the top to return to the program.

Relative Motion

If relative motion is selected, the **Move** node defines the motion type and the target or rotational position of the motion:

- The motion type must conform to the motion type of the motion group (**Motion group** node):
  - A Cartesian motion group can contain linear, circular and spline motions.
  - An axis-specific motion group can only contain Axis (PTP) motions.
- The reference determines the direction of the relative motion. By default, the reference is set to the TCP of the **Motion group**. Alternatively, the reference can be set to the WORLD coordinate system.
- The **Position offset** parameter can be used to specify the relative motion from the current position of the robot. Depending on this position and the respective reference coordinate system, the target position of the relative motion is obtained.
- The **Angle offset** parameter can be used to specify a relative rotation about each axis. This rotation is carried out relative to the previous rotational position and depends on the respective reference coordinate system.

Move type

- **Axis (PTP):**

  The robot guides the TCP (Tool Center Point) along the fastest path to the target point. Since the motions of all robot axes to the target point are simultaneous and rotational, the resulting path is a curved path.

  The axis (joint) motion is a fast positioning motion. The exact path of the motion cannot be predicted and depends on the override, velocity and acceleration, but can always be reproduced identically as long as these general conditions are not altered.
- **Linear:**

  The robot guides the TCP (Tool Center Point) at a defined velocity and acceleration along a straight line to the target point.
- **Circle:**

  The robot guides the TCP (Tool Center Point) at a defined velocity and acceleration along a circular segment to the end point. In order to define the radius of the circle segment, a circular segment requires two end points: the end point of the motion (**Target frame 2**) and an auxiliary point (**Target frame 1**) situated on the circular segment that is passed through on the way to the end point.
- **Spline:**

  Spline is a motion type that is particularly suitable for complex, curved paths. The path is defined by several commands of type **Move** whose end frames are located on the path. The desired path can thus be generated easily. The path always remains the same, irrespective of the override setting, velocity or acceleration. The robot moves as fast as possible within the constraints of the programmed velocity, i.e. as fast as its physical limits will allow.

10.2.1.4 Loop

A loop repeats all subordinate nodes in the specified order until a certain condition is met.

Possible conditions for exiting the loop are:

- **Count**

  The loop is executed exactly n times.
- **Timeout**

  The loop is executed for n milliseconds.
- **Infinite**

  The loop is executed for an infinite duration and not exited.

  This is suitable if the break condition is to be programmed within the loop.
- **While**

  The loop is executed as long as a condition is met, e.g. as long as a specific signal is present.
- **Until**

  The loop is executed as long as a condition is met, e.g. until a specific signal is present.

Conditions for exiting the loop cannot be nested or linked.

10.2.1.5 Wait

With this node, the program pauses until a condition is met.

Conditions for resuming the program can be the following:

- **While**

  The program is paused as long as a condition is met, e.g. as long as a signal is present.
- **Until**

  The program is paused until a condition is met, e.g. until a signal is present or a return value takes on a specific state.
- **Millis**

  The program is paused for n milliseconds.

Conditions cannot be nested or linked.

10.2.1.6 Set

This node is used to assign values by means of expressions. It is possible, for example, to set the values of signals.

> Further information about signals can be found in the help function under “I/O configuration”.

10.2.1.7 Grip & Release

The two nodes of type **Capability** are only available if a gripper is selected from a preinstalled toolbox. Both nodes open or close the gripper on the robot flange. The gripper must be configured for this.

> Further information can be found in the help function under “Payload configuration”.

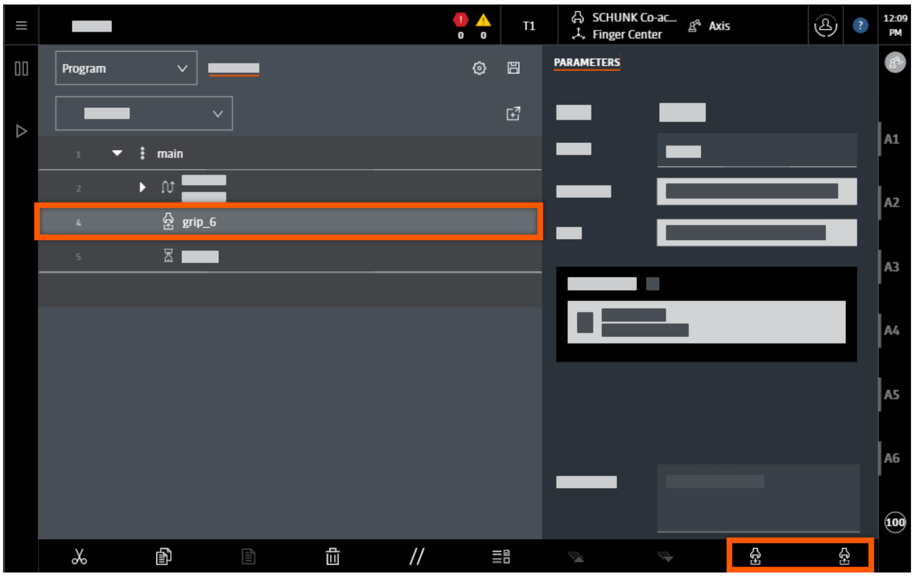


Fig. 10-3: Grip / Release

- For every **Grip** / **Release** command, a set of **Capabilities** must be selected with which it is to be executed. The tool that executes the commands is determined automatically by this set.
- To simplify program creation, the commands can be tested using the buttons in the tool bar. For this, the robot must be in T1 mode, no program may be executed and the enabling switch must be pressed.
- If several capabilities are configured, e.g. for a Custom Dual Gripper, the capability to be operated can be assigned to the buttons in the toolbar by means of quick access.
  - Pressing briefly if not yet assigned: Assign capability
  - Pressing briefly if already assigned: Operate assigned capability
  - Pressing longer: Reassign capability
- Depending on how the set of **Capabilities** is configured, the command returns a return value. This return value can be used in another following node, e.g. as a break condition for a loop or with the **Wait** command.

  This can be used, for example, to ensure that the gripper is completely open or closed before the program is resumed.

10.2.1.8 GetState

This node of type **Capability** is only available if a gripper is selected from a preinstalled toolbox. This node can be used to query the status of the gripper. The answer, e.g. **Gripped**, is saved in a variable. This variable can be used in subsequent nodes, e.g. If nodes. The variable can be inserted in the selection menu of the Expression Editor under **Library** > **Variables** > **Return Variables**.

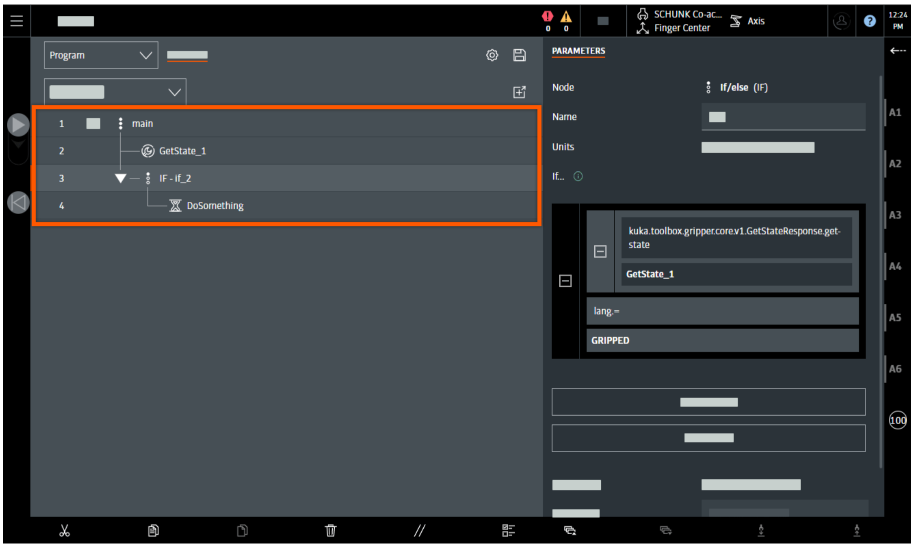


Fig. 10-4: GetState

10.2.1.9 If/else – simple branch

This node can be used to program the simplest form of a branch: If a specific condition is fulfilled, then all nodes under the If node are executed. Otherwise, they are skipped and the program is resumed at the next node.

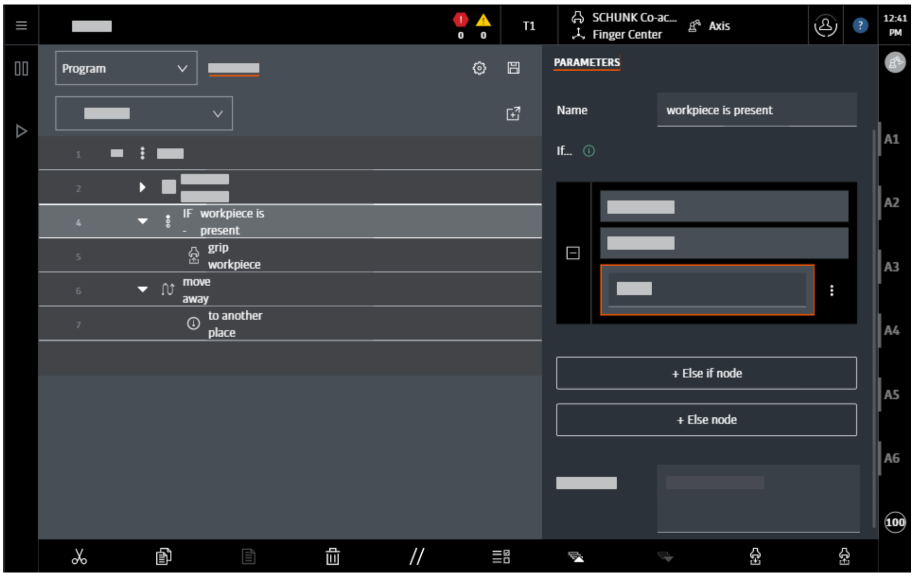


Fig. 10-5: If/else

- Conditions which are mutually exclusive, i.e. no more than one of which is to be executed in any case, are programmed in an **If/else group**.
- An If node can easily be converted to an **If/else group** by adding an Else If or an Else node in the parameter view.

