Training

KUKA Roboter GmbH

Robot Operation
KUKA System Software 8.x

Training Documentation, KUKA Roboter GmbH

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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.

Translation of the original documentation

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Contents

1 Description of a KUKA robot

1.1 Introduction to robotics

What is a robot?

The term *robot* comes from the Slavic word *robota*, meaning *hard work*.

According to the official definition of an industrial robot: “A robot is a freely programmable, program-controlled handling device”.

The robot thus also includes the controller and the operator control device, together with the connecting cables and software.

Fig. 1-1: Industrial robot

1 Controller ((V)KR C4 control cabinet)
2 Manipulator (robot arm)
3 Teach pendant (KUKA smartPAD)

Everything outside the system limits of the industrial robot is referred to as the *periphery*:

- Tooling (end effector/tool)
- Safety equipment
- Conveyor belts
- Sensors
- Machines
- etc.

1.2 Manipulator

What is a manipulator?

A manipulator is the mechanical system of an industrial robot. The individual elements of this mechanical system move relative to one another. They are referred to an motion axes (“axes”).

Fig. 1-2: Overview of manipulator components

1	Base frame	4	Link arm
2	Rotating column	5	Arm
3	Counterbalancing system	6	Wrist

The individual axes are numbered from bottom (robot base) to top (robot flange):

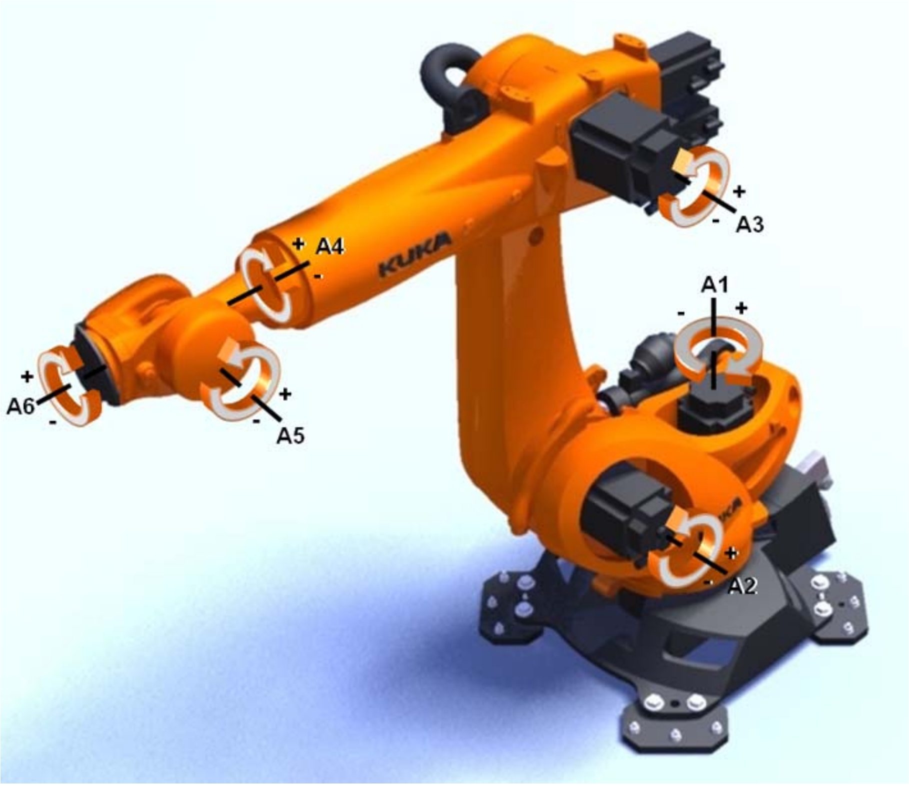


Fig. 1-3: Degrees of freedom of a KUKA robot

1.3 KR C4 robot controller

Who controls motion?

The manipulator is moved by means of servomotors controlled by the KR C4 controller.

Fig. 1-4: (V)KR C4 control cabinet

Properties of the KR C4 controller:

- Robot control of six robot axes plus up to two external axes.

Fig. 1-5: (V)KR C4 axis control

- Communication options via bus systems
- Communication options via network

Fig. 1-6: (V)KR C4 communication options

1.4 The KUKA smartPAD

How is a KUKA robot operated?

The KUKA robot is operated by means of the KUKA smartPAD teach pendant.

Fig. 1-7

Features of the KUKA smartPAD:

- Touch screen (touch-sensitive user interface) for operation by hand or using the integrated stylus
- Large display in portrait format
- KUKA menu key
- Eight jog keys
- Keys for operator control of the technology packages
- Program execution keys (Stop/Backwards/Forwards)
- Key for displaying the keypad
- Keyswitch for changing the operating mode
- EMERGENCY STOP button
- Space Mouse
- Unpluggable
- USB connection

1.5 Robot programming

A robot is programmed so that motion sequences and processes can be executed automatically and repeatedly.

The controller requires a large amount of information for programming:

- Robot position = position of the tool in space.
- Type of motion
- Velocity / acceleration
- Signal information

- Logic: wait conditions, branches, dependencies

What language does the controller speak?

The programming language is **KRL** - **K**UKA **R**obot **L**anguage

Example program:

```
PTP P1 Vel=100% PDAT1
PTP P2 CONT Vel=100% PDAT2
WAIT FOR IN 10 'Lichtschranke Bauteil in Pos.'
PTP P3 Vel=100% PDAT3
```

How is a KUKA robot programmed?

Programming with the teaching method.

Fig. 1-8: Robot programming with the KUKA smartPAD

> **Teaching**
> "Teaching" means programming motion sequences into the robot. The robot is moved to positions that are to be programmed and the coordinates there are saved ("taught").

1.6 Robot safety

A robot system must always have suitable safety features. These include, for example, physical safeguards (fences, gates, etc.), EMERGENCY STOP buttons, dead-man switches, axis range limitations, etc.

Example: College training cell

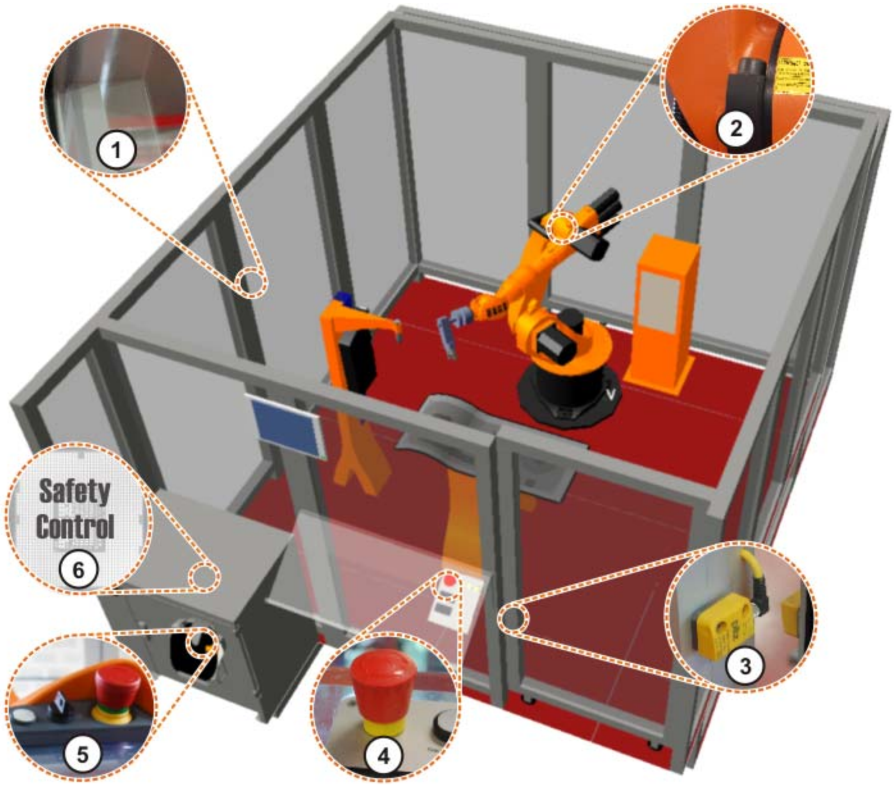


Fig. 1-9: Training cell

1 Safety fence
2 Mechanical end stops or axis range limitation for axes 1, 2 and 3
3 Safety gate with contact for monitoring the closing function
4 EMERGENCY STOP button (external)
5 EMERGENCY STOP button, enabling switch, keyswitch for calling the connection manager
6 Integrated (V)KR C4 safety controller

DANGER In the absence of functional safety equipment and safeguards, the robot system can cause personal injury or material damage. If safety equipment or safeguards are dismantled or deactivated, the robot system may not be operated.

EMERGENCY STOP device

The EMERGENCY STOP device for the industrial robot is the EMERGENCY STOP button on the KCP. The button must be pressed in the event of a hazardous situation or emergency.

Reactions of the industrial robot if the EMERGENCY STOP button is pressed:

- The manipulator and any external axes (optional) are stopped with a safety stop 1.

Before operation can be resumed, the EMERGENCY STOP button must be turned to release it and the ensuing stop message must be acknowledged.

WARNING Tools and other equipment connected to the manipulator must be integrated into the EMERGENCY STOP circuit on the system side if they could constitute a potential hazard.
Failure to observe this precaution may result in death, severe injuries or considerable damage to property.

There must always be at least one external EMERGENCY STOP device installed. This ensures that an EMERGENCY STOP device is available even when the KCP is disconnected.

External E-STOP

There must be EMERGENCY STOP devices available at every operator station that can initiate a robot motion or other potentially hazardous situation. The system integrator is responsible for ensuring this.

There must always be at least one external EMERGENCY STOP device installed. This ensures that an EMERGENCY STOP device is available even when the KCP is disconnected.

External EMERGENCY STOP devices are connected via the customer interface. External EMERGENCY STOP devices are not included in the scope of supply of the industrial robot.

Operator safety

The **operator safety** signal is used for interlocking physical safeguards, e.g. safety gates. Automatic operation is not possible without this signal. In the event of a loss of signal during automatic operation (e.g. safety gate is opened), the manipulator stops with a safety stop 1.

Operator safety is not active in the test modes T1 (Manual Reduced Velocity) and T2 (Manual High Velocity).

⚠ WARNING Following a loss of signal, automatic operation must not be resumed merely by closing the safeguard; it must first additionally be acknowledged. It is the responsibility of the system integrator to ensure this. This is to prevent automatic operation from being resumed inadvertently while there are still persons in the danger zone, e.g. due to the safety gate closing accidentally.

- The acknowledgement must be designed in such a way that an actual check of the danger zone can be carried out first. Acknowledgement functions that do not allow this (e.g. because they are automatically triggered by closure of the safeguard) are not permissible.
- Failure to observe this may result in death to persons, severe injuries or considerable damage to property.

Safe operational stop

The safe operational stop can be triggered via an input on the customer interface. The state is maintained as long as the external signal is FALSE. If the external signal is TRUE, the manipulator can be moved again. No acknowledgement is required.

External safety stop 1 and external safety stop 2

Safety stop 1 and safety stop 2 can be triggered via an input on the customer interface. The state is maintained as long as the external signal is FALSE. If the external signal is TRUE, the manipulator can be moved again. No acknowledgement is required.

