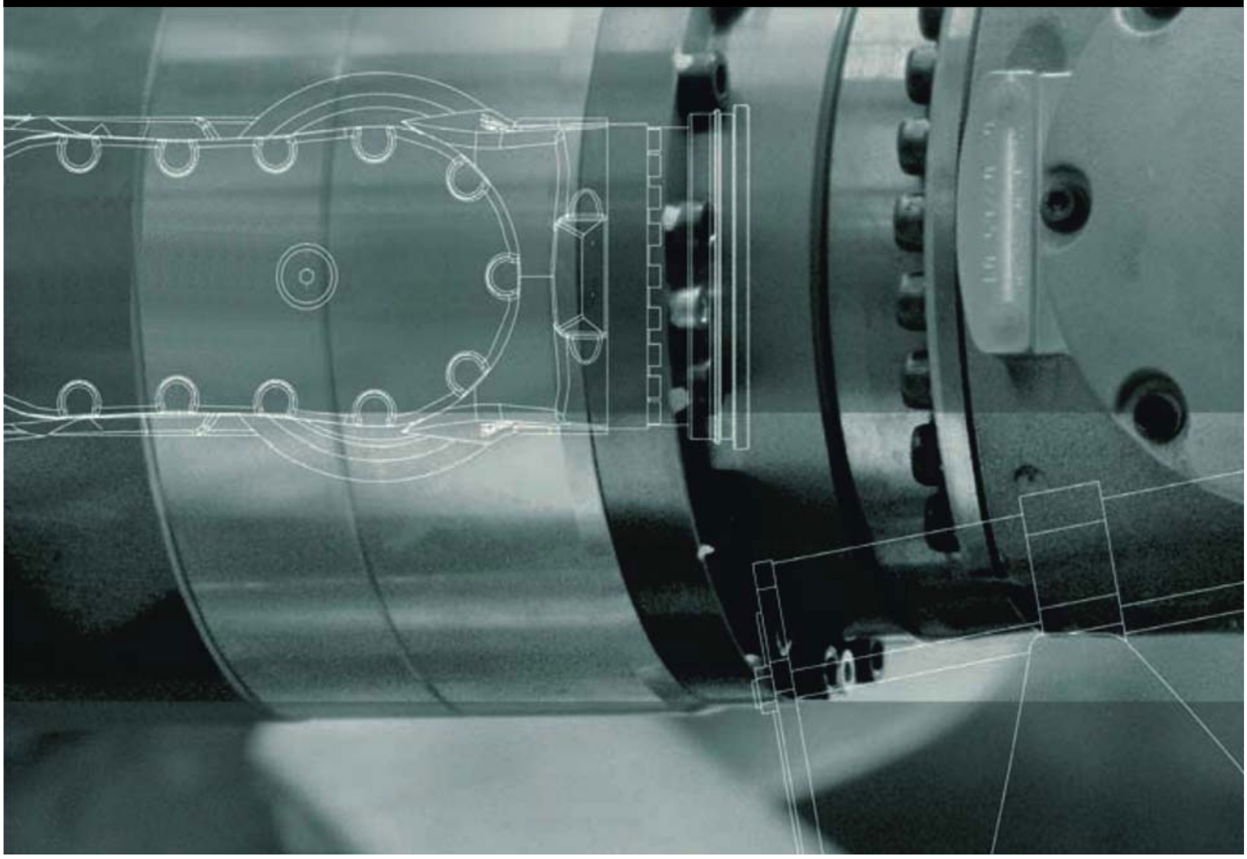
KUKA System Technology

KUKA Roboter GmbH

KUKA.ForceTorqueControl 3.0

For KUKA System Software 8.2



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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 Introduction

1.1 Target group

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

- Advanced KRL programming skills
- Advanced knowledge of the robot controller system
- Advanced knowledge of field bus interfaces

For optimal use of our products, we recommend that our customers take part in a course of training at 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 manipulator
- Documentation for the robot controller
- Operating and programming instructions for the KUKA System Software
- Documentation relating to options and accessories
- Parts catalog on storage medium

Each of these sets of instructions is a separate document.

1.3 Representation of warnings and notes

Safety

These warnings are relevant to safety 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 INSTRUCTIONS Procedures marked with this warning **must** be followed exactly.