10.2.2 Advanced nodes

10.2.2.1 If/else group – advanced branch

Advanced branches can be programmed using **If/else group**. It is possible to formulate multiple conditions of which at most one or exactly one is executed.

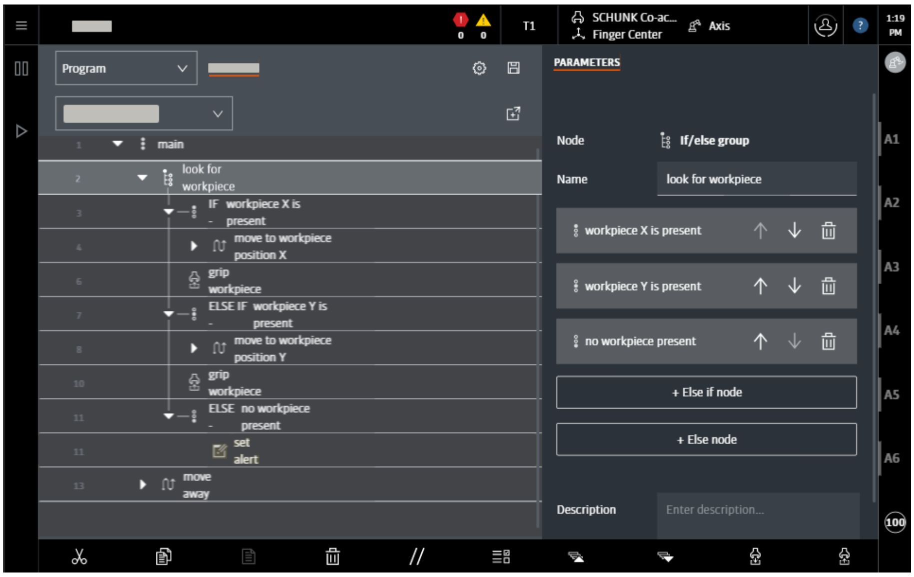


Fig. 10-6: If/else group

- Every **If/else group** begins with an If node.

  This condition is checked first. If it is met, the rest of the **If/else group** will be skipped and the program will be resumed after the **If/else group**.
- Multiple Else If nodes can be inserted after the first If node.

  These conditions are checked one after the other if the previous condition is not met. If an Else If condition is met, the subordinate branch is executed and the remainder of the **If/else group** is skipped.
- If one of the branches is to be executed in any case, insert an Else node as the last node. This is executed if none of the other conditions is met.
- In the parameter view of the **If/else group**, the order of the conditions can be changed and individual conditions can be deleted.

10.2.2.2 Break (exit loop or resume)

Description

The **Break** node can be used to exit a loop or resume it. The following break types can be selected in the parameter view of the node:

- **Break**

  Aborts the execution of the loop. The loop is exited and the program is resumed with the next command.
- **Continue**

  Aborts the current loop execution. The loop is resumed with the next loop execution.

Example

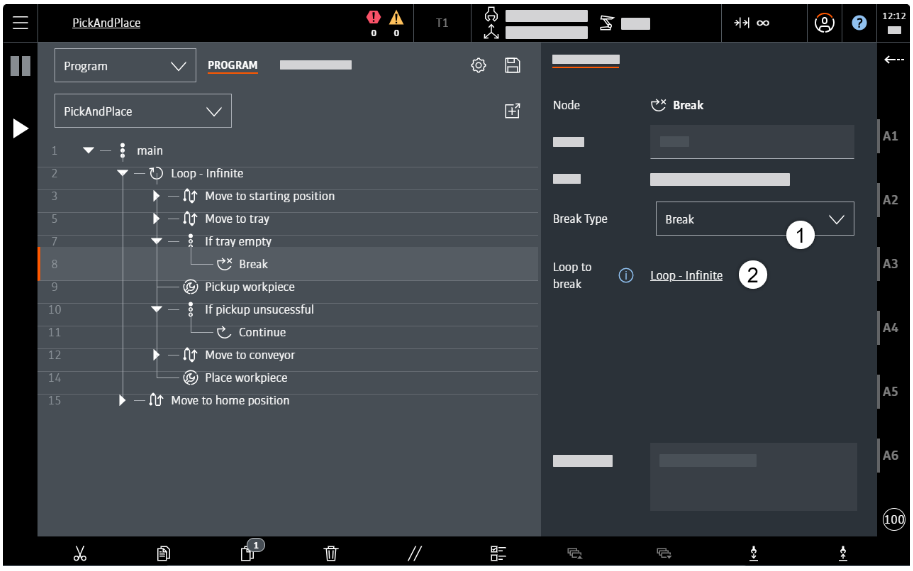


Fig. 10-7: Break node in a loop

1	Selection of break type
2	Name of the loop that is aborted

The robot takes a workpiece out of a compartment and places it on a conveyor. The loop is executed as long as workpieces are available. If a workpiece is available, but the robot cannot pick it up, the robot attempts it again from the start position.

Line	Description
2 … 14	Endless loop
7 … 8	**Break** When the compartment is empty, the loop is exited and the program is resumed at line 15.
10 … 11	**Continue** If the removal of the workpiece was unsuccessful, the rest of the loop is skipped. The program jumps back to line 3.

10.2.2.3 Halt (pause or reset program)

There are two different types of **Halt type** available:

- **Pause**
  The program is paused. Pressing the Start key again resumes it at the same point; alternatively, the program can be reset manually.
- **Stop and reset**
  The program is terminated and reset. The next time it is executed, it is started from the beginning.

10.2.2.4 Subroutine (creating a subprogram)

The **Subroutine** node creates a new subroutine (subprogram). Subroutines are small portions of a program that can be used multiple times in a program. The subroutine is created on the **Subroutines** tab and can be edited there. In the program, the subroutine is declared below the first **Sequence** node.

(>>> *10.5 "Creating and executing subroutines" Page 202*)

10.2.2.5 Execute (execute subprogram)

The **Execute** node enables the execution of a predefined subroutine. In the parameter view, the subroutine that is to be executed can be selected under **Subroutine**. The subroutine is executed in the program at the point where the node is located in the program structure. Once the subroutine is completed, the program structure is resumed at the next node.

10.2.2.6 Position hold (holding position under impedance control)

The motion command **Position hold** makes it possible to hold an impedance-controlled robot at its Cartesian setpoint position for an adjustable period of time.

> The **Position hold** motion command cannot be used in a motion group (**Motion group**) and combined with **Move** nodes.

(>>> *10.7.3 "Holding position under impedance control" Page 214*)

10.3 Editing the program structure

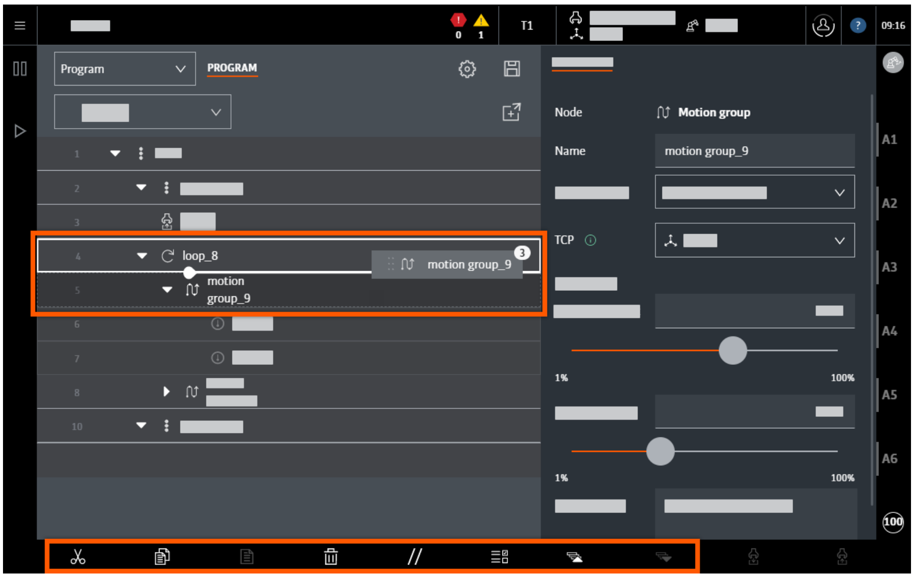


Fig. 10-8: Editing the program structure

- To move a node and all its child nodes, hold it down until it is highlighted.
- Drag the node to the desired position. A white line displays the insertion position and the hierarchy level at which the node will be inserted.
- If nodes are nested in an impermissible manner and the hierarchy is invalid, the node in question is highlighted in yellow.
- The tool bar at the bottom of the screen contains additional functions for modifying the program structure:
  - Cut selected nodes.
  - Copy nodes.
  - Paste copied nodes.

- Delete selected nodes or entire branches.
- Deactivate selected nodes.

  Deactivated nodes are skipped during program execution and are not executed; they are commented out.
- Toggle between single selection and multiple selection of nodes.
- Expand or collapse all child nodes of the node currently selected.

• Nodes can also be exchanged between different programs via the commands in the tool bar.

• Nodes are inserted with default designations. Each node can be renamed to provide a better overview.

> Node deletion cannot be undone and moved nodes can only be manually moved back to their previous position. For this reason, save changes regularly during programming. Undesired changes can then be discarded by closing the program without saving.

10.4 Program variables

Overview

The **Variables** tab is available in the first node of a program (sequence with the default name **main**). There, variables for the program can be created, edited with the Expression Editor or deleted.

- The variables are valid throughout the program and are initialized when the program is started
- Variable values can be defined as constant
- Common data types are, for example, number, boolean, Vec3, quaternion
- The variables are available in the selection menu of the Expression Editor under **LIBRARY** > **Variables**
- The variables can be used in expressions:
  - Variable values can be read in corresponding nodes, e.g. in “if” conditions
  - Variable values can be written in the **Set** node
- If the program is restarted, the variables are initialized with the specified value.