1.7 Coordinate systems in conjunction with robots

During the operator control, programming and start-up of industrial robots, the coordinate systems are of major significance. The following coordinate systems are defined in the robot controller:

- WORLD | world coordinate system
- ROBROOT | robot base coordinate system

- BASE | base coordinate system
- FLANGE | flange coordinate system
- TOOL | tool coordinate system

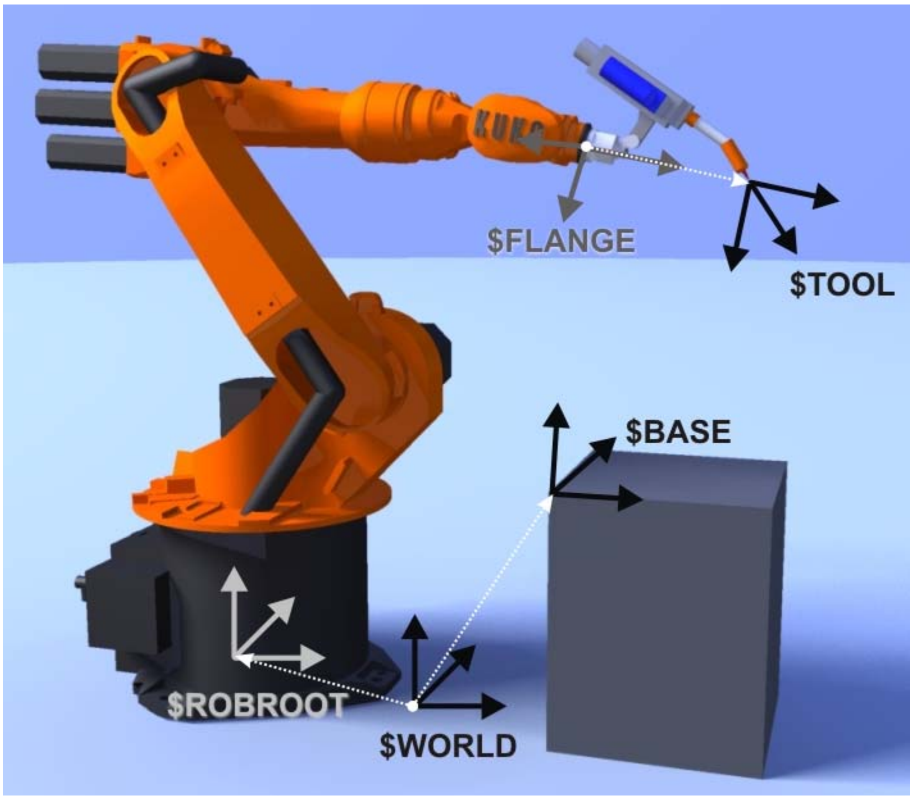


Fig. 1-10: Coordinate systems on the KUKA robot

Name	Location	Use	Special feature
WORLD	Freely definable	Origin for ROB-ROOT and BASE	Located in the robot base in most cases.
ROB-ROOT	Fixed in the robot base	Origin of the robot	Defines the position of the robot relative to WORLD.
BASE	Freely definable	Tools, fixtures	Defines the position of the base relative to WORLD.
FLANGE	Fixed at the robot flange	Origin for TOOL	Origin is the center of the robot flange.
TOOL	Freely definable	Tools	The origin of the TOOL coordinate system is called the "**TCP**". (*TCP = Tool Center Point*)

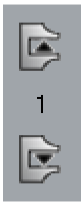
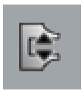
2 Using technology packages

2.1 Gripper operation with KUKA.GripperTech

Technology package KUKA.GripperTech

KUKA.Gripper&SpotTech is an add-on technology package. It simplifies the use of a gripper in terms of:

The following status keys are required for operating the gripper:

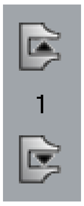
Status key	Description
	Select gripper. The number of the gripper is displayed. ■ Pressing the upper key counts upwards. ■ Pressing the lower key counts downwards.
	Toggle between the gripper states (e.g. open or close). The current state is not displayed. The possible states depend on the configured gripper type. In the case of weld guns, the possible states depend on the configuration of the manual gun control.

Procedure for gripper operation

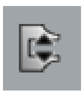
> **NOTICE** Before a gripper can be operated using the status keys, the status keys must first be activated!
> In the main menu, select **Configuration** > **Status keys** > **GripperTech**.

> **⚠ WARNING** **Warning!**
> When using the gripper system there is a risk of crushing and cutting. Anyone using the gripper must ensure that no part of the body can be crushed by the gripper.

1. Select the gripper using the status key.



2. Activate operating mode T1 or T2.
3. Press enabling switch.
4. Control the gripper using the status key.



3 Moving the robot

3.1 Reading and interpreting robot controller messages

Overview of messages

Fig. 3-1: Message window and message counter

1 Message window: the current message is displayed.

2 Message counter: number of messages of each message type.

The controller communicates with the operator via the message window. It has five different message types:

Overview of message types:

Icon	Type
	**Acknowledgement message** ■ Displays states that require confirmation by the operator before program execution is resumed (e.g. “Ackn. EMERGENCY STOP”). ■ An acknowledgement message always causes the robot to stop or not to start.
	**Status message** ■ Status messages signal current controller states (e.g. “EMERGENCY STOP”). ■ Status messages cannot be acknowledged while the status is active.
	**Notification message** ■ Notification messages provide information for correct operator control of the robot (e.g. “Start key required”). ■ Notification messages can be acknowledged. They do not need to be acknowledged, however, as they do not stop the controller.
	**Wait message** ■ Wait messages indicate the event the controller is waiting for (status, signal or time). ■ Wait messages can be canceled manually by pressing the “Simulate” button.

⚠ **WARNING**	The command “Simulate” may only be used if there is no risk of a collision or other hazards!

	Dialog message ■ Dialog messages are used for direct communication with the operator, e.g. to ask the operator for information. ■ A message window with buttons appears, offering various possible responses.

An acknowledgeable message can be acknowledged with **OK**. All acknowledgeable messages can be acknowledged at once with **All OK**.

Influence of messages

Messages influence the functionality of the robot. An acknowledgement message always causes the robot to stop or not to start. The message must be acknowledged before the robot can be moved.

The command **OK** (acknowledge) represents a prompt to the operator, forcing a conscious response.

Tips for dealing with messages:

- Read attentively!
- Read older messages first. A newer message could simply be a follow-up to an older one.
- Do not simply press “All OK”.
- Particularly after booting: look through the messages. Display all messages. Touching the message window expands the message list.

Dealing with messages

Messages are always displayed with the date and time in order to be able to trace the exact time of the event.

Fig. 3-2: Acknowledging messages

Procedure for viewing and acknowledging messages:

1. Touch the message window to expand the message list.
2. Acknowledge:
   - Acknowledge individual messages with **OK**.
   - Alternatively: acknowledge all messages with **All OK**.
3. Touching the top message again or the “X” at the left-hand edge of the screen closes the message list.

3.2 Moving individual robot axes

Description: Axis-specific motion

Fig. 3-3: Degrees of freedom of a KUKA robot

Moving robot axes

- Move each axis individually in the plus and minus direction.
- The jog keys or Space Mouse of the KUKA smartPAD are used for this.
- The velocity can be modified (jog override: HOV).
- Jogging is only possible in T1 mode.
- The enabling switch must be pressed.

Principle

The drives are activated by pressing the enabling switch. As soon as a jog key or the Space Mouse is pressed, servo control of the robot axes starts and the desired motion is executed.

Continuous motion and incremental motion are possible. The size of the increment must be selected in the status bar.

The following messages influence manual operation:

Message	Cause	Remedy
"Active commands inhibited"	A (STOP) message or state is present which inhibits active commands (e.g. EMERGENCY STOP pressed or drives not yet ready).	Release EMERGENCY STOP and/or acknowledge messages in the message window. As soon as an enabling switch is pressed, the drives are available immediately.
"Software limit switch A5"	The robot has moved to the software limit switch of the axis indicated (e.g. A5) in the direction indicated (+ or -).	Move the indicated axis in the opposite direction.

Safety instructions relating to axis-specific jogging

Operating mode
Manual operation of the robot is only permissible in T1 mode (Manual Reduced Velocity). The maximum jog velocity in T1 is 250 mm/s. The operating mode is set via the connection manager.

Enabling switches
In order to be able to jog the robot, an enabling switch must be pressed. There are three enabling switches installed on the smartPAD. The enabling switches have three positions:

- not pressed
- Center position
- Panic position

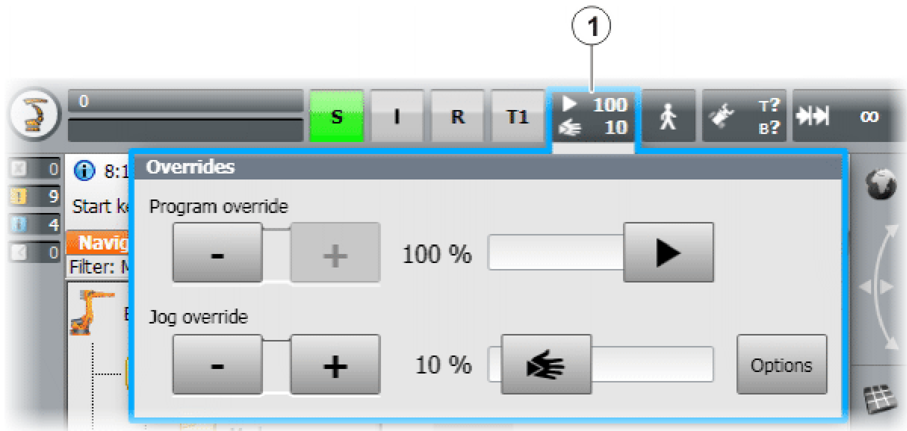
Software limit switches
The motion of the robot is also limited in axis-specific jogging by means of the maximum positive and negative values of the software limit switches.

> ⚠ **CAUTION** If the message “Perform mastering” appears in the message window, these limits can be exceeded. This can result in damage to the robot system!

Procedure: Executing an axis-specific motion

1. Select **Axis** as the option for the jog keys.

2. Set jog override



3. Press the enabling switch into the center position and hold it down.

Axes A1 to A6 are displayed next to the jog keys.

4. Press the Plus or Minus jog key to move an axis in the positive or negative direction.

Moving the robot in emergencies without the controller

Fig. 3-4: Release device

Description

The release device can be used to move the robot mechanically after an accident or malfunction. The release device can be used for the main axis drive motors and, depending on the robot variant, also for the wrist axis drive motors. It is **only** for use in exceptional circumstances and emergencies (e.g. for freeing people). After use of the release device, the affected motors must be exchanged.

> **⚠ WARNING** The motors reach temperatures during operation which can cause burns to the skin. Contact must be avoided. Appropriate safety precautions must be taken, e.g. protective gloves must be worn.

Procedure

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

2. Remove the protective cap from the motor.
3. Push the release device onto the corresponding motor and move the axis in the desired direction.

   Labeling of the directions with arrows on the motors can be ordered as an option. It is necessary to overcome the resistance of the mechanical motor brake and any other loads acting on the axis.

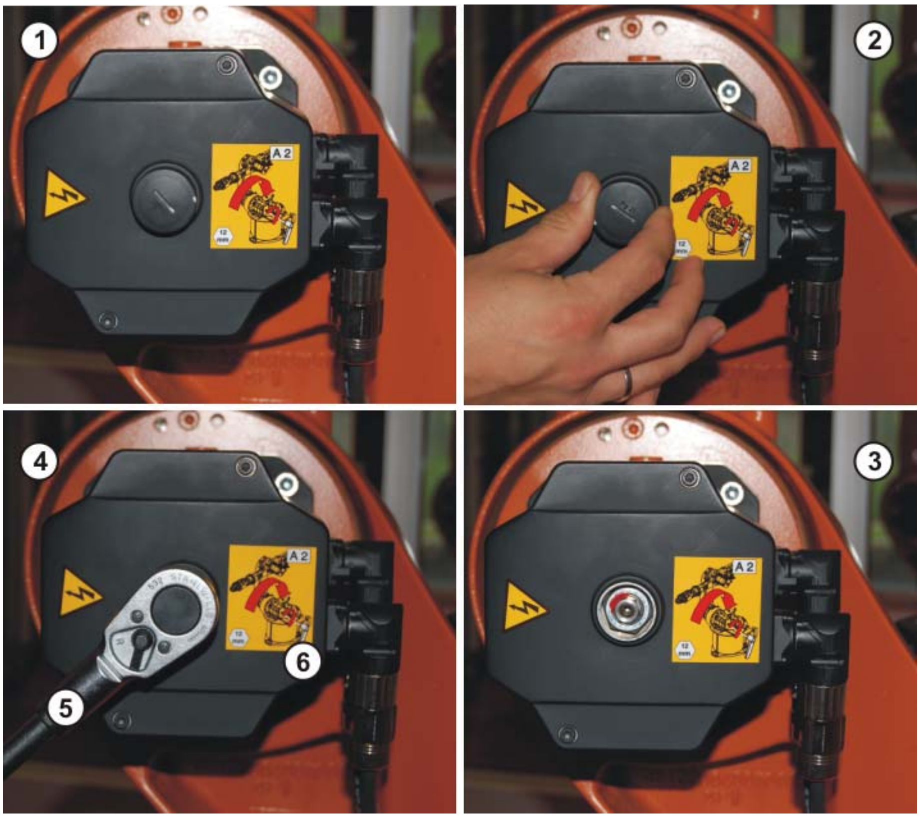


Fig. 3-5: Procedure for using release device

Item	Description
1	Motor A2 with protective cap fitted
2	Removing the protective cap from motor A2
3	Motor A2 with protective cap removed
4	Mounting the release device on motor A2
5	Release device
6	Sign (optional) indicating the direction of rotation

⚠ WARNING **Warning!**
Moving an axis with the release device can damage the motor brake. This can result in personal injury and material damage. After using the release device, the affected motor must be exchanged.