Notes

These hints 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 Terms used

Term	Description
KLI	Line bus for the integration of the system in the customer network (KUKA Line Interface) The KLI is the Ethernet interface of the robot controller for external communication.
KUKA smartHMI	KUKA smart human-machine interface User interface of the KUKA System Software
RCS	Reference coordinate system The reference coordinate system is the reference system for force/torque control. (>>> 2.4 "Reference coordinate system: RCS" Page 13)
RSI	Robot Sensor Interface Interface for communication between the industrial robot and a sensor system.
RSI monitor	Monitor for online visualization of RSI signals. The RSI monitor can display and record defined signals of the force/torque control.
Sensor coordinate system	The sensor coordinate system depends on the sensor system used. The position and orientation of the sensor coordinate system can be found on the sensor and is described in the sensor system documentation.
Sensor override	The sensor override refers to the program override $OV_PRO programmed for the start of motion. In the case of a velocity adaptation (“velocity change”) due to ForceTorqueControl, the start value for $OV_PRO is reduced by a specified percentage.
TCP	Tool Center Point and origin of the TOOL coordinate system
TTS	Tool-based technological system The TTS is a coordinate system that moves along the path with the robot. It is calculated for every LIN, CIRC, SLIN and SCIRC motion.

1.5 Trademarks

- **Windows** is a trademark of Microsoft Corporation.
- EtherCAT Technology Group is a trademark of Beckhoff Automation GmbH.

2 Product description

2.1 Overview of ForceTorqueControl

Functions

ForceTorqueControl is an add-on technology package with the following functions:

- Execution of motions as a function of measured process forces and torques
- Compliance with process forces and torques irrespective of the position and size of the workpiece
- Compliance with complex process force characteristics during the machining of workpieces
- Velocity adaptation along the programmed path as a function of the measured process forces.
- Compensation for deviations in workpiece size and position by programming a degree of compliance for the robot
- Distortion-free positioning: motion until contact is made
- Monitoring of the sensor load limits
- Monitoring of the sensor correction limits

Functional principle

ForceTorqueControl gives the robot a sense of touch, as it were, enabling it to react sensitively to external forces and torques and to exert programmable forces and torques on a workpiece.

Servo-control is possible in up to 6 degrees of freedom (Fx, Fy, Fz, Tx, Ty, Tz). When force/torque control is active, the robot moves until the sensor detects the defined force or torque. In the case of superposed force/torque control, the robot also moves on a programmed path. A reference coordinate system is defined as a reference system.

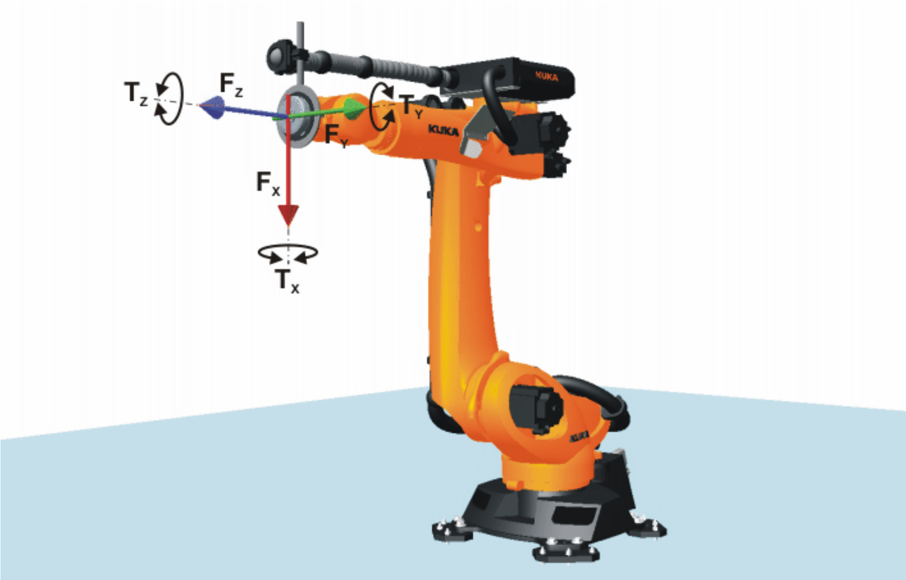

Fig. 2-1: Degrees of freedom of force/torque control

Areas of application

- Handling
- Joining, e.g. bonding, riveting, assembly
- Forming, e.g. roll hemming
- Cutting, e.g. grinding, deburring, polishing