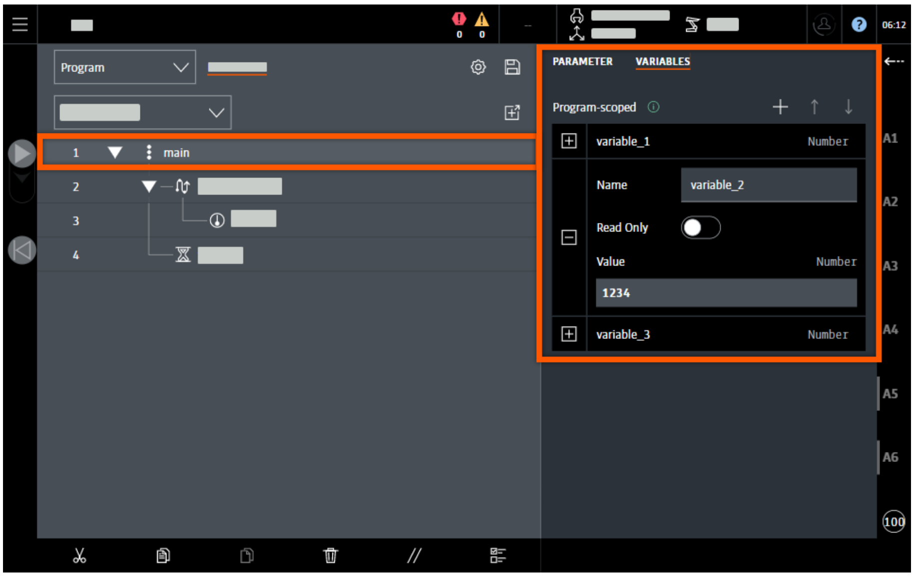


Fig. 10-9: Variables

10.4.1 Creating value with new data type

Description

By default, a newly created variable receives a value of type "Number". To change the data type, proceed as follows. The procedure also applies if the data type has to be changed again during subsequent processing of the variable.

Procedure

1. Deleting default value/current value: To do so, select the value and select **Delete** from the context menu.
2. The value is now undefined. Select a new data type in the selection menu of the Expression Editor.

10.4.2 Example of a program variable

Description

An axis-specific home position is created as a variable for a program and used in a PTP motion to the home position.

Procedure

Create variable:

1. Add a new variable, select the default value and delete it via the context menu.
2. To enter axis positions in degrees, select **LIBRARY** > **Functions** > **robot** > **Joint6** > **from-deg()** in the selection menu.

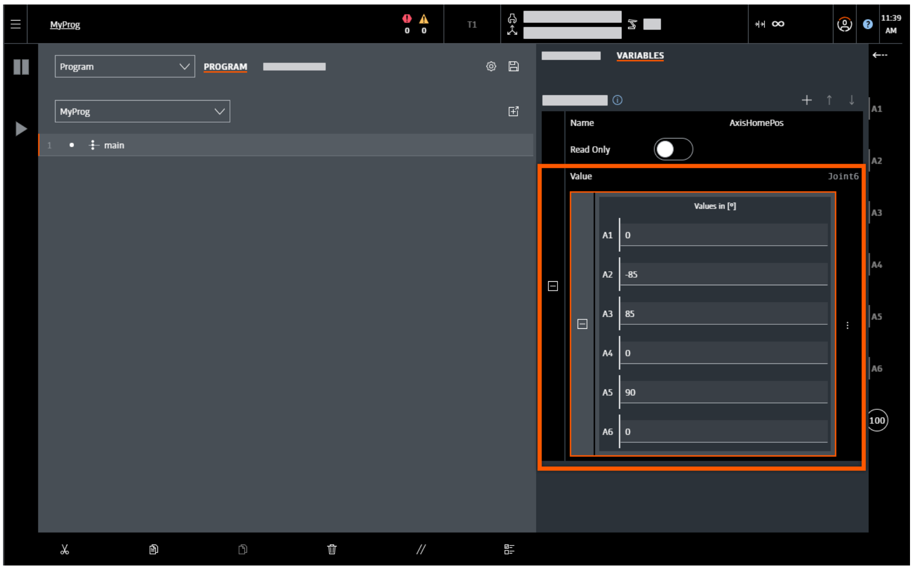


Fig. 10-10: Axis-specific home position as a variable

Use variable in motions:

1. In the motion group, select the motion type **Axis (PTP)** and the robot flange as the TCP.
2. In the motion, select the target type **Axis target**.
3. Select the axis values in the target type and delete them via the context menu.

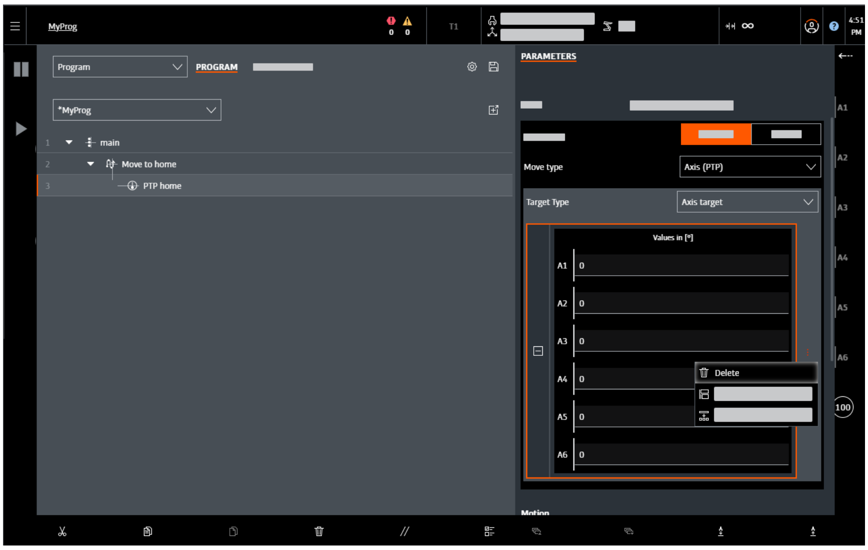


Fig. 10-11: Deleting axis values in target type

4. Apply the variable in the target type: For this, select the variable under **LIBRARY** > **Variables**.

10.5 Creating and executing subroutines

Description

Subroutines (subprograms) are small portions of a program that can be used multiple times in a program. Subroutines can be created in the Feature menu **Program** via the **Subroutines** tab. The subroutines in the program can be executed via the **Execute** node. A subroutine can use all variables whose validity range includes the **Subroutine** node.

Procedure

Creating subroutines:

1. In the **Program** Feature menu, open the **Subroutines** tab.
2. Press **New subroutine**.
3. Assign a name for the subroutine.
4. Create the subroutine by adding nodes.
   Nodes can also be copied from the program and inserted into the subroutine.
5. Save the subroutine.

Executing subroutines:

1. In the **Program** Feature menu, open the **Program** tab.
2. Open the node palette and switch to the **ADVANCED** tab.
3. Insert the **Execute** node at the desired point.
4. Select the desired subroutine in the parameter view under **Subroutine**.

10.6 Expression Editor

Description

The Expression Editor extends the programming capability of variables and nodes. Logical operators and mathematical functions enable the programming of complex expressions. The expressions are evaluated during the runtime of the program.

> Unless otherwise stated, the expressions indicate lengths in millimeters (mm) and angles in degrees (°). The system calculates in the background for lengths in meters (m) and axis angles in radians (rad). Therefore, when expressions are edited, values may be displayed in the converted unit.

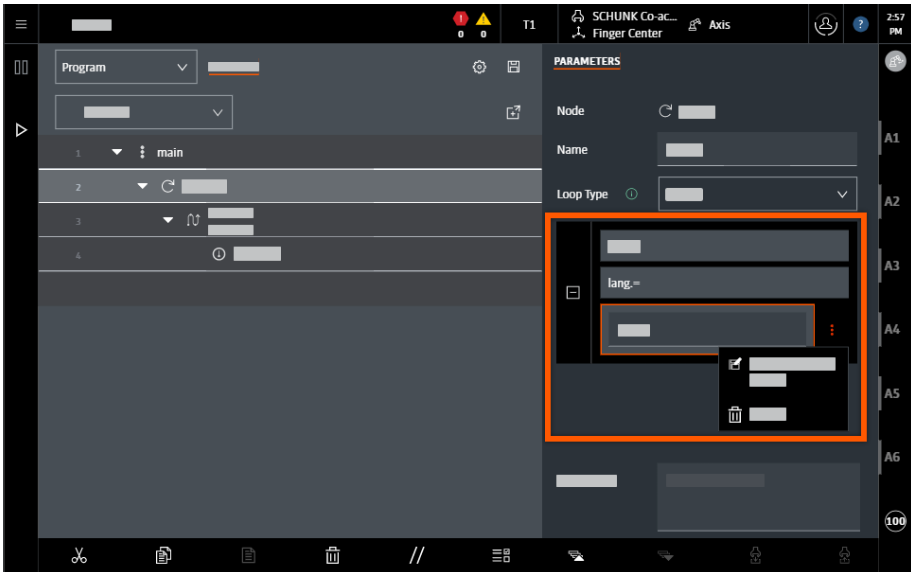


Fig. 10-12: Expression Editor

- The Expression Editor is recursive. Any number of expressions can be nested together in a logic command.
- The Expression Editor only allows type-safe entries.
- Press on an empty expression to open a selection menu.

- Under **BASICS**, the selection menu suggests useful programming options for filling in the expression. All of the programming options available in the context, such as data, variables and functions, can be found under in the **LIBRARY**.
- Placeholders are displayed for mathematical operations, e.g. **? + ?** for addition. **0** must be selected for entering numbers.
- Values can be entered and edited using the keyboard.
- There is a context menu at the edge of each expression. The context menu can be used, for example, to open full screen mode or to delete the expression.
- Beyond a certain nesting depth, expressions can only be edited in full screen mode.
- Certain logic commands, e.g. the **Wait** node, are displayed in a simplified view (short form). They can also be displayed in their long form via the context menu.
- Expressions can be expanded and collapsed using the plus and minus icons.