Further information is contained in the robot operating or assembly instructions.

3.3 Moving the robot in the world coordinate system

Motion in the world coordinate system

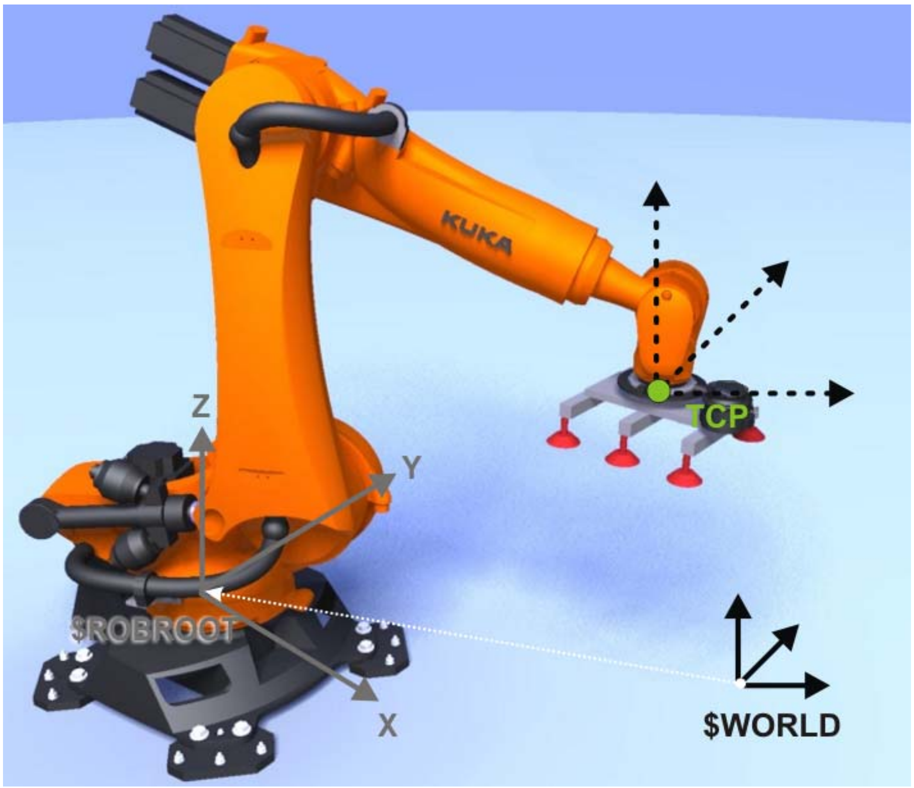


Fig. 3-6: Principle of jogging in the world coordinate system

- The robot tool can be moved with reference to the coordinate axes of the world coordinate system.
  In this case, **all** robot axes move.
- The jog keys or Space Mouse of the KUKA smartPAD are used for this.
- By default, the world coordinate system is located in the base of the robot (Robroot).
- The velocity can be modified (jog override: HOV).
- Jogging is only possible in T1 mode.
- The enabling switch must be pressed.

Space Mouse

- The Space Mouse allows intuitive motion of the robot and is the ideal choice for jogging in the world coordinate system.
- The mouse position and degrees of freedom can be modified.

Principle of jogging in the world coordinate system

A robot can be moved in a coordinate system in two different ways:

- Translational (in a straight line) along the orientation directions of the coordinate system: X, Y, Z
- Rotational (turning/pivoting) about the orientation directions of the coordinate system: angles A, B and C

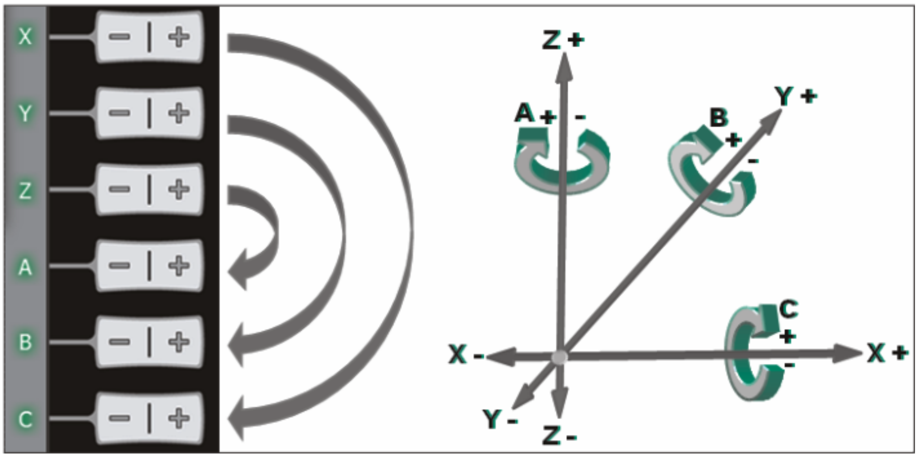


Fig. 3-7: Cartesian coordinate system

In the case of a motion command (e.g. jog key pressed), the controller first calculates a path. The starting point of the path is the tool center point (TCP). The direction of the path is specified by the world coordinate system. The controller then controls the axes to guide the tool along this path (translation) or about it (rotation).

Advantages of using the world coordinate system:

- The motion of the robot is always predictable.
- The motions are always unambiguous, as the origin and coordinate axes are always known.
- The world coordinate system can always be used with a mastered robot.
- The Space Mouse allows intuitive operator control.

Using the Space Mouse

- All motion types are possible with the Space Mouse:
  - Translational: by pushing and pulling the Space Mouse

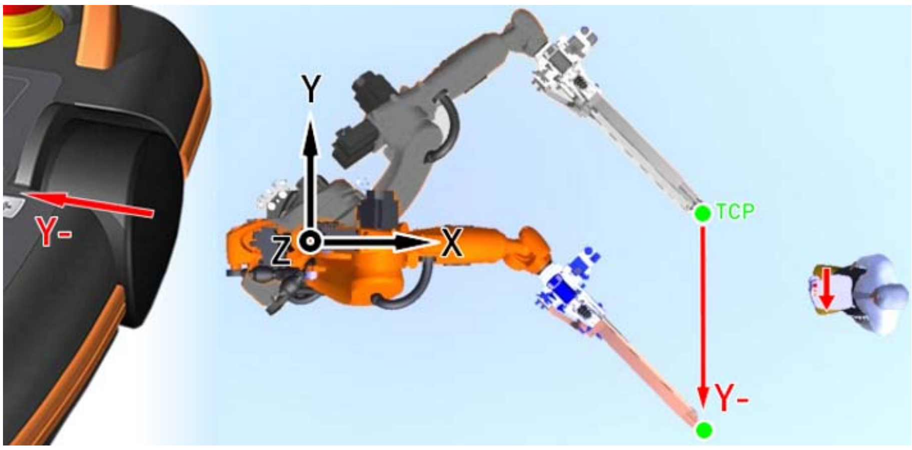


Fig. 3-8: Example: motion to the left

  - Rotational: by turning the Space Mouse

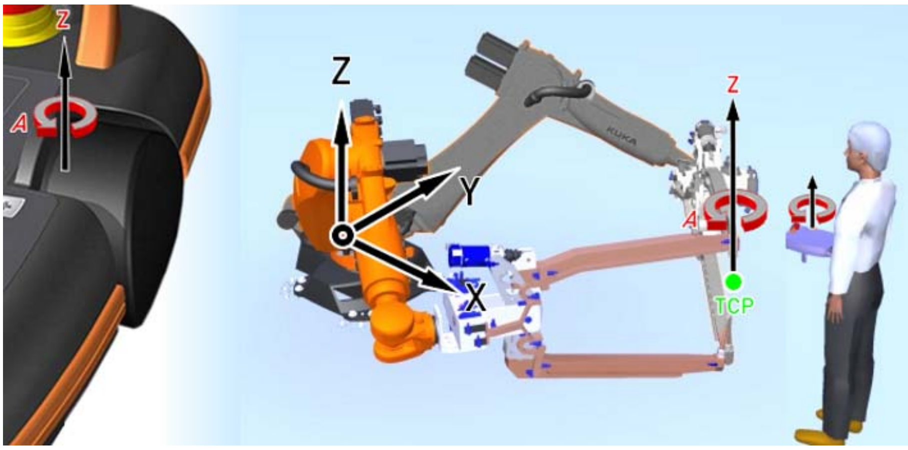


Fig. 3-9: Example: rotational motion about Z – angle A

- The Space Mouse position can be adapted to the position of the operator relative to the robot.

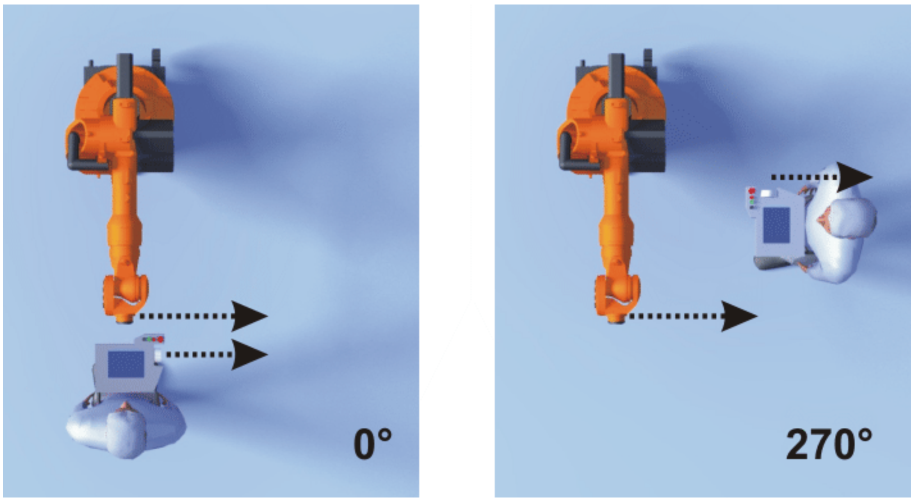
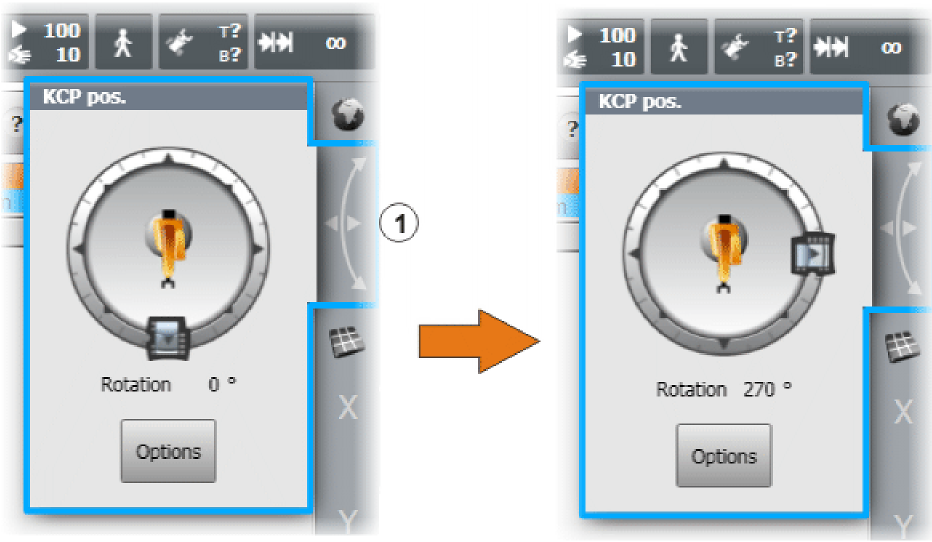


Fig. 3-10: Space Mouse: 0° and 270°

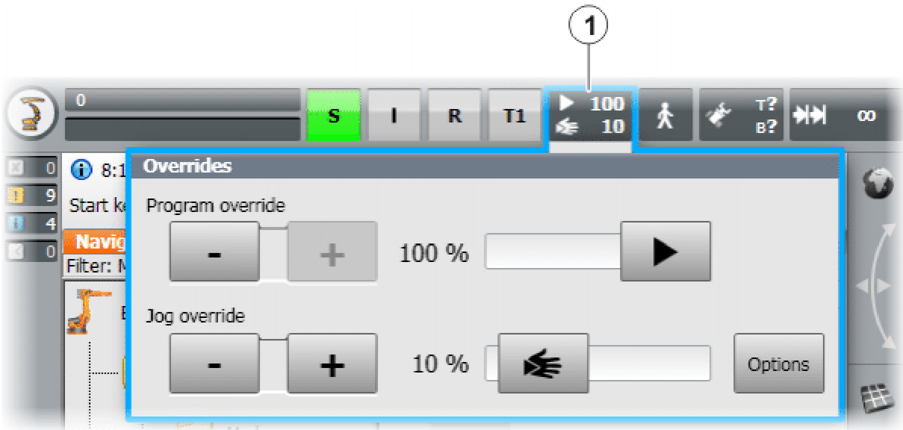
Executing a translational motion (world)

1. Set the KCP position by moving the slider control (1).



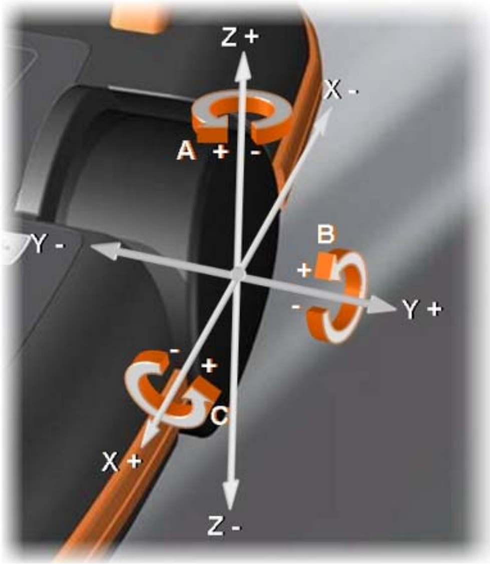
2. Select **World** as the option for the Space Mouse.