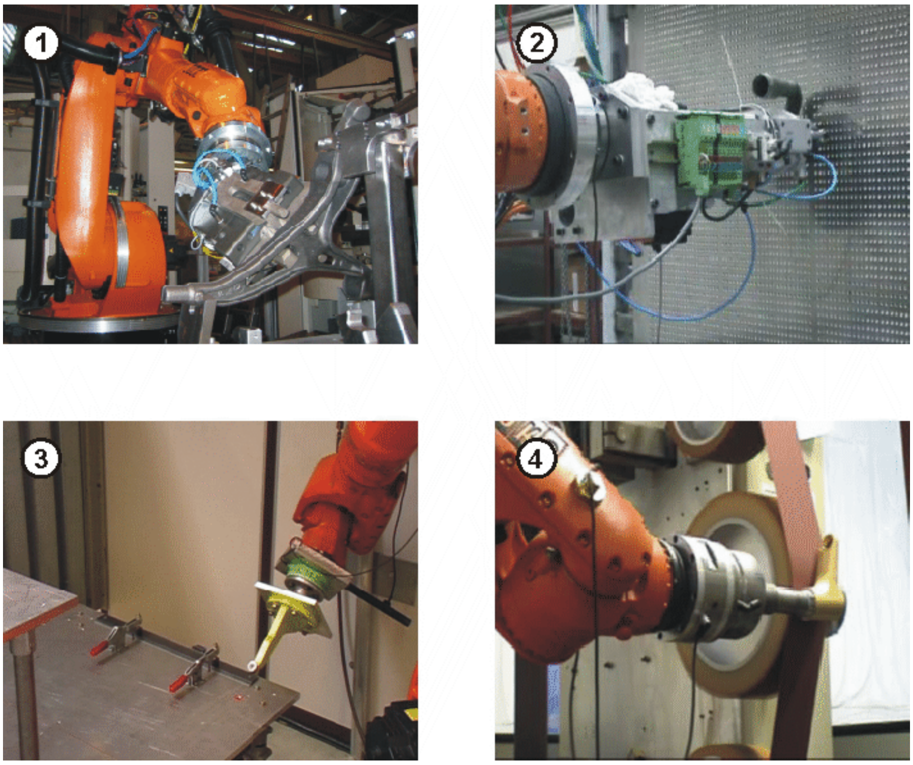

Fig. 2-2: Areas of application, ForceTorqueControl

1	Handling	3	Roll hemming
2	Riveting	4	Grinding

Components

These software components are included in the ForceTorqueControl package:

- KUKA.RobotSensorInterface 3.1
- KUKA.UserTech 3.1
- Program for determining the load data of the sensor

Sensor systems

ForceTorqueControl supports the following sensor systems:

- ATI DAQ F/T sensor system
- ATI NET F/T sensor system

> These sensor systems are not included in the scope of supply for ForceTorqueControl. Information about the available sensor systems and selection of the right sensor system for the planned application can be obtained from KUKA Roboter GmbH. (>>> 10 "KUKA Service" Page 65)

- User-specific sensor systems

  It is possible to connect sensors via the I/O system of the robot. A field bus can be used to integrate sensors that supply the measured value as an analog output or as a digital output.

Communication

The robot controller can communicate with the sensor system via the I/O system or via Ethernet. This depends on the sensor used:

- ATI DAQ F/T sensor system:

  Communication via a bus system. We recommend using the EtherCAT bus coupler from Beckhoff.
- ATI NET F/T sensor system:

  Communication via the Ethernet interface of the robot controller (KLI)

- User-specific sensor systems:
  Communication via a bus system

WorkVisual To configure the sensor system ATI DAQ F/T or a user-specific sensor system, the following software is required:

- WorkVisual 2.3 or higher

2.2 Overview of connecting cables

The connection between the robot, the sensor and the robot controller depends on the sensor system used. The figure gives an overview of the connecting cables for the NET F/T sensor system.