Full screen mode

The Expression Editor can be opened in full screen mode in order to edit complex expressions in a larger view. To do so, select the desired expression and open the context menu at the side.

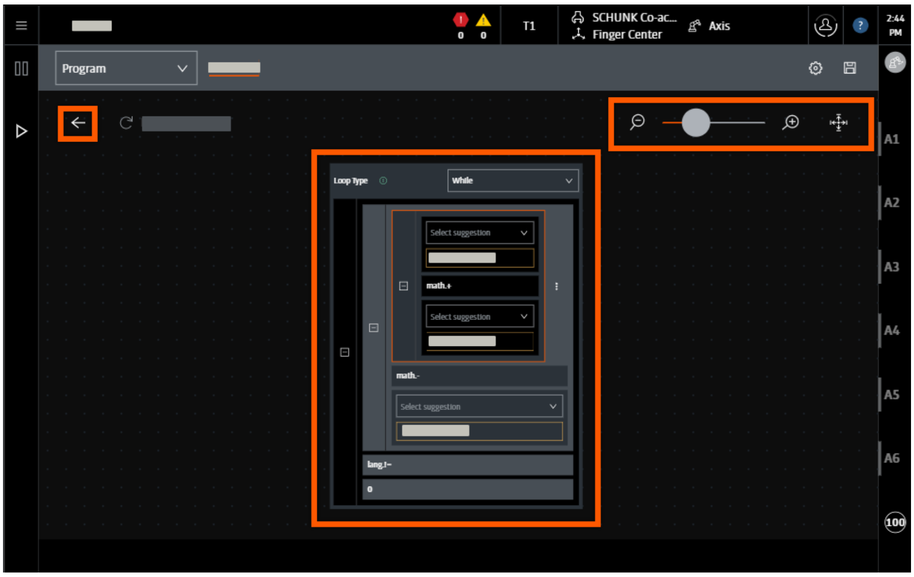


Fig. 10-13: Expression Editor in full screen mode

- The Expression Editor can be moved freely on the screen.
- Move the slider between the magnifying glass icons to reduce or enlarge the Editor.
- Press the button (**Zoom to fit**) next to the magnifying glass icons to reset the view and align the Expression Editor to the left.
- Press the left arrow to exit full screen mode.

10.6.1 Functions in the Expression Editor

Description

The following namespaces are available in the Expression Editor:

Name-space	Description
geo	Functions and data types with reference to the modeled world
kuka	Functions and data types from toolboxes
lang	Basic functions and data types
math	Computational functions and mathematical data types
nodes	Data types with reference to specific nodes
robot	Functions and data types with reference to the robotics
trigger	Functions and data types for configuring triggers

The elements of a namespace are divided into the following menus by means of automatic categorization:

- **Data**

  The elements used to generate a data structure directly are always located under *Data*. These elements are referred to as constructors.
- **Functions**

  All remaining functions can be found under *Functions*.
- **Variables**

  All remaining values that are not functions can be found under *Variables*.

Structure of Expressions

Expressions are composed of function calls, values, variables and some other constructs. There is exactly one constructor function for most data types.

Many functions accept 2 parameters. Functions can, however, also accept only one or multiple parameters.

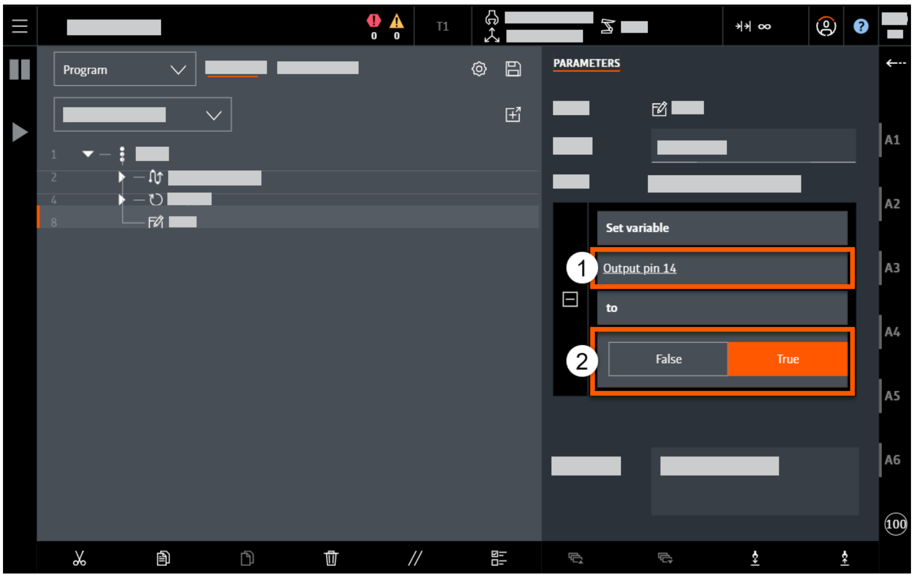


Fig. 10-14: Example of a function call

1 1st parameter: Variable reference

2 2nd parameter: Value of the variable reference

The values to be specified depend on the selected variable type. For example, if a variable reference of the *Boolean* data type is selected, only one Boolean value can be entered.

Functions as value
It is possible to treat functions as values. Functions proposed as "*Function as value*" can be transferred to other functions or saved as variables.

10.6.2 Namespace lang

Description

The **lang** namespace contains basic programming options.

Expressions

Call:

- Under Library, select **Functions** > **lang**.

Expression 1st level	Expression 2nd level	Description
Ref	get-id	Function accepts a *lang.Ref* and returns the value of the attribute "id".
? = ?		Function compares if 1st and 2nd parameters are equal.
? != ?		Function compares if 1st and 2nd parameters are unequal.
? or ?		Function checks whether 1st or 2nd parameter is true.
not(?)		Function negates a logical expression.
? and ?		Function checks whether the 1st and 2nd parameters are true.
if(cond: ?, then: ?, else: ?)		Conditional expression: Function accepts a Boolean value *cond* as well as the values *then* and *else*. If *cond* is true, the result is *then*. Otherwise, it is *else*.

10.6.2.1 lang.List data type

Description

The **lang.List** data type represents lists of any length.

Expressions

Call:

- Under Library, select **Functions** > **lang** > **List**.

Expression 1st level	Expression 2nd level	Description
Cons	get-head(?)	Function reads the header element of a non-empty list.
	get-tail(?)	Function reads the rest (all elements except header elements) of a non-empty list.

Expression 1st level	Expression 2nd level	Description
is-Nil?(?)		Function checks whether a list is an empty list.
? concat ?		Function appends the second list to the first.
get(value: ?, at: ?)		Function accepts a list value *value* and a number *at*. Function returns the list element at this index.
filter(pred: ?, value: ?)		Function returns a list containing only the *value* elements that are true when applied to *pred*.
map(func: ?, value: ?)		Function returns a new list where each element has been converted from *value* to *func* through application.
reverse(?)		Function returns a list consisting of the elements of *value* in reverse order.
set(value: ?, at: ?, to: ?)		Function returns a list. The element *at* is replaced by *to*.
length(?)		Function returns the number of characters or elements in this object.
is-Cons?(?)		Function checks whether a list is a non-empty list.

Constructors

Call:

- Under Library, select **Data** > **lang** > **List**.

Constructor	Description
Cons(head: ?, tail: ?)	Constructor generates a list from a header element and another list.
Nil	The constant *Nil* is an empty list.

10.6.2.2 Data type “lang.Maybe”

Description

The data type “**lang.Maybe**” represents optional values.

Expressions

Call:

- Under Library, select **Functions** > **lang** > **Maybe**.

Expression	Description
get-value(?)	Function returns the value of a *Maybe* if it was created via *Just*.
is-Nothing?(?)	Function checks whether a *Maybe* really is a *Nothing*. An optional value is missing.
is-Just?(?)	Function checks whether a *Maybe* really is a *Just*. An optional value is present.

Constructors

Call:

- Under Library, select **Data** > **lang** > **Maybe**.

Constructor	Description
Just(?)	Constructor creates a *Maybe* with a contained value.
Nothing	*Nothing* is the constant for a *Maybe* with no value in it.

10.6.3 Namespace math

Description

The namespace **math** contains mathematical operations and data types.

Expressions

Call:

- Under Library, select **Functions** > **math**.

Expression 1st level	Expression 2nd level	Description
Vec3	get-x(?)	Function supplies the X component of the 3 vector.
	get-y(?)	Function supplies the Y component of the 3 vector.
	from-mm(x: ?, y: ?, z: ?)	Function creates a vector (in m) from components in millimeters.
	get-z(?)	Function supplies the Z component of the 3 vector.
Vec6	get-x1(?) … get-x6(?)	Function supplies the X1 … X6 component of the 6 vector.
Quaternion	Rotation(rx: ?, ry: ?, rz: ?)	Generates a quaternion from three Euler angles in the KUKA convention. Here, the angles are specified in degrees.
	get-w(?) … get-z(?)	Function supplies the W, X, Y or Z component of the quaternion.
? + ?		Function adds the 1st and 2nd parameter.
cos(?)		Cosine function The argument is expected in radians.
? * ?		Function multiplies the 1st and 2nd parameter.
? >= ?		Function compares whether the 1st parameter is greater than the 2nd parameter or equal to the 2nd parameter.
? <= ?		Function compares whether the 1st parameter is smaller than the 2nd parameter or equal to the 2nd parameter.

Expression 1st level	Expression 2nd level	Description
? - ?		Function subtracts the 2nd parameter from the 1st.
? / ?		Function divides the 1st parameter by the 2nd.
neg(?)		Function negates the parameter.
deg-to-rad(?)		Function converts from degrees to radians.
sin(?)		Sine function The argument is expected in radians.
rad-to-deg(?)		Function converts from radians to degrees.
? < ?		Function compares whether the 1st parameter is smaller than the 2nd parameter.
? > ?		Function compares whether the 1st parameter is greater than the 2nd parameter.
? % ?		Function carries out integer division using the 1st and 2nd parameter and returns the remainder.