3. Set jog override.



4. Press the enabling switch into the center position and hold it down.

5. Move in the corresponding direction using the Space Mouse.



6. Alternatively, the jog keys can be used.

3.4 Exercise: Operator control and jogging

Aim of the exercise

On successful completion of this exercise, you will be able to carry out the following activities:

- Switch the robot controller on and off
- Basic operator control of the robot using the smartPAD
- Jog the robot (axis-specific and in the WORLD coordinate system) by means of the jog keys and Space Mouse
- Interpret and reset first simple system messages

Preconditions

The following are preconditions for successful completion of this exercise:

- Completion of safety instruction

> **Note!**
> Safety instruction must be completed and documented before commencing this exercise!

- Theoretical knowledge of the general operator control of a KUKA industrial robot system
- Theoretical knowledge of axis-specific jogging and jogging in the WORLD coordinate system

Task description

Carry out the following tasks:

1. Switch the control cabinet on and wait for the system to boot.
2. Release and acknowledge the EMERGENCY STOP.
3. Ensure that T1 mode is set.
4. Activate axis-specific jogging.
5. Perform axis-specific jogging of the robot with various different jog override (HOV) settings using the jog keys and Space Mouse.
6. Explore the motion range of the individual axes, being careful to avoid any obstacles present, such as a table or cube magazine with fixed tool (accessibility investigation).
7. On reaching the software limit switches, observe the message window.
8. In joint (axis-specific) mode, move the tool (gripper) to the reference tool (black metal tip) from several different directions.
9. Repeat this procedure in the World coordinate system.
10. Place a cube on the table manually.
11. Move the gripper to the cube. Select what you consider to be the correct coordinate system.
12. Close the gripper. The cube must **not** move when the gripper closes.

What you should now know:

1. How can messages be acknowledged?

. . . .

. . . .

2. Which icon represents the world coordinate system?

a) 

b) 

c) 

d) 

3. What is the name of the velocity setting for jog mode?

. . . .

4. What operating modes are there?

. . . .

. . . .

3.5 Moving the robot in the tool coordinate system

Jogging in the tool coordinate system

Fig. 3-11: Robot tool coordinate system

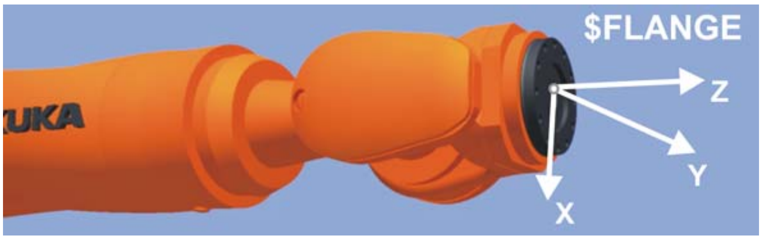
- In the case of jogging in the tool coordinate system, the robot can be moved relative to the coordinate axes of a previously calibrated tool.

  The coordinate system is thus not fixed (cf. world/base coordinate system), but guided by the robot.

  In this case, **all** required robot axes move. Which axes these are is determined by the system and depends on the motion.

  The origin of the tool coordinate system is called the **TCP** and corresponds to the working point of the tool.
- The jog keys or Space Mouse of the KUKA smartPAD are used for this.
- There are 16 tool coordinate systems to choose from.
- The velocity can be modified (jog override: HOV).
- Jogging is only possible in T1 mode.
- The enabling switch must be pressed.

In the case of jogging, uncalibrated tool coordinate systems always correspond to the flange coordinate system.



Principle of jogging – tool

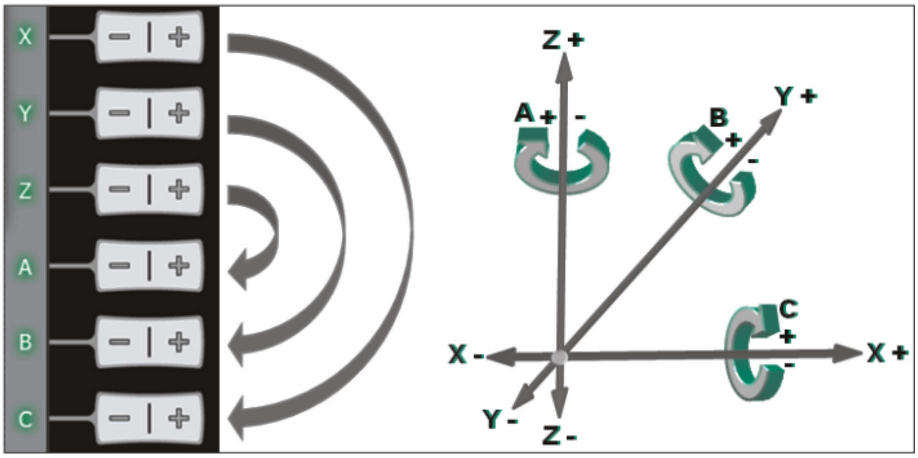


Fig. 3-12: Cartesian coordinate system

A robot can be moved in a coordinate system in two different ways:

- Translational (in a straight line) along the orientation directions of the coordinate system: X, Y, Z
- Rotational (turning/pivoting) about the orientation directions of the coordinate system: angles A, B and C

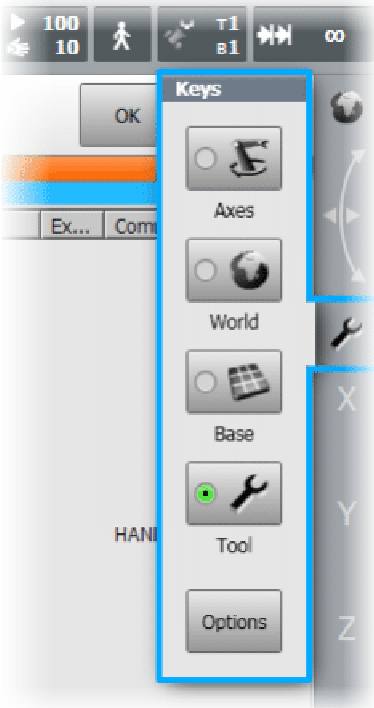
Advantages of using the tool coordinate system:

- The motion of the robot is always predictable as soon as the tool coordinate system is known.
- It is possible to move in the tool direction or to orient about the TCP.

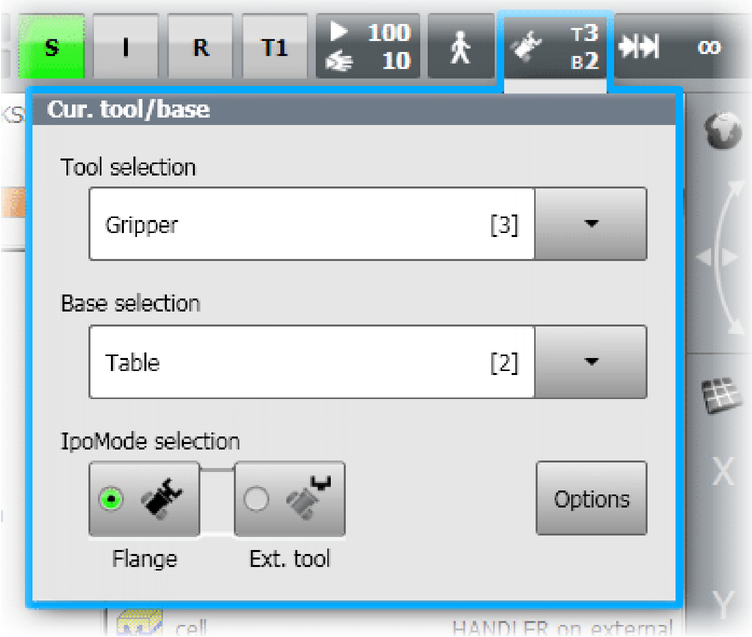
  The *tool direction* is the working or process direction of the tool: the direction in which adhesive is dispensed from an adhesive nozzle, the direction of gripping when gripping a workpiece, etc.

Procedure

1. Select **Tool** as the coordinate system to be used.

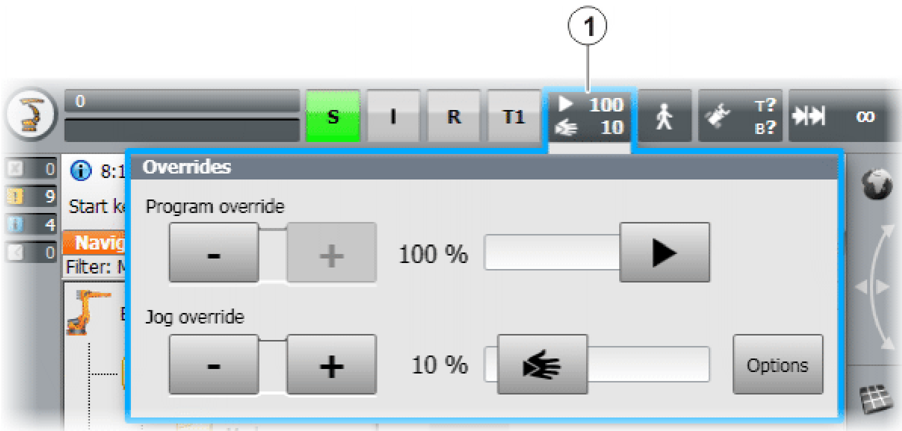


2. Select the tool number.



.

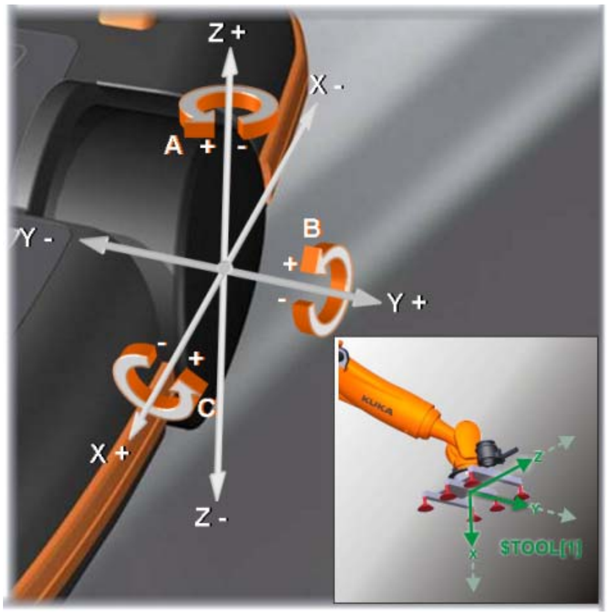
3. Set jog override.