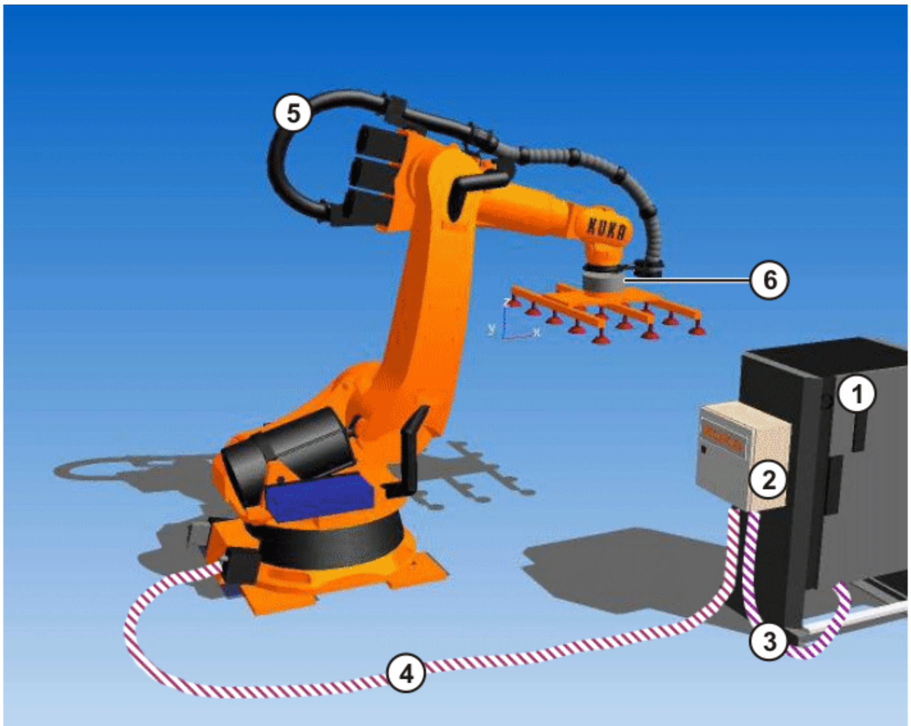

Fig. 2-3: Overview of connecting cables (example)

1 Robot controller
2 KUKA FT-NET controller box
3 Ethernet cable to the KLI
4 Sensor cable
5 Energy supply system with sensor cable
6 NET F/T sensor

> The KUKA FT-NET controller box is a compact control cabinet with its own power supply, which comprises all the necessary components for operating the NET F/T sensor system.
> (>>> 4.4.1 "KUKA FT-NET controller box" Page 28)

2.3 Motion types

Overview The following motion types can be configured with ForceTorqueControl:

- Sensor-guided motion
  (>>> 2.3.1 "Sensor-guided motion" Page 12)

- Superposed force/torque control
  (>>> 2.3.2 "Superposed force/torque control" Page 12)

2.3.1 Sensor-guided motion

Description

When the robot executes a sensor-guided motion, the robot does not move to a programmed end point, but is moved from a start point on the basis of the measured sensor data. The robot moves until a defined break condition is satisfied. In order to move the robot, force and torque setpoints can be set for up to 6 degrees of freedom (Fx, Fy, Fz, Tx, Ty, Tz). A reference coordinate system is selected as a reference system.

Example

The robot moves in the Z direction in the TOOL coordinate system until the defined force setpoint of 100 N is reached.