Constructors

Call:

- Under Library, select **Data** > **math**.

Constructor	Description
Rotation(rx: 0, ry: 0, rz: 0)	Constructor creates a rotation from three Euler angles. The resulting value is of type *math.Quaternion*.
Vec3(x: ?, y: ?, z: ?)	Constructor creates a 3 vector.
Vec6(x1: ?, x2: ?, x3: ?, x4: ?, x5: ?, x6: ?)	Constructor creates a 6 vector.

10.7 Programming of a compliant robot

Overview

Robots with integrated joint torque sensors can be moved under impedance control. Impedance control can be parameterized for a motion group (node **Motion group**) and for the motion command **Position hold**.

(>>> *10.7.3 "Holding position under impedance control" Page 214*)

The following control modes are available on the **Sensitivity** tab of the specified nodes:

- **Position Control** (default)
  Position control is preselected by default. In position control, the robot is not compliant and follows the programmed path as accurately as possible. Position control has no adjustable parameters.

- **Cartesian impedance**

  Cartesian impedance control can be used if the robot is to react in a compliant manner to external forces/torques, e.g. to obstacles on the programmed path or process forces.

  (>>> *10.7.1 "Cartesian impedance control" Page 210*)
- **Axis impedance**

  Axis impedance control can be used if one or more axes are to react in a compliant manner to external forces/torques.

  (>>> *10.7.2 "Axis impedance control" Page 213*)

The control mode selected in a **Motion group** node as well as its parameters apply to all motions of this motion group.

10.7.1 Cartesian impedance control

Description

The Cartesian impedance control is modeled on a virtual spring damper system with configurable values for stiffness and damping. This spring is extended between the setpoint and actual positions of the TCP. As a result, the robot reacts in a compliant manner to externally applied forces or torques.

(>>> *10.7.1.1 "Calculation of the forces on the basis of Hooke's law" Page 211*)

Compliance can also be used to apply Cartesian forces or torques to the robot in a targeted manner. These applied forces and torques overlay the forces and torques generated by the spring stiffness.

Cartesian impedance control always refers to the TCP (motion frame) set in **Motion group** node or **Position hold** node. The values for stiffness, damping and overlaid forces/torques can be set for each of the 6 degrees of freedom for this frame.

- Translational degrees of freedom: X, Y, Z
- Rotational degrees of freedom: Rx, Ry, Rz

Stiffness

The stiffness parameters determine how much the robot yields when a force is applied.

- If a low stiffness is set for a degree of freedom, the robot is very compliant in this direction. It reacts to obstacles and external forces by deviating from its path.
- Conversely, high stiffness leads to good path tracking with low compliance along the degree of freedom.

WARNING

Risk of unpredictable motions with zero stiffness

Setting zero stiffness can cause the robot to move freely and uncontrollably in the corresponding directions. This particularly applies to joint torque sensors that are not properly mastered. Injuries or damage to property may result.

- Use zero stiffness values only in contact situations combined with external force application in order to achieve a controlled application of force.

Damping

The damping parameters determine how much the robot oscillates after a force has been applied.

- If high damping is set for a degree of freedom, the oscillation is reduced in this direction.

Force/Torque overlay

External Cartesian forces and torques can also be applied here. These overlay the Cartesian forces and torques that result from the spring stiffness.

WARNING
Risk of injury and damage to property due to strong acceleration of the robot in the direction of force application An application of force can result in strong acceleration and rapid motion of the robot in the corresponding direction. Injuries or damage to property may result. • Only apply forces if the robot has already moved on contact in the corresponding direction.

Example

High stiffness is set in the Z direction of the TCP (motion frame) and low stiffness in the X/Y direction. In this way, the TCP can follow the programmed path well during a motion in the tool direction Z and at the same time swerve in the XY plane.

10.7.1.1 Calculation of the forces on the basis of Hooke's law

Description

If the measured and specified robot positions correspond, the virtual springs are slack. As the robot's behavior is compliant, an external force or a motion command results in a deviation between the setpoint and actual positions of the robot. This results in a deflection of the virtual springs, leading to a force in accordance with Hooke's law.

The resultant force F can be calculated on the basis of Hooke's law using the set spring stiffness C and the deflection Δx:

$F = C \cdot \Delta x$

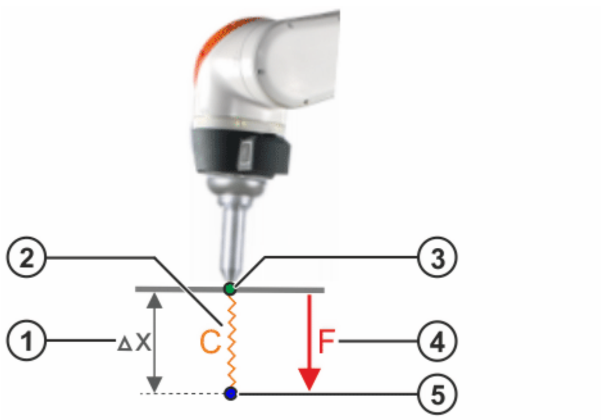


Fig. 10-15: Virtual spring with spring stiffness C

1	Deflection Δx
2	Virtual spring

3 Actual position
4 Resulting force F
5 Setpoint position

If the robot is at a resistance, it exerts the calculated force. If it is in free space, it moves to the setpoint position. On the way to the setpoint position, path deviations occur due to internal frictional forces in the joints. The extent of these deviations depends on the set spring stiffness. Higher stiffness values lead to smaller deviations.

If the robot is already at the setpoint position and an external force is applied to the system, the robot yields to this force until the forces resulting from compliance control cancel out the external forces.

Examples

The force exerted at the contact point depends on the difference between the setpoint position and the actual position and the set stiffness.

Fig. 10-16: Force exerted on contact

As shown in the figure (>>> *Fig. 10-16*), a large position difference and low stiffness can result in the same force as a smaller position difference and greater stiffness. If the force is increased by a motion in a contact situation, the time required to reach this force differs if the Cartesian velocity is identical.

If higher stiffness values are used, a desired force can be reached earlier, as only a small position difference is required. Since the setpoint position is reached quickly, a jerk can be produced in this way.

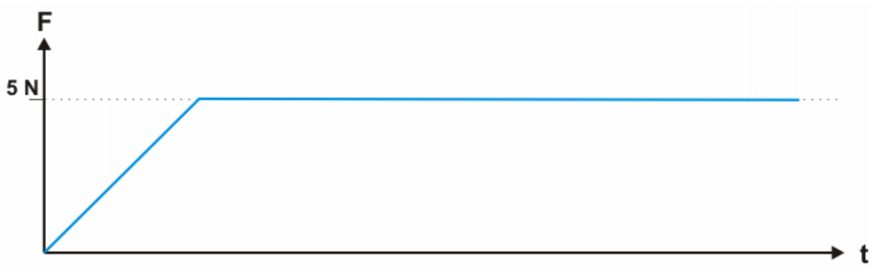


Fig. 10-17: Force over time (high stiffness, small position difference)

In the case of a large position difference and low stiffness, the force is built up more slowly. This can be used, for example, if the robot moves to the contact point and the impact loads are to be reduced.

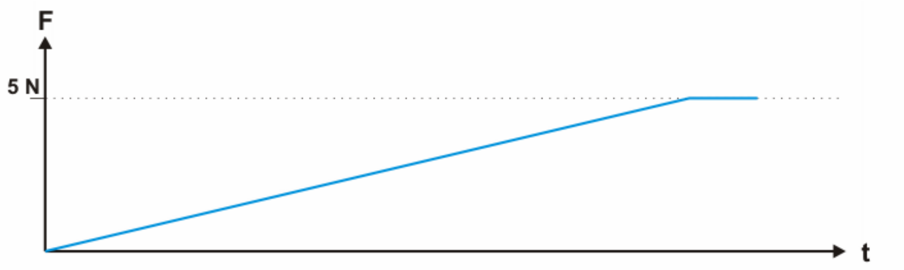


Fig. 10-18: Force over time (low stiffness, large position difference)

Setpoint/actual deviations in more than one direction lead to deflection of all the affected virtual springs. The magnitude and direction of the overall force results from vector addition of the individual forces for each direction.

The deflection in the X direction by Δx and in the Y direction by Δy result in force F_x in the X direction and F_y in the Y direction. The vector addition results in the overall force F_{res}.

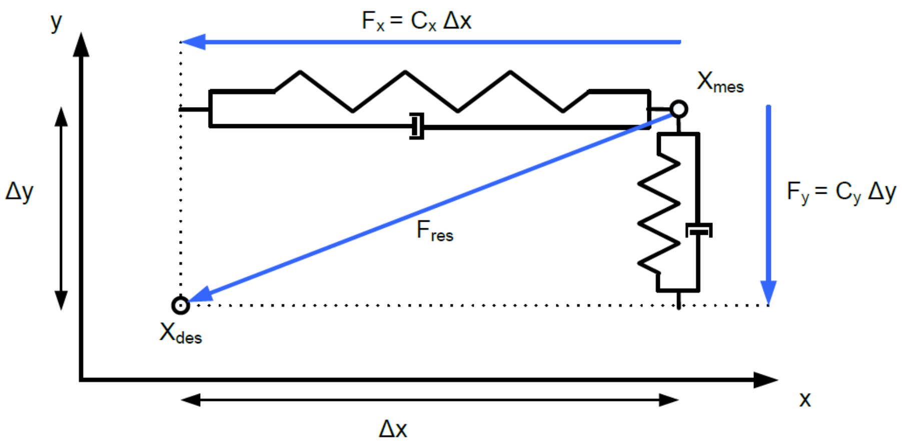


Fig. 10-19: Overall force in the case of deflection in 2 directions

10.7.2 Axis impedance control

Description

With axis impedance control, the following parameters can be set for each individual axis:

- **Stiffness**
  The stiffness parameter determines the degree of compliance of an axis when force is applied
  - If a low stiffness is set for an axis, the axis is very compliant and can be easily moved by hand.
  - Conversely, high stiffness for an axis results in low compliance.