4. Press the enabling switch into the center position and hold it down.

5. Move the robot using the jog keys.

6. Alternatively: Move in the corresponding direction using the Space Mouse.



3.6 Exercise: Jogging in the tool coordinate system

Aim of the exercise

On successful completion of this exercise, you will be able to carry out the following activities:

- Jog the robot, in the tool coordinate system, by means of the jog keys and Space Mouse
- Jog the robot in the working direction of the tool

Preconditions

The following are preconditions for successful completion of this exercise:

- Completion of safety instruction

> **Note!**
> Safety instruction must be completed and documented before commencing this exercise!

- Theoretical knowledge of jogging in the tool coordinate system

Task description

Carry out the following tasks:

1. Release and acknowledge the EMERGENCY STOP.
2. Ensure that T1 mode is set.

3. Activate the tool coordinate system.
4. Jog the robot in the tool coordinate system with various different jog override (HOV) settings using the jog keys and Space Mouse. Test motion in the working direction of the tool and re-orientation about the TCP.
5. Fetch the panel from the holder using the tool “Gripper”.
6. Fetch the pen from the holder using the tool “Gripper”.
7. Fetch the cube from the magazine using the tool “Gripper”.

3.7 Moving the robot in the base coordinate system

Motion in the base coordinate system

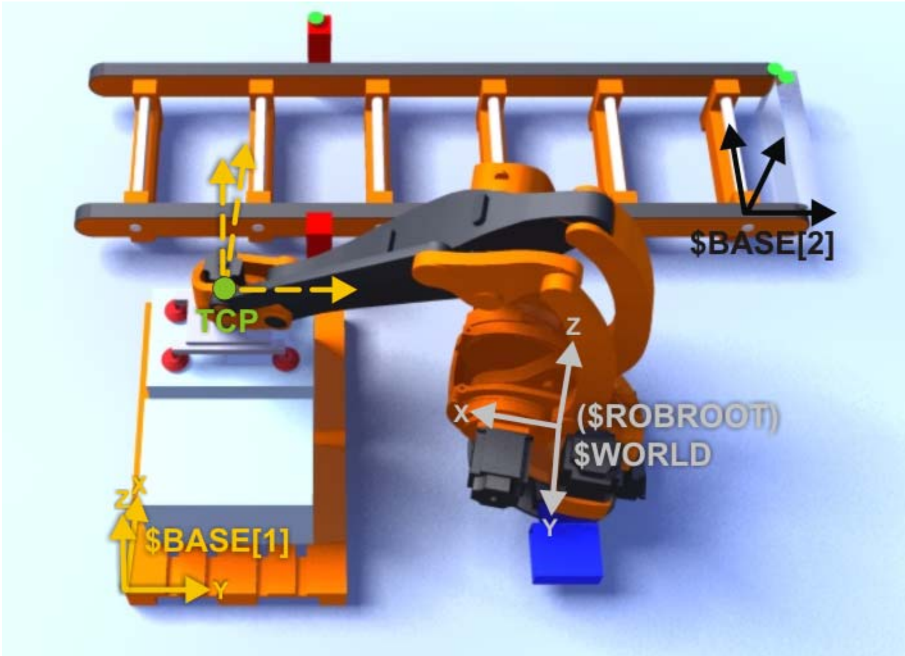


Fig. 3-13: Jogging in the base coordinate system

Description of bases

- The robot tool can be moved with reference to the coordinate axes of the base coordinate system. Base coordinate systems can be calibrated individually and are often oriented along the edges of workpieces, workpiece locations or pallets. This allows convenient jogging!

  In this case, **all** required robot axes move. Which axes these are is determined by the system and depends on the motion.
- The jog keys or Space Mouse of the KUKA smartPAD are used for this.
- There are 32 base coordinate systems to choose from.
- The velocity can be modified (jog override: HOV).
- Jogging is only possible in T1 mode.
- The enabling switch must be pressed.

Principle of jogging – base

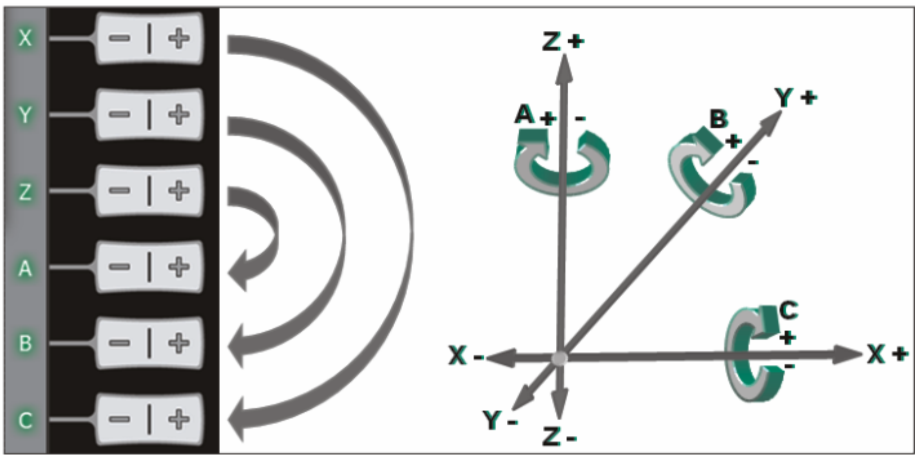


Fig. 3-14: Cartesian coordinate system

A robot can be moved in a coordinate system in two different ways:

- Translational (in a straight line) along the orientation directions of the coordinate system: X, Y, Z

- Rotational (turning/pivoting) about the orientation directions of the coordinate system: angles A, B and C

In the case of a motion command (e.g. jog key pressed), the controller first calculates a path. The starting point of the path is the tool center point (TCP). The direction of the path is specified by the world coordinate system. The controller then controls the axes to guide the tool along this path (translation) or about it (rotation).

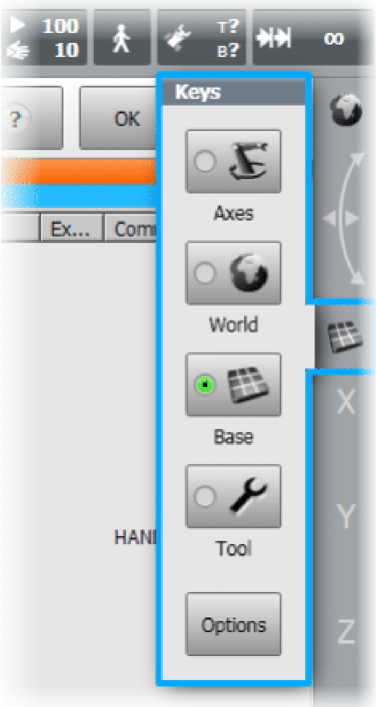
Advantages of using the base coordinate system:

- The motion of the robot is always predictable as soon as the base coordinate system is known.
- Here also, the Space Mouse allows intuitive operator control. A precondition is that the operator is standing correctly relative to the robot or the base coordinate system.

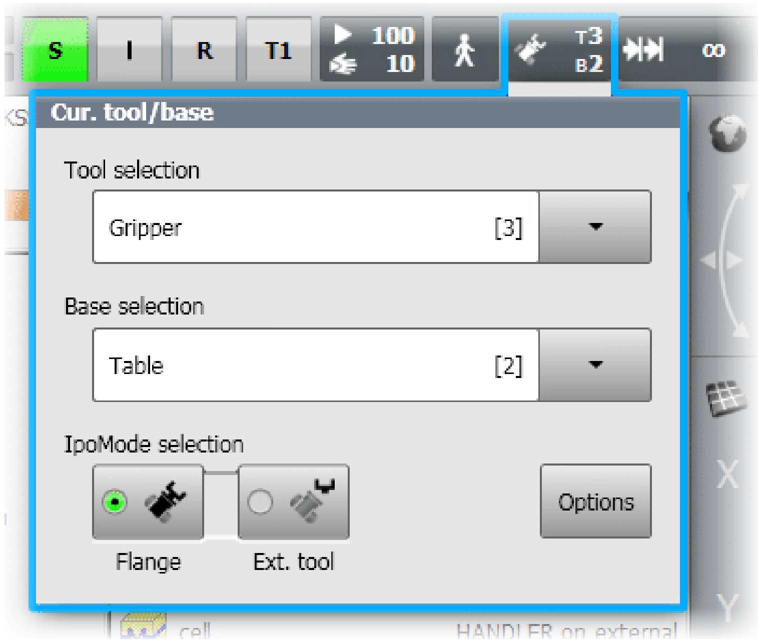
NOTICE	If the correct tool coordinate system is also set, re-orientation about the TCP is possible in the base coordinate system.

Procedure

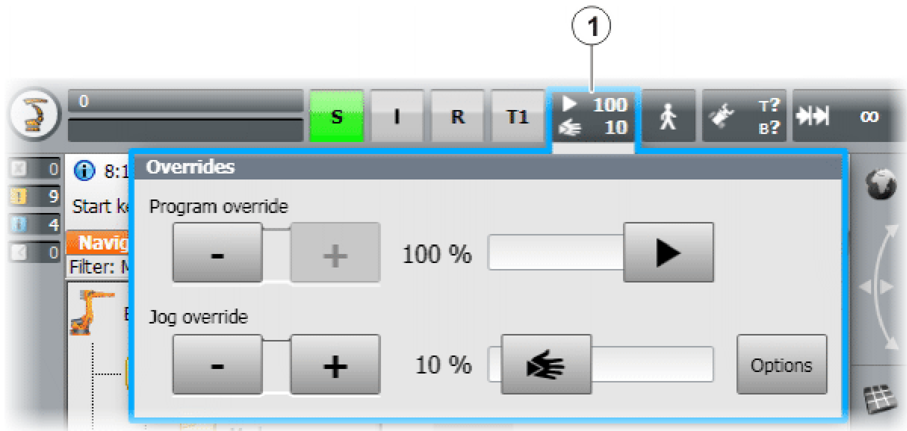
1. Select **Base** as the option for the jog keys.



2. Select tool and base.



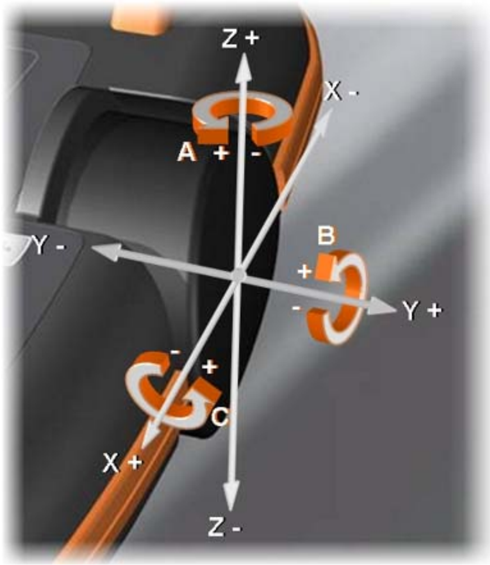
3. Set jog override.



4. Press the enabling switch into the center position and hold it down.

5. Move in the desired direction using the jog keys.

6. Alternatively, jogging can be carried out using the Space Mouse.



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 different stop reactions according to the operating mode that has been set.

Term	Description
Safe operational stop	The safe operational stop is a standstill monitoring function. It does not stop the robot motion, but monitors whether the robot axes are stationary. If these are moved during the safe operational stop, a safety stop STOP 0 is triggered. The safe operational stop can also be triggered externally. When a safe operational stop is triggered, the robot controller sets an output to the field bus. The output is set even if not all the axes were stationary at the time of triggering, thereby causing a safety stop STOP 0 to be triggered.
Safety STOP 0	A stop that is triggered and executed by the safety controller. The safety controller immediately switches off the drives and the power supply to the brakes. **Note:** This stop is called safety STOP 0 in this document.

Term	Description
Safety STOP 1	A stop that is triggered and monitored by the safety controller. The braking process is performed by the non-safety-oriented part of the robot controller and monitored by the safety controller. As soon as the manipulator is at a standstill, the safety controller switches off the drives and the power supply to the brakes. When a safety STOP 1 is triggered, the robot controller sets an output to the field bus. The safety STOP 1 can also be triggered externally. **Note:** This stop is called safety STOP 1 in this document.
Safety STOP 2	A stop that is triggered and monitored by the safety controller. The braking process is performed by the non-safety-oriented part of the robot controller and monitored by the safety controller. The drives remain activated and the brakes released. As soon as the manipulator is at a standstill, a safe operational stop is triggered. When a safety STOP 2 is triggered, the robot controller sets an output to the field bus. The safety STOP 2 can also be triggered externally. **Note:** This stop is called safety STOP 2 in this document.
Stop category 0	The drives are deactivated immediately and the brakes are applied. The manipulator and any external axes (optional) perform path-oriented braking. **Note:** This stop category is called STOP 0 in this document.
Stop category 1	The manipulator and any external axes (optional) perform path-maintaining braking. The drives are deactivated after 1 s and the brakes are applied. **Note:** This stop category is called STOP 1 in this document.
Stop category 2	The drives are not deactivated and the brakes are not applied. The manipulator and any external axes (optional) are braked with a path-maintaining braking ramp. **Note:** This stop category is called STOP 2 in this document.