WARNING

Risk of unpredictable motions with zero stiffness
Setting zero stiffness can cause the robot to move freely and uncontrollably in the corresponding directions. This particularly applies to joint torque sensors that are not properly mastered. Injuries or damage to property may result.

- Use zero stiffness values only in contact situations combined with external force application in order to achieve a controlled application of force.

- **Damping**

  The damping parameters determine how much an axis oscillates after a force has been applied

  - If high damping is set for an axis, the oscillation is reduced.

10.7.3 Holding position under impedance control

Description

Using the **Position hold** motion command, the robot can hold its Cartesian setpoint position over a set period of time and remain under servo control.

This can be used in combination with corresponding settings for impedance control so that the robot exerts corresponding forces and/or torques at the current position. In addition, the impedance-controlled robot can respond in a compliant manner to external forces – thus enabling, for example, position corrections.

During a **Position Hold**, the impedance-controlled robot can be brought away from its setpoint position by external forces. Whether and in which direction the robot moves from the setpoint position depends on the set controller parameters and the resulting forces.

The **Position hold** motion command cannot be used in a motion group (**Motion group**) and combined with **Move** nodes.

Parameters

The following parameters can be defined on the **Parameters** tab:

- **TCP**

  The TCP defines the motion frame to which the parameters of the Cartesian impedance control refer (not relevant for position control or axis impedance control).

- **Duration**

  The following switches can be used to define how long the motion command **Position hold** is executed.

  - **Fixed**: The exact duration can be set (default: 10000 ms).
  - **Infinite**: If this switch is active, the duration is not limited.

    The command can only be aborted by means of a stop condition (trigger with action **Break**).

Triggers

In addition to the defined duration, a condition can be programmed on the **Triggers** tab in order to cancel the motion command.

(>>> *10.8 "Trigger programming" Page 216*)

Example

A robot is to move on contact and press against a workpiece for 5 seconds with a force of 15 N in the contact direction.

1. Move the robot into the contact position, e.g. by means of manual guidance or by a programmed motion used for moving on contact.

   Example of programming a motion to contact: (>>> *"Example" Page 218*)
2. Program the motion command **Position hold** for a duration of 5 seconds with Cartesian impedance control.
   - Maximum stiffness and damping in all directions, with the exception of the contact direction, zero stiffness there
   - External force application of 15 N in the contact direction

10.7.4 Notes on using impedance control

Setpoint-actual comparison

In a setpoint-actual comparison, the commanded position (setpoint) of the robot is compared to the actual position (actual) of the robot. This corrects a possible deviation of the setpoint position from the actual position in the case of compliant impedance control. This prevents unexpected jumps from occurring if the stiffness of the robot changes.

- If a change is made from a motion under impedance control to another motion (**Motion group** or **Position hold**), an automatic setpoint-actual comparison of the robot position is always carried out. Exception: The subsequent motion is an impedance-controlled motion with identical parameters.
- If no further motion follows, a setpoint-actual comparison is carried out when the brakes of the robot are applied. A simultaneous relaxation of any contact forces that may be present is also carried out.
- If an application is paused during the execution of a motion under impedance control, setpoint-actual comparison is carried out when the brakes are applied.

Repositioning

Setpoint-actual comparison while a motion is paused under impedance control has the effect that the application cannot be resumed until the robot has been repositioned using the Start key.

The motion back to the setpoint position is always carried out using the controller parameters of the paused motion.

It is advisable to perform repositioning approximately from the position at which the motion was interrupted. If this is not observed, it may be that the motion is not resume from the position at which it was actually interrupted.

WARNING

Risk of injury and damage to property due to strong acceleration of the robot during repositioning with external force application

If an impedance-controlled motion with external force application has been paused, repositioning with external force application also takes place. If the robot is in free space during repositioning, this can lead to strong accelerations of the robot. Injuries or damage to property may result.

- Manually bring the robot back in contact before repositioning.

10.8 Trigger programming

Description

Triggers can be programmed in the **Motion group** node and the **Position hold** node.

Triggers consist of a condition and an action. The action is executed if the condition is fulfilled.

The following condition types can be programmed on the **Triggers** tab of the above-mentioned nodes:

- Force component condition

  The condition is met if the external Cartesian force measured along the set axis of the set TCP lies outside a defined range (**Min**…**Max**).
- Torque component condition

  The condition is met if the external Cartesian torque measured about the set axis of the set TCP lies outside a defined range (**Min**…**Max**).

If the condition is met, the **Break** action is triggered by default. This action ends the current motion (**Motion group** or **Position hold**) and executes the next program command. Other actions cannot be programmed.

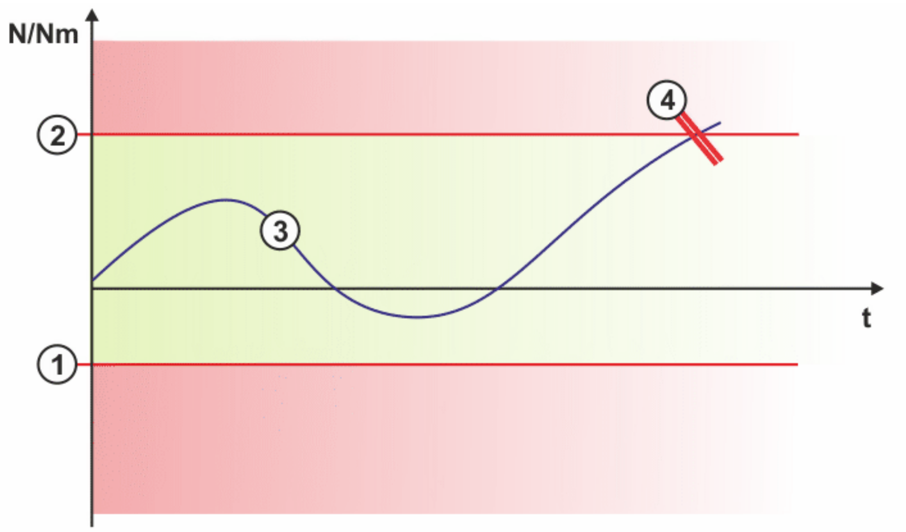


Fig. 10-20: Trigger: Cancellation of motion due to force or torque

1	Minimum external force/minimum external torque
2	Maximum external force/maximum external torque
3	Measured external force/measured external torque
4	Action **Break** is triggered

Furthermore, the negation of a force component condition or torque component condition can be programmed. The negation of a condition is met if the measured external force or the measured external force torque is within a defined range (**Min**…**Max**).

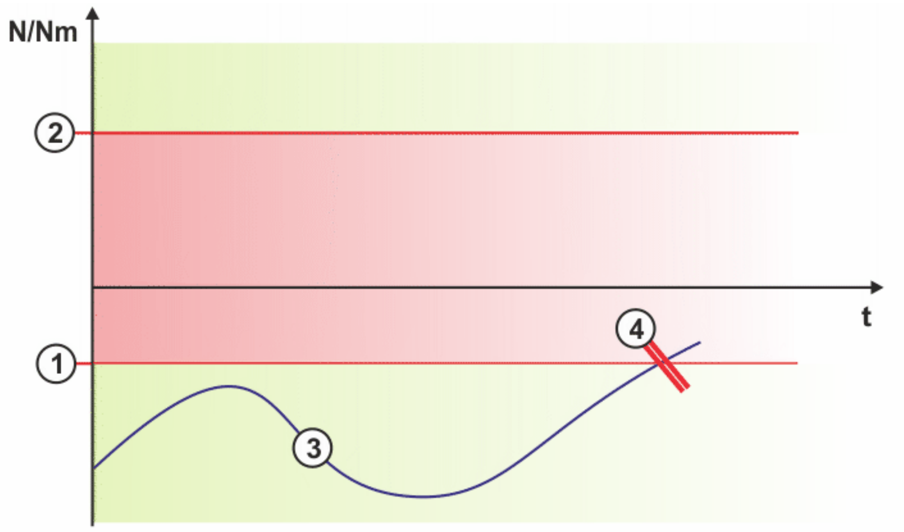


Fig. 10-21: Trigger: Cancellation of motion due to force or torque (negation “not”)

1	Minimum external force/minimum external torque
2	Maximum external force/maximum external torque
3	Measured external force/measured external torque
4	Action **Break** is triggered

Procedure

1. On the **Triggers** tab of the nodes **Motion group** or **Position hold**, press the **Add trigger** button.
2. Assign a name for the trigger.
3. Select the type of condition:
   - **Force Component**
   - **Torque Component**
   - **Not**

     Negation of a force component condition or torque component condition; see step 5.
4. Define the parameters of the condition:
   - **Measuring axis**

     Axis of the measurement frame at which the external force or torque is measured
   - **Measurement Frame**

     Reference frame for measuring the external force or torque
   - **Min**

     Minimum value for the external force or the external torque
   - **Max**

     Maximum value for the external force or the external torque
5. If the condition type **Not** is selected, proceed as follows:

   a. Select the following entry under **LIBRARY** in the selection menu of the Expression Editor:
      - **Data** >**Trigger** > **ForceComponent(…)** or **TorqueComponent(…)**

   b. In order to be able to define the parameters of the condition, the expression must be opened in full-screen mode. To do so, select the expression and select the corresponding entry in the context menu to the right.

Example

Move robot on contact

As soon as contact is established and a defined force is measured, a trigger is triggered and the motion is stopped.

1. Bring the robot into the pre-position for the expected contact.
2. Create the **Motion group** node.
3. Program the search run as a relative motion (LIN) in the direction of the expected contact.
   a. Select TCP.
   b. Select tool direction Z.
4. Configure Cartesian impedance control on the **Sensitivity** tab of the **Motion group** node.
   a. Set maximum stiffness and damping in all directions.
   b. Set stiffness to medium stiffness in search direction (1000 N/m).
5. On the **Triggers** tab, add a trigger with the condition **Force Component** to the search run.
   - Select measuring axis **Z** to measure the force along the Z axis of the TCP.
   - Set minimum force to -10 N.
   - Set maximum force to high value, e.g. to 100000 N.