<table>
<tr><th>Trigger</th><th>T1, T2</th><th>AUT, AUT EXT</th></tr>
<tr><td>Start key released</td><td>STOP 2</td><td>-</td></tr>
<tr><td>STOP key pressed</td><td colspan="2">STOP 2</td></tr>
<tr><td>Drives OFF</td><td colspan="2">STOP 1</td></tr>
<tr><td>“Motion enable” input drops out</td><td colspan="2">STOP 2</td></tr>
<tr><td>Robot controller switched off (power failure)</td><td colspan="2">STOP 0</td></tr>
<tr><td>Internal error in non-safety-oriented part of the robot controller</td><td colspan="2">STOP 0 or STOP 1
(dependent on the cause of the error)</td></tr>
<tr><td>Operating mode changed during operation</td><td colspan="2">Safety stop 2</td></tr>
<tr><td>Safety gate opened (operator safety)</td><td>-</td><td>Safety stop 1</td></tr>
<tr><td>Releasing the enabling switch</td><td>Safety stop 2</td><td>-</td></tr>
<tr><td>Enabling switch pressed fully down or error</td><td>Safety stop 1</td><td>-</td></tr>
<tr><td>E-STOP pressed</td><td colspan="2">Safety stop 1</td></tr>
<tr><td>Error in safety controller or periphery of the safety controller</td><td colspan="2">Safety stop 0</td></tr>
</table>

3.8 Exercise: Jogging in the workpiece coordinate system

Aim of the exercise

On successful completion of this exercise, you will be able to carry out the following activities:

- Jog the robot, in the workpiece coordinate system, by means of the jog keys and Space Mouse
- Jog along predefined workpiece edges

Preconditions

The following are preconditions for successful completion of this exercise:

- Completion of safety instruction

> **Note!**
> Safety instruction must be completed and documented before commencing this exercise!

- Theoretical knowledge of jogging in the workpiece coordinate system

Task description

Carry out the following tasks:

1. Release and acknowledge the EMERGENCY STOP.
2. Ensure that T1 mode is set.
3. Activate the workpiece coordinate system “Blue”.
4. Clamp the pen in the gripper and select the tool coordinate system “Pen”.
5. Jog the robot in the workpiece coordinate system with various different jog override (HOV) settings using the jog keys and Space Mouse.
6. Move the pen along the outer contour on your worktable.

3.9 Displaying the current robot position

Options for displaying robot positions

The current robot position can be displayed in two different ways:

- **Axis-specific:**

  $AXIS_ACT={A1...,A2...,A3...,A4...,A5...,A6...,E1...,...,E6...}

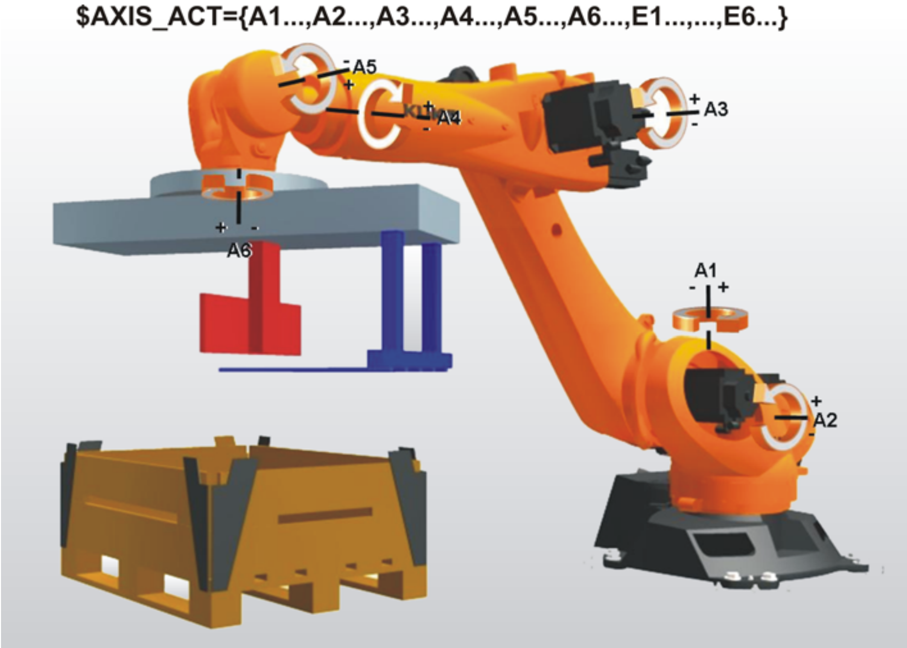


Fig. 3-15: Axis-specific robot position

  The current axis angle is displayed for every axis: this corresponds to the absolute axis angle relative to the mastering position.

- **Cartesian:**

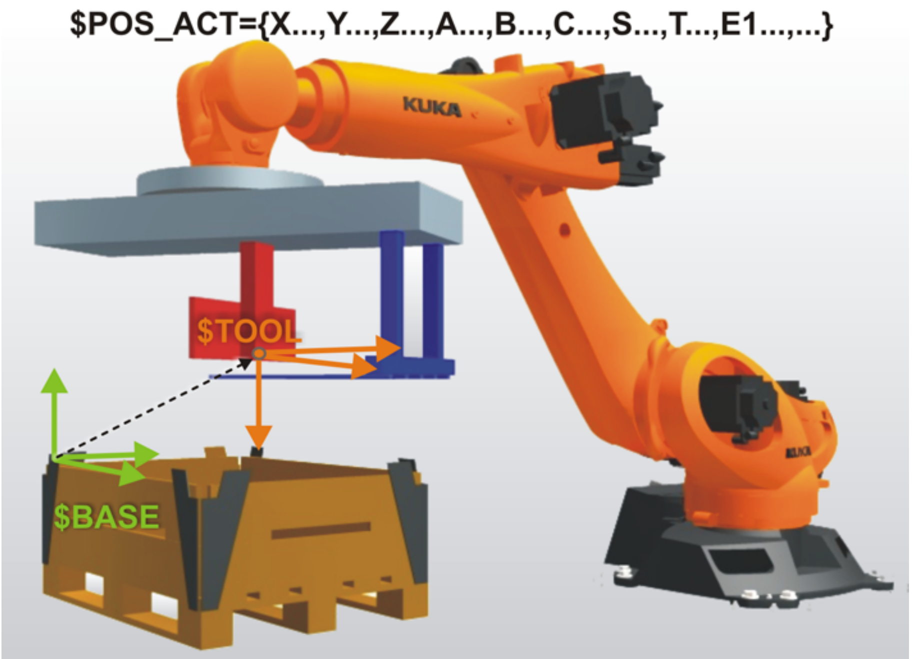


Fig. 3-16: Cartesian position

The current position of the current TCP (tool coordinate system) is displayed relative to the currently selected base coordinate system.

If no tool coordinate system is selected, the flange coordinate system applies!

If no base coordinate system is selected, the world coordinate system applies!

Cartesian position with different base coordinate systems

Looking at the Figure below, it is immediately apparent that the robot is in the same position in all three instances. The position display contains different values in each of the three cases, however:

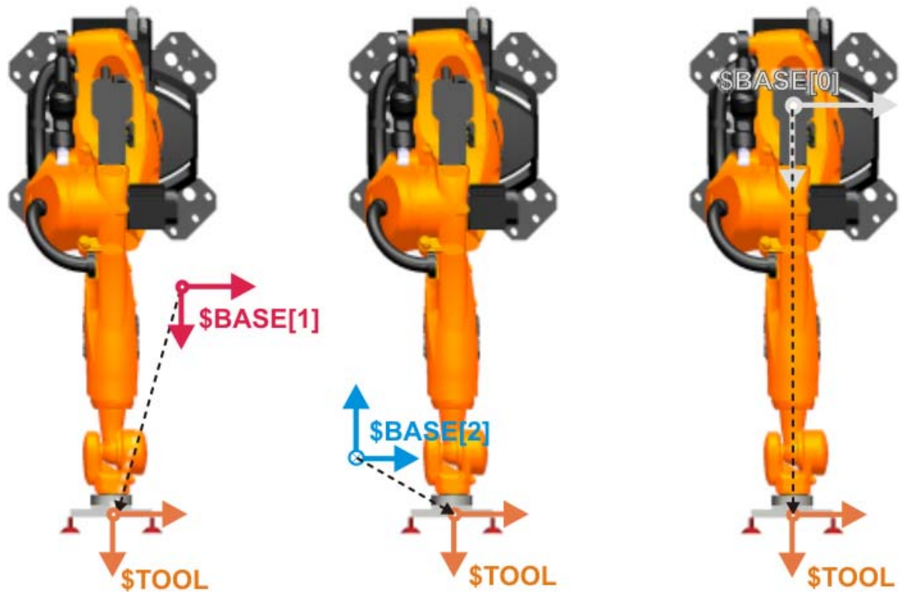


Fig. 3-17: Three robot positions – one robot position!

The position of the tool coordinate system/TCP is displayed in the respective base coordinate system:

- for base **1**
- for base **2**

- for base **0**: this corresponds to the robot root point coordinate system (in most cases identical to the world coordinate system)!

Fig. 3-18:

The Cartesian actual value display only provides sensible values if the correct base and tool are selected!

Displaying the robot position

Procedure:

- Select **Display** > **Actual position** in the menu. The Cartesian actual position is displayed.
- To display the axis-specific actual position, press **Axis spec.**.
- To display the Cartesian actual position again, press **Cartesian**.

3.10 Exercise: Displaying the robot position

Aim of the exercise

On successful completion of this exercise, you will be able to carry out the following activities:

- Display the robot position relative to the origin coordinate systems

Preconditions

The following are preconditions for successful completion of this exercise:

- Completion of safety instruction

Note!
Safety instruction must be completed and documented before commencing this exercise!

- Theoretical knowledge of jogging in all coordinate systems
- Theoretical knowledge about displaying the robot position

Task description

Carry out the following tasks:

1. Release and acknowledge the EMERGENCY STOP.
2. Ensure that T1 mode is set.
3. Clamp the “pen” in the gripper.
4. Activate the tool coordinate system “Pen”.
5. Activate the workpiece coordinate system “Blue”.
6. Jog the tool tip to the origin of the workpiece coordinate system “Blue”.
7. Open the Cartesian position display and view the current position.
8. Jog the tool tip to the origin of the workpiece coordinate system “Red”.
9. Display the current Cartesian position.

4 Executing robot programs

4.1 Selecting and setting the operating mode

Operating modes of a KUKA robot

- T1 (Manual Reduced Velocity)
  - For test operation, programming and teaching
  - Velocity in program mode max. 250 mm/s
  - Velocity in jog mode max. 250 mm/s
- T2 (Manual High Velocity)
  - For test operation
  - Velocity in program mode corresponds to the programmed velocity!
  - Jog mode: not possible.
- AUT (Automatic)
  - For industrial robots without higher-level controllers
  - Velocity in program mode corresponds to the programmed velocity!
  - Jog mode: not possible.
- AUT EXT (Automatic External)
  - For industrial robots with higher-level controllers (PLC)
  - Velocity in program mode corresponds to the programmed velocity!
  - Jog mode: not possible.

Safety instructions – operating modes

Manual mode T1 and T2

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

- Teaching/programming
- Executing a program in jog mode (testing/verification)

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

In **Manual Reduced Velocity mode (T1)**:

- Operator safety (safety gate) is inactive!
- If it can be avoided, there must be no other persons inside the safeguarded area.

  If it is necessary for there to be several persons inside the safeguarded area, the following must be observed:
  - All persons must have an unimpeded view of the robot system.
  - Eye-contact between all persons must be possible at all times.
- The operator must be so positioned that he can see into the danger area and get out of harm’s way.

In **Manual High Velocity mode (T2)**:

- Operator safety (safety gate) is inactive!
- This mode may only be used if the application requires a test at a velocity higher than manual reduced velocity.
- Teaching is not permissible in this operating mode.
- Before commencing the test, the operator must ensure that the enabling devices are operational.
- The operator must be positioned outside the danger zone.
- There should be no other persons inside the safeguarded area.

Operating modes **Automatic** and **Automatic External**

- Safety equipment and safeguards must be present and fully operational.
- All persons are outside the safeguarded area.

Procedure

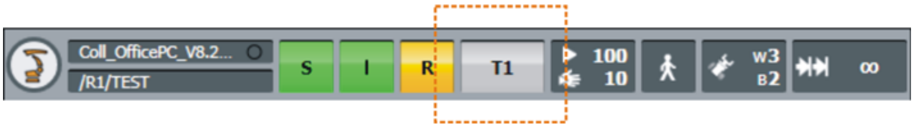
> If the operating mode is changed during operation, the drives are immediately switched off. The industrial robot stops with a safety stop 2.

1. On the KCP, turn the switch for the connection manager. The connection manager is displayed.

2. Select the operating mode.

3. Return the switch for the connection manager to its original position.

   The selected operating mode is displayed in the status bar of the smartPAD.



4.2 Performing an initialization run

BCO run

The initialization run of a KUKA robot is called a BCO run.

> BCO stands for **B**lock **CO**incidence. Coincidence means “coming together” of events in time/space.

A BCO run is carried out in the following cases:

- Program selection
- Program reset
- Jogging in program mode
- Program modifications
- Block selection

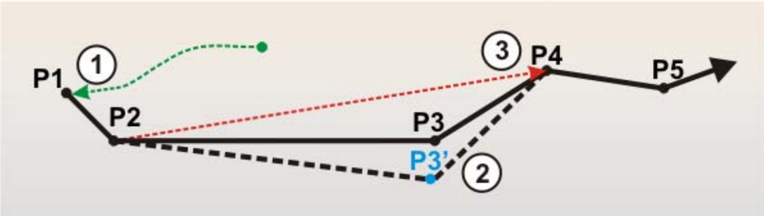


Fig. 4-1: Examples of reasons for a BCO run

Examples for the performance of a BCO run:

1 BCO run to the home position following program selection or reset
2 BCO run following modification of a motion command: point deleted, taught, etc.
3 BCO run following block selection

Reasons for a BCO run

A BCO run is necessary to ensure that the current robot position matches the coordinates of the current point in the robot program.

Path planning can only be carried out if the current robot position is the same as a programmed position. The TCP must therefore always be moved onto the path.

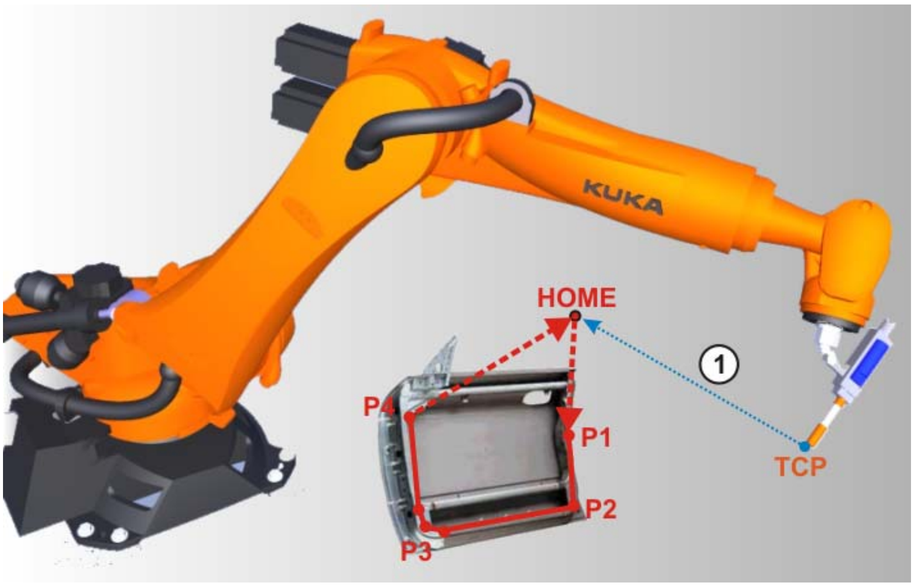


Fig. 4-2: Example of a BCO run

1 BCO run to the home position following program selection or reset

4.3 Selecting and starting robot programs

Selecting and starting robot programs

If a robot program is to be executed, it must be selected. The robot programs are available in the Navigator in the user interface. Motion programs are generally created in folders. The Cell program (management program for controlling the robot from a PLC) is always located in the folder “R1”.

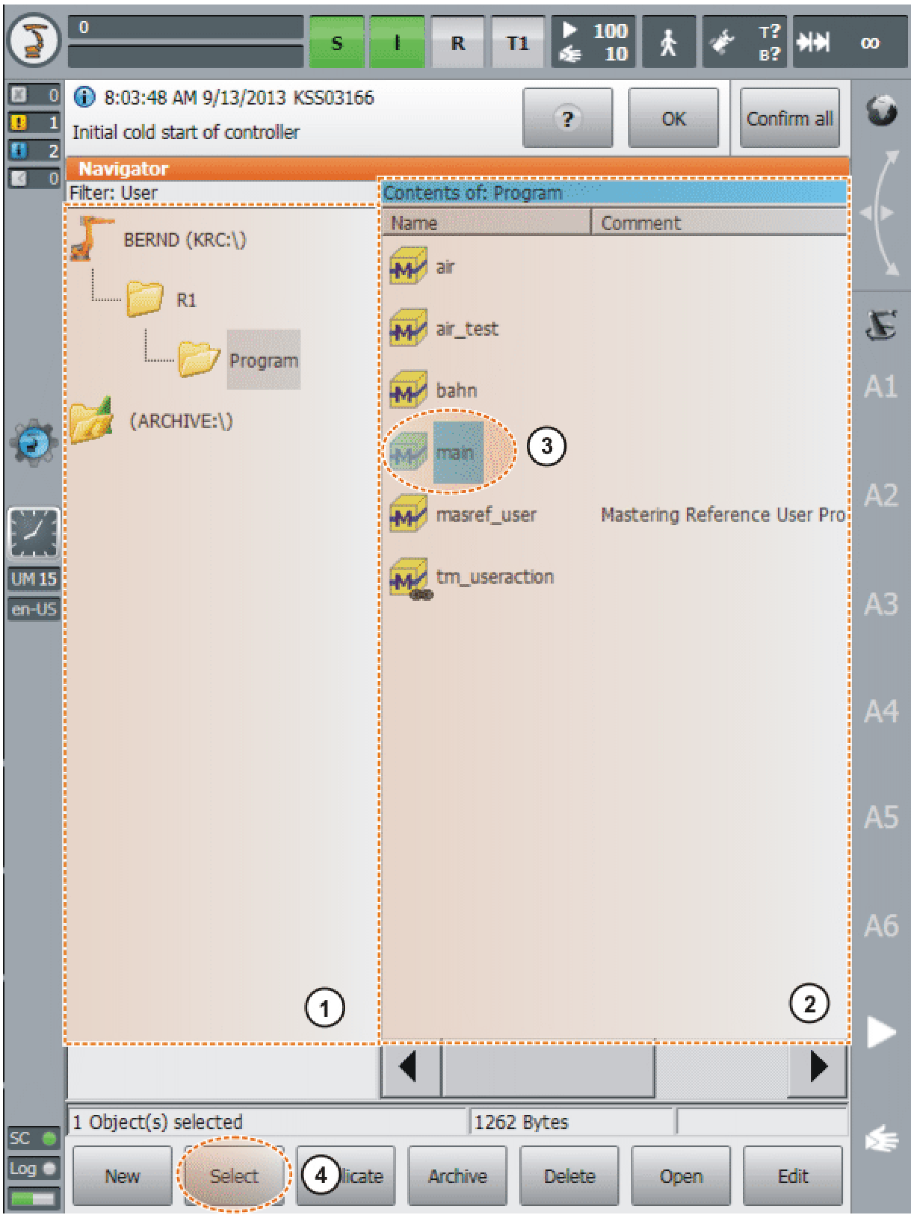


Fig. 4-3: Navigator

1 Navigator: directory/drive structure
2 Navigator: directory/data list
3 Selected program
4 Button for selecting a program

The Start forwards and Start backwards keys are available for starting a program.

Fig. 4-4: Program execution directions: forwards/backwards

When a program is executed, there are various **program run modes** available for program-controlled robot motion:

	**GO** ■ Program runs continuously to the end of the program. ■ In test mode, the Start key must be held down.
	**Motion** ■ In the program run mode Motion Step, each motion command is executed separately. ■ At the end of each motion, Start must be pressed again.
	**Single Step** | Only available in the user group “Expert”! ■ In Incremental Step mode, the program is executed line by line (irrespective of the contents of the individual lines). ■ The Start key must be pressed again after every line.

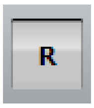
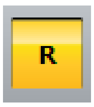
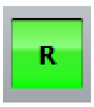
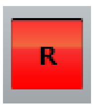
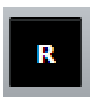
What does a robot program look like?

```
1   DEF kuka_rocks( )
2   INI
3   PTP HOME  Vel= 100 % DEFAULT
4   PTP P1 Vel=100 % PDAT1 Tool[1] Base[0]
5   PTP P2 Vel=100 % PDAT2 Tool[1] Base[0]
6   PTP P3 Vel=100 % PDAT3 Tool[1] Base[0]
7   OUT 1'' State=TRUE CONT
8   LIN P4 Vel=2 m/s CPDAT1 Tool[1] Base[0]
9   PTP HOME  Vel= 100 % DEFAULT
10  END
```

Fig. 4-5: Structure of a robot program

1	**Only visible in the user group "Expert":** ■ "DEF *Program name()*" always stands at the start of a program. ■ "END" defines the end of a program.
2	■ The "INI" line contains calls of standard parameters that are required for correct execution of the program. ■ The "INI" line must always be executed first!
3	■ Actual program text with motion commands, wait commands, logic commands, etc. ■ The motion command "PTP Home" is often used at the start and end of a program, as this is a known and clearly defined position.

Program state

Icon	Color	Description
	Gray	No program is selected.
	Yellow	The block pointer is situated on the first line of the selected program.
	Green	The program is selected and is being executed.
	Red	The selected and started program has been stopped.
	Black	The block pointer is situated at the end of the selected program.

Starting a program

Procedure for starting robot programs:

1. Select program.

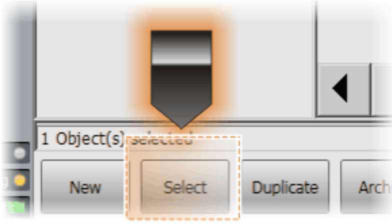


Fig. 4-6: Program selection

2. Set program velocity (program override, POV).

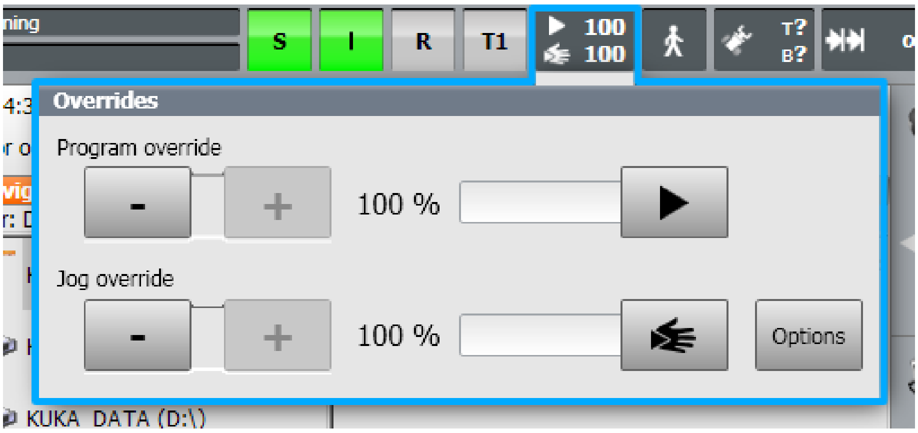


Fig. 4-7: POV setting

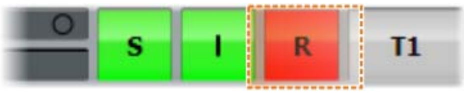
3. Press enabling switch.