> If, in the search direction, a force of < -10 N is measured during the search run, the trigger is triggered and the motion stops. The measured contact forces act against the direction of travel.

10.8.1 Checking whether trigger is triggered

Description

Whether a trigger programmed for a motion group has been triggered can be checked as follows.

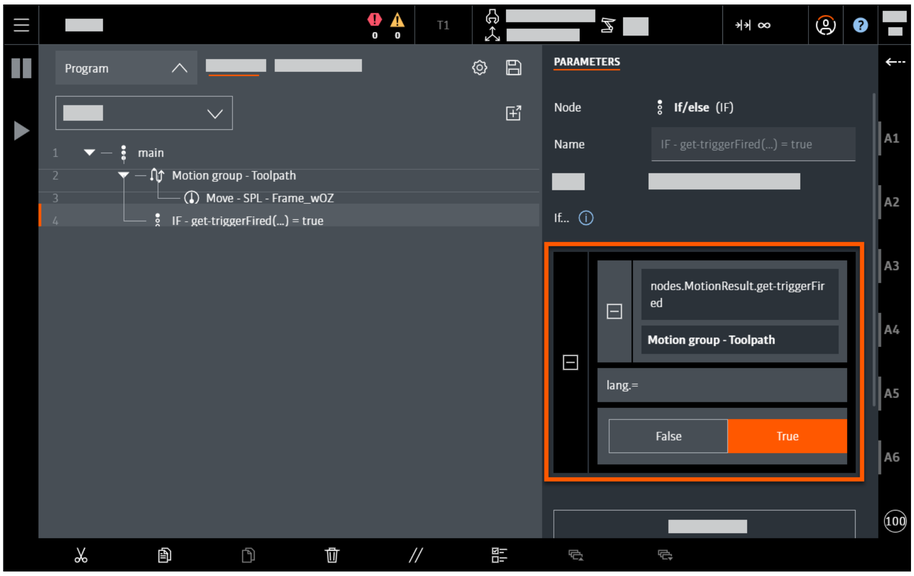


Fig. 10-22: Checking whether trigger is triggered

Procedure

1. Create and select a **If/else** node in the motion group.
2. Set the 1st operator in the **If/else** node:
   a. Select 1st value: *Functions* > *nodes* > MOTIONRESULT *get-triggerFired(?)*
   b. Select 2nd value: *Variables* > RETURN VARIABLES

> The return variable has the same name as the motion group.

3. Compare the result of the trigger with the desired value:

> Operand *lang.*= is preset.

   - Set the 2nd operator to true/false in the **If/else** node.

   The result is a Boolean value:

   - True: Trigger is triggered.
   - False: Trigger is not triggered.

10.9 Grid Patterns toolbox

Overview

The Grid Patterns toolbox is pre-installed on the robot controller. Grid patterns make it possible to move the robot by means of a programmed pattern.

Grid patterns are defined in the scene editor and in the capabilities. Grid patterns can be integrated into programs.

10.9.1 Defining grid patterns in scene

Procedure

1. In the Feature menu, select **Scene**.
2. In the object selection menu, select **Devices** > **Grid Patterns**.

> A new grid pattern can only be created under **World**.

3. Show the object tree and check whether the grid pattern has been created.
4. Rename grid pattern.
5. Manually enter coordinates in the parameter view.
6. In the object tree, select **World**.
7. Select **Frame** in the object selection menu. The first frame is added.
   Overall, the following frames must be created:
   - Origin
   - Corner X
   - Corner Y
   - Iteration
8. Specify frame accordingly.
9. Move the robot to the desired position by jogging or manual guidance and record the frame via **Touch up**.

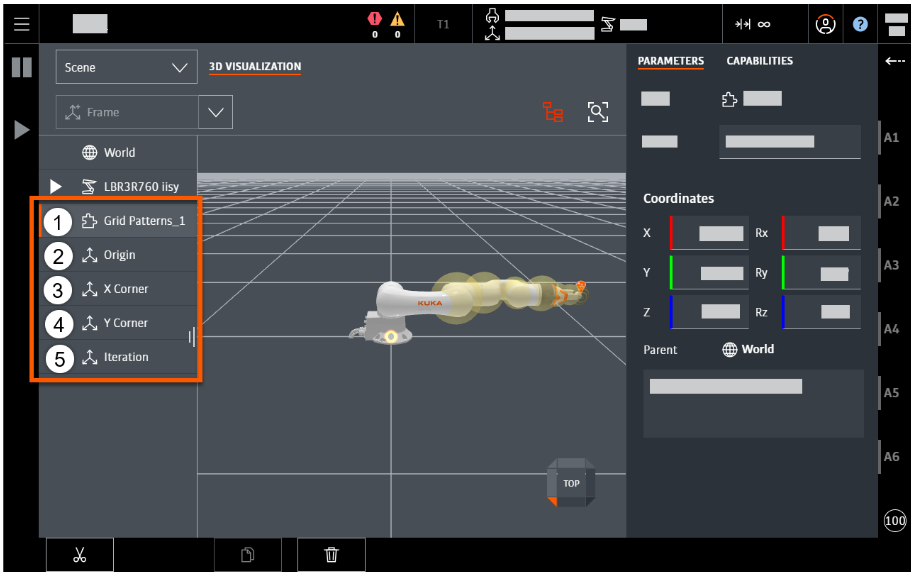


Fig. 10-23: Grid patterns in scene - Example

1 Grid Patterns

2 Origin

This frame defines the gripper orientation at the removal points.

By default, the cell index is 0. The cell index can be changed manually in the Feature menu **Capabilities** in the Parameter view.
(>>> *10.9.2 "Defining grid patterns in capabilities" Page 220*)

3 Corner X

This frame defines the direction of the first iteration.

4 Corner Y

This frame defines the direction of the second iteration.

5 Iteration

This frame can be generated at any position.

10.9.2 Defining grid patterns in capabilities

Precondition

- At least one grid pattern has already been created in the scene editor.

Procedure

1. In the Feature menu, select **Setup** > **Capabilities**.
2. Select the newly created grid pattern in the drop-down menu.
3. Open the grid pattern and press **Parameters**.
4. Enter the X and Y values in the parameter view.

The X and Y values correspond to the array size.

5. Select parameters for the traversal order.
   There are 2 options to choose from:
   - ZIG_ZAG
   - SNAKE

6. Select the frame references for the respective frames Origin, Corner X, Corner Y and Iteration:
   - **New project frame**
   - **Existing project frame...**
7. If **New project frame** is selected:
   - Frame is created at the current position.
8. If **Existing project frame...** is selected:
   a. A dialog is opened. Show object tree.
   b. Select frame.
   c. Press **Select target**. The assignment is applied.
9. Optional: Change index.
   The index is preset to 0 by default.
10. Click on **Apply** to save the change.

10.9.3 Using grid patterns in a program

Procedure

1. In the Feature menu, select **Program**.
2. Create a new program.
3. Open the node palette and select **Motion group**.
4. Add the **Loop** node.
5. Under the **Loop** node, add the **GridIteration** node.
6. Under the **Loop** node, add a **Move** node.
7. Configuring the first node **Motion group**:
   a. Select the **Motion group** node.
   b. Rename **Motion group**.
   c. Select the motion type **Axis (PTP)**.
   d. Set the motion as required.
8. Configuring the **Loop** node:
   a. Select the **Loop** node.
   b. Rename **Loop**.
   c. Select the loop type **Infinite**.
9. Configuring the **GridIteration** node:
   a. Select the **GridIteration** node.
   b. Select the available grid patterns under Capability.
10. Configuring the **Move** node under **Loop** node:
    a. Select the **Move** node.
    b. Select the **Linear** motion type.
    c. Select the **Frame Reference target** target type. A dialog is opened.
    d. Select **Use existing project frame** and confirm the selection.
    e. Show the object tree and select the iteration frame.
    f. Press **Select target**.

Example

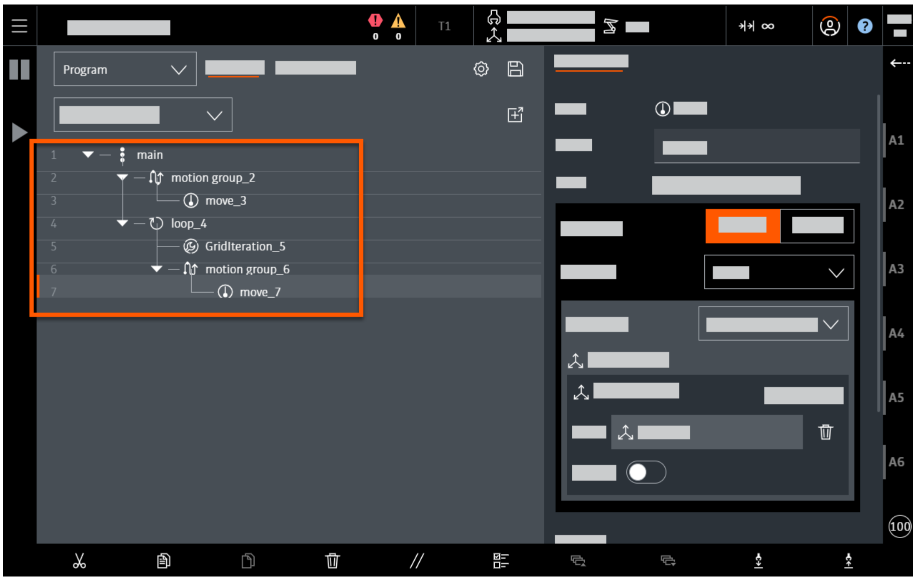


Fig. 10-24: Using grid patterns in a program – Example

Nodes

The following nodes are available in the node palette:

Node	Description
GridIteration	Automatically selects the available grid pattern capability. If more than one grid pattern capability is available, the desired grid pattern can be selected in the node.
GridReset	Resets the grid pattern

11 Diagnosis

11.1 Creating a diagnosis package

Description

If it is necessary for an error to be analyzed by KUKA, a diagnosis package can be created on the robot controller. All relevant data are collected and compressed in a ZIP file.

The following storage media can be used:

1. SD card

   XGSD interface (SD card slot) on the front of the robot controller
2. USB stick (formatted as FAT32 or exFAT)

   Interface XFUSB1 or XFUSB2 on the front of the robot controller

There is an optional setting to create a subfolder on the storage medium with the name of the robot controller.

- The name can be changed in the system settings (**Controller** tab).

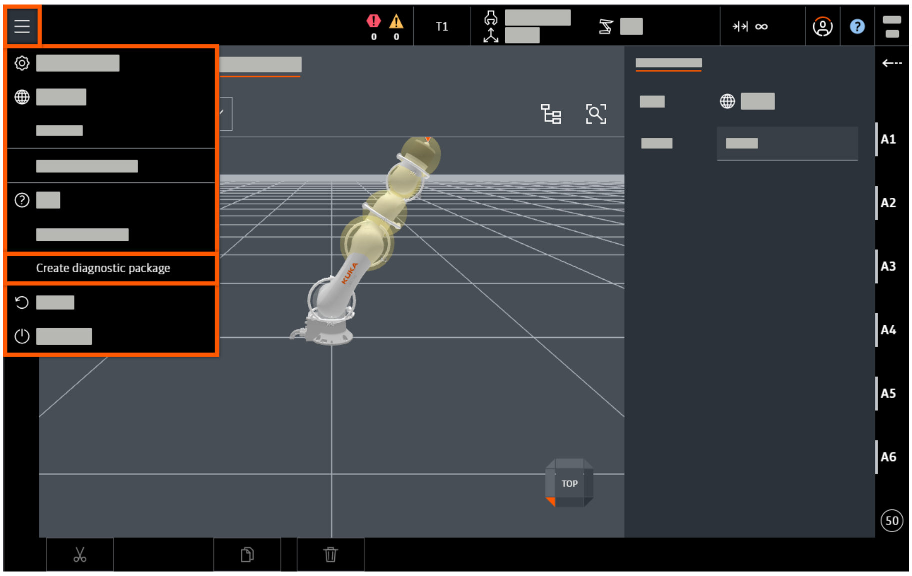


Fig. 11-1: Creating a diagnosis package

Precondition

- A storage medium is connected to the robot controller.
- There is sufficient free space on the storage medium.

Procedure

1. In the main menu, select **Create diagnostic package**. A dialog is opened.
2. Select the storage medium.
3. If desired, activate the **Use Controller name "{controllerName}" as subfolder** option (activate the check box).
4. Select the **Create** button. Creation of the diagnosis package starts.
   - The progress of the creation process is displayed. It may take a few minutes to complete the creation process.
   - The creation process can be canceled at any time.

- Once the creation process has been completed, a message is displayed.

NOTICE

Incomplete data due to premature removal of the storage medium
If the storage medium is removed while data are still being written, the diagnosis package is incomplete.

- Do not remove the storage medium until the message indicating completion of the creation process has been displayed.

11.2 Message log

Description

All messages about events and changes in state of the system are logged. The message log displays the messages in the order in which they occur.

- The messages can be filtered by time interval, source and category.
- The filter window can be moved on the user interface.
- Depending on the filter and the number of messages, the messages are displayed on one or more pages (maximum 20 messages per page).
- The category of the messages is displayed using symbols (icons).
- If a message is selected that is related to other messages, this is represented graphically as follows:
  - Solid gray line with nodes for the associated messages, e.g. between the error message and the notification message that signals the elimination of the underlying error.
  - Broken gray line for messages that are not loaded.
  - Messages that are not related to the selected message can be hidden. See filter button (>>> *Fig. 11-2*).
- The detail view shows the details of a selected message.

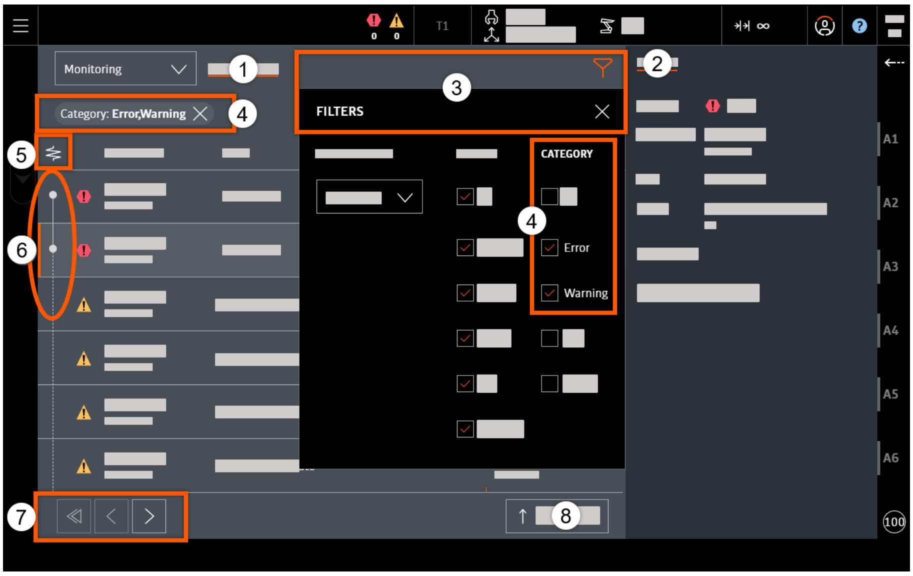


Fig. 11-2: Message log

1	Message log
2	Detail view

3 Message filter
4 Filter by category
5 Filter button (inactive)
6 Associated messages
7 Navigation between the pages
8 To top of page

Procedure

- To display the message log, select **Monitoring** in the Feature menu.

11.3 Alert display

Description

An alarm indicator in the status bar of the user interface indicates the number of warning and error messages that are currently active.

Procedure

- To display more details about the warning and error messages, tap on the display in the status bar.

Overview

The tabs in the **Alerts** window display various messages.

- **RUNTIME** tab
  Messages that have been generated during the runtime
- **ENGINEERING** tab
  Messages concerning the configuration

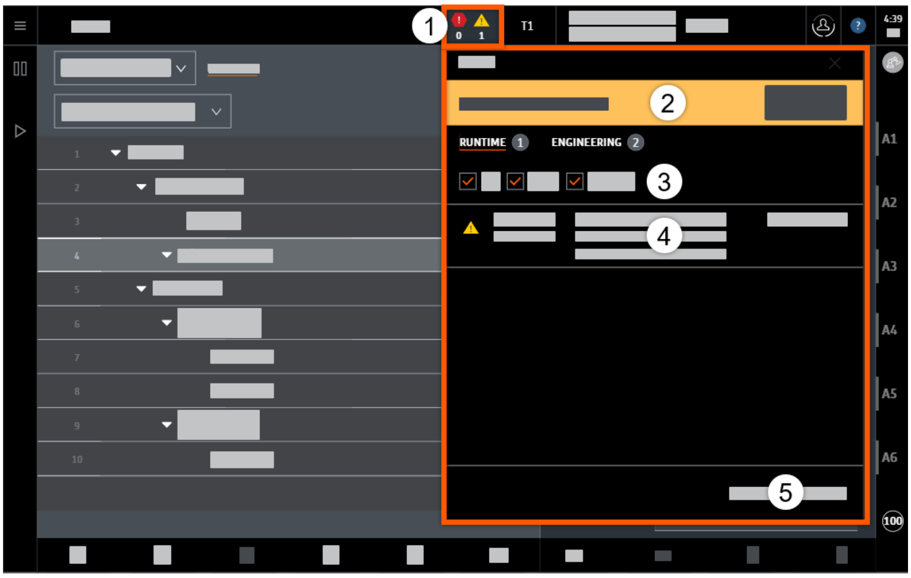


Fig. 11-3: "Alerts" window

1 Alert display
2 Safety-related message
3 Alert filter
4 Alert details
5 **Show Message History**

Functions

The following functions are available in the tabs:

- Filter messages
- **Show Message History** button
  Switch to the message log
  (>>> *11.2 "Message log" Page 224*)
- Display of safety-related messages
  The following messages may be generated:
  - **Safety system paused**
    (>>> *11.4 "Resuming the safety controller" Page 226*)
  - **Safety needs to be re-applied**
    Changes have been made to the safety configuration that have not yet been applied and approved. The **Go to Safety** button can be used to navigate directly to the safety configuration.

11.4 Resuming the safety controller

If there are connection or periphery errors, the safety controller is paused (after one or more occurrences depending on the error). As a result, the robot is stopped and all safe outputs are deactivated.

- If the safety controller is paused, this is indicated by the **Safety system paused** message in the **Alerts** window.
- Depending on the error, the **Resume** button is displayed together with the message, or no button is displayed.
- If the **Resume** button is present, the safety controller can be resumed once the cause of the error has been eliminated.
- If no button is present, proceed as follows:
  1. Eliminate the cause of the error.
  2. Reboot the robot controller.
  3. If the safety controller is still paused after the reboot, contact KUKA Customer Support.

12 KUKA Service

12.1 Requesting support

Introduction

This documentation provides information on operation and operator control, and provides assistance with troubleshooting. For further support, please contact your local subsidiary.

Information

The following information is required for processing a support request:

- Description of the problem, including information about the duration and frequency of the fault
- The greatest possible amount of information about the hardware and software components of the overall system

  The following list gives an indication of the information which is relevant in many cases:

  - Model and serial number of the kinematic system, e.g. the manipulator
  - Model and serial number of the controller
  - Model and serial number of the energy supply system
  - Designation and version of the system software
  - Designations and versions of other software components or modifications
  - System software diagnosis package

    Additionally for KUKA Sunrise: Existing projects including applications

    For versions of KUKA System Software older than V8: Archive of the software (Diagnosis package is not yet available here.)
  - Application used
  - External axes used

12.2 KUKA Customer Support

The contact details of the local subsidiaries can be found at:
www.kuka.com/customer-service-contacts

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