Fig. 4-8: Enabling switches

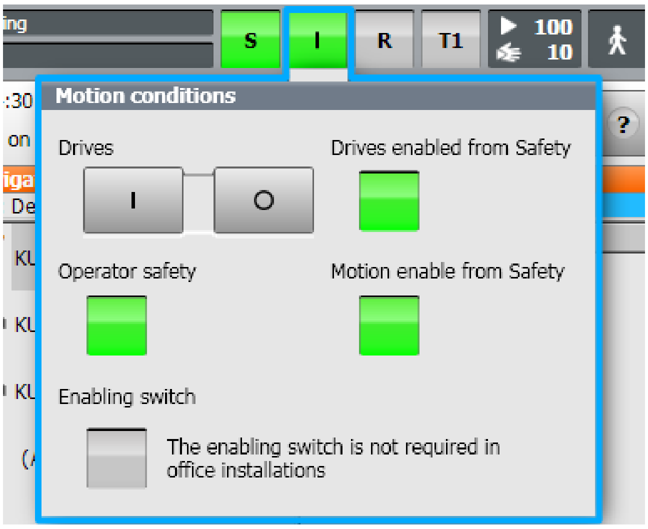
4. Press and hold down the Start (+) key.
   - The “INI” line is executed.
   - The robot performs the BCO run.

Fig. 4-9: Program execution directions: forwards/backwards

> **⚠ WARNING** A BCO run is executed as a PTP motion from the actual position to the target position if the selected motion block contains the motion command PTP. If the selected motion block contains LIN or CIRC, the BCO run is executed as a LIN motion. The motion must be observed in order to avoid collisions. The velocity is automatically reduced during the BCO run.

5. Once the end position has been reached, the motion is stopped. 

The notification message "*Programmed path reached (BCO)*" is displayed.
6. Continued sequence (depending on what operating mode is set):
   - **T1 and T2**: Continue the program by pressing the Start key.
   - **AUT**: Activate drives.



     Then start the program by pressing *Start*.
   - In the Cell program, switch the operating mode to **EXT** and transfer the motion command from the PLC.

4.4 Exercise: Starting robot programs

Aim of the exercise

On successful completion of this exercise, you will be able to carry out the following activities:

- Start robot programs
- Execute robot programs in various run modes

Preconditions

The following are preconditions for successful completion of this exercise:

- Completion of safety instruction

> **Note!**
> Safety instruction must be completed and documented before commencing this exercise!

- Theoretical knowledge of selecting programs
- Theoretical knowledge about setting program velocities
- Theoretical knowledge about different program run modes
- Theoretical knowledge about performing the BCO run
- Theoretical knowledge about starting robot programs

Task description

Carry out the following tasks:

1. Release and acknowledge the EMERGENCY STOP.
2. Ensure that T1 mode is set.
3. Select the program “Air”.
4. Execute the BCO run.
5. Test the program in the modes T1, T2 and Automatic. Start with T1 mode.
6. Test the program in the different program run modes.

4.5 Preparation for program start from PLC

Robot in system group

If robot processes are to be controlled centrally (by a host computer or PLC), this is carried out using the Automatic External interface.

Fig. 4-10: PLC connection

System structure principle

The following is required for successful communication between the KR C4 and a PLC:

- **Automatic External mode**: Operating mode in which a host computer or PLC assumes control of the robot system.
- **CELL.SRC**: Organization program for selecting robot programs from outside.
- Signal exchange between PLC and robot: **Automatic External interface** for configuration of the input and output signals:
  - Control signals to the robot (inputs): start and stop signal, program number, error acknowledgement
  - Robot status (outputs): status of drives, position, errors, etc.

Safety instructions – external program start

Once the CELL program has been selected, a BCO run must be carried out.

> **⚠ WARNING** A BCO run is executed as a PTP motion from the actual position to the target position if the selected motion block contains the motion command PTP. If the selected motion block contains LIN or CIRC, the BCO run is executed as a LIN motion. Observe the motion to avoid collisions. The velocity is automatically reduced during the BCO run.

If the BCO run is successful, no further BCO run is performed in the case of the external start.

> **⚠ WARNING** There is no BCO run in Automatic External mode. This means that the robot moves to the first programmed position after the start at the programmed (not reduced) velocity and does not stop there.

Procedure – external program start

Preconditions

- Operating mode T1 or T2
- Inputs/outputs for Automatic External and the program CELL.SRC are configured.

1. Select the program CELL.SRC in the Navigator. The CELL program is always located in the directory KRC:\R1.
2. Set program override to 100%. (This is the recommended setting. A different value can be set if required.)

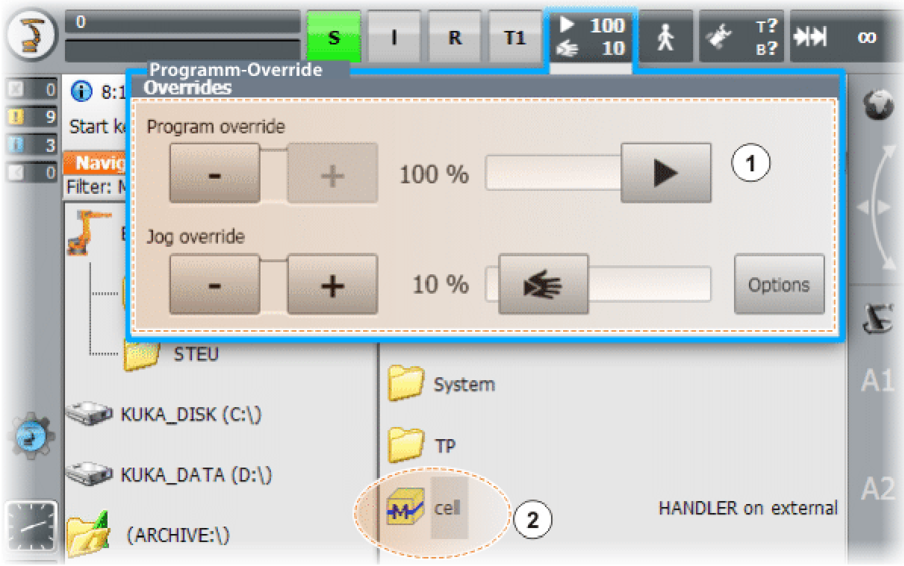


Fig. 4-11: Cell selection and jog override setting

1 Jog override setting
2 Cell.src selection

3. Carry out a BCO run:
   Hold down the enabling switch. Then press the Start key and hold it down until the message “Programmed path reached (BCO)” is displayed in the message window.
4. Select “Automatic External” mode.
5. Start the program from a higher-level controller (PLC).

5 Starting up the robot

5.1 Mastering principle

Why is mastering carried out?

An industrial robot can only be used optimally if it is also completely and correctly mastered. Only then can it exploit its pose accuracy and path accuracy to the full, or be moved using programmed motions at all.

> During mastering, a reference value is assigned to every axis.

A complete mastering operation includes the mastering of every single axis. With the aid of a technical tool (EMD = Electronic Mastering Device), a reference value (e.g. 0°) is assigned to every axis in its **mechanical zero position**. Since, in this way, the mechanical and electrical positions of the axis are matched, every axis receives an unambiguous angle value.

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

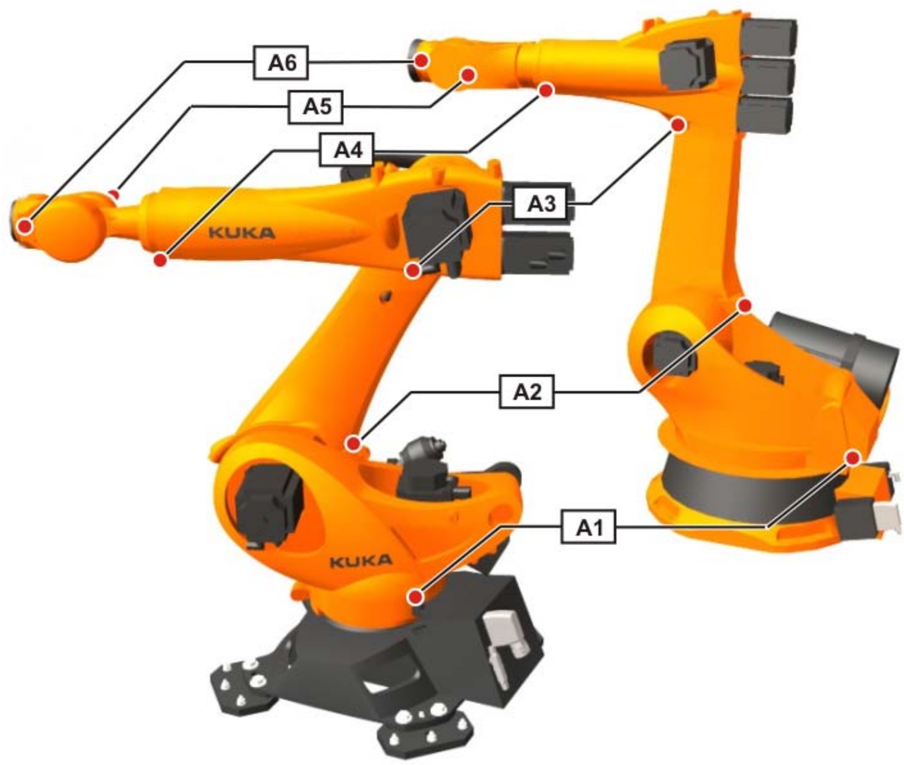


Fig. 5-1: Positions of the mastering cartridges

Angle values of the mechanical zero position (= reference values)

Axis	“Quantec” robot generation	Other robot types (e.g. Series 2000, KR 16, etc.)
A1	-20°	0°
A2	-120°	-90°
A3	+110°	+90°
A4	0°	0°
A5	0°	0°
A6	0°	0°

When is mastering carried out?

A robot must always be mastered. Mastering must be carried out in the following cases:

- During commissioning
- Following maintenance work to components that are involved in the acquisition of position values (e.g. motor with resolver or RDC)
- If robot axes are moved without the controller (e.g. by means of a release device)
- Following mechanical repairs/problems, the robot must first be unmastered before mastering can be carried out:
  - After exchanging a gear unit
  - After an impact with an end stop at more than 250 mm/s
  - After a collision

> **NOTICE** Before carrying out maintenance work, it is generally a good idea to check the current mastering.

Safety instructions for mastering

The functionality of the robot is severely restricted if robot axes are not mastered:

- Program mode is not possible: programmed points cannot be executed.
- No translational jogging: motions in the coordinate systems are not possible.
- Software limit switches are deactivated.

> **CAUTION** **Warning!**
> The software limit switches of an unmastered robot are deactivated. The robot can hit the end stop buffers, thus damaging the robot and making it necessary to exchange the buffers. An unmastered robot should not be jogged, if at all avoidable. If it must be jogged, the jog override must be reduced as far as possible.

Performing mastering

Fig. 5-2: EMD in operation

Mastering is carried out by determining the mechanical zero point of the axis. The axis is moved until the mechanical zero point is reached. This is the case when the gauge pin has reached the lowest point in the reference notch. Every axis is thus equipped with a mastering cartridge and a mastering mark.

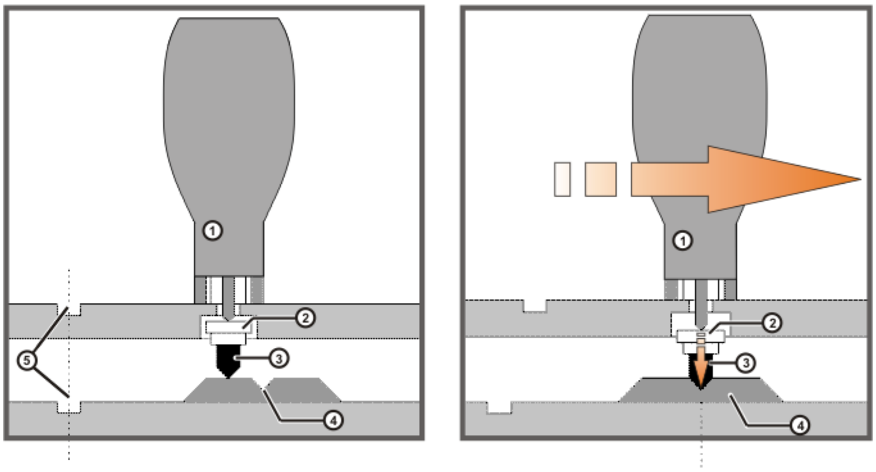


Fig. 5-3: EMD mastering sequence

1	EMD (Electronic Mastering Device)	4	Reference notch
2	Gauge cartridge	5	Premastering mark
3	Gauge pin		

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