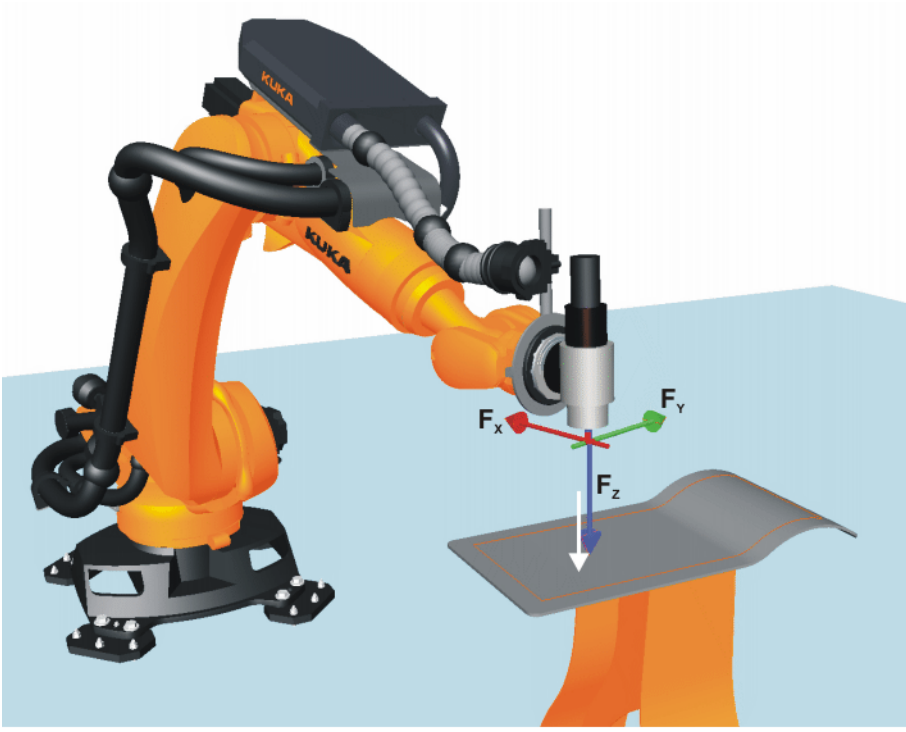

Fig. 2-4: Sensor-guided motion

2.3.2 Superposed force/torque control

Description

The robot moves along a programmed path. While moving along this path, the robot exerts the defined force and torque setpoints. Force and torque setpoints can be set for up to 6 degrees of freedom (Fx, Fy, Fz, Tx, Ty, Tz). A reference coordinate system is selected as a reference system.

The following motion types can be executed with superposed force/torque control:

- PTP, LIN, CIRC
- SLIN, SCIRC

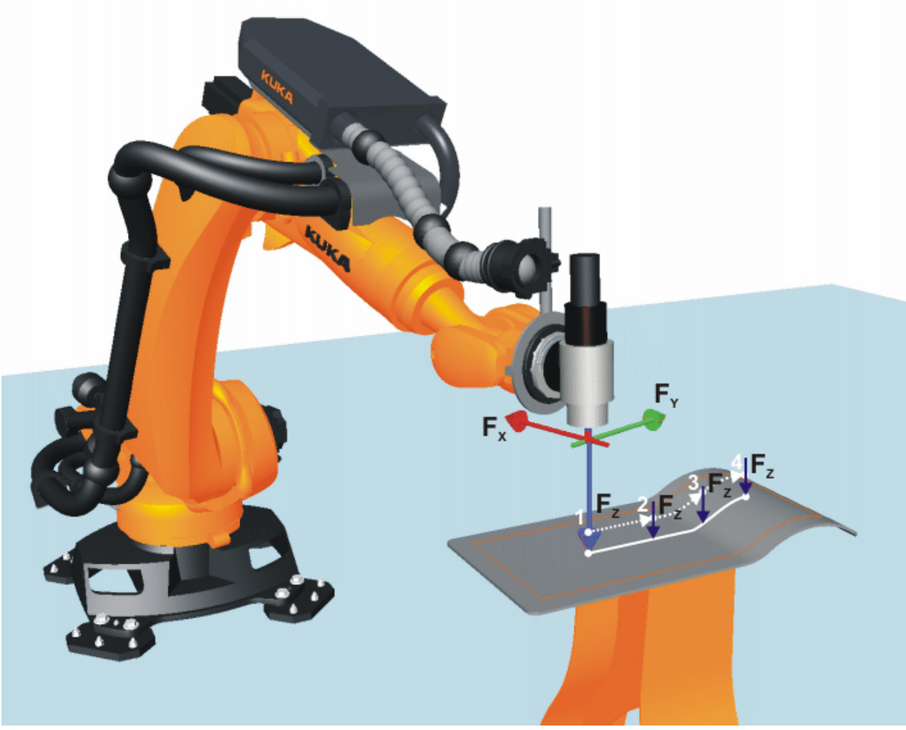

Fig. 2-5: Superposed force/torque control

> In the case of a PTP motion, note that the robot guides the TCP along the fastest path to the end point. This is generally a curved path.

Example

The robot executes a programmed path in the XY plane in the BASE coordinate system. Additionally, the robot exerts a defined force setpoint of 100 N in the Z direction along the programmed path.

2.4 Reference coordinate system: RCS

Overview

The reference coordinate system RCS is the reference system for force/torque control. The origin of the reference coordinate system is always the current TCP.

(>>> 2.4.4 "RCS origin TCP, exemplified by RCS orientation BASE or TOOL" Page 17)

The orientation of the reference coordinate system can be defined using the following coordinate systems:

RCS orientation	Description
BASE	Reference coordinate systems with the orientation of the BASE, WORLD or ROBROOT coordinate system are independent of the orientation of the tool. (>>> 2.4.1 "RCS orientation: BASE" Page 14)
WORLD	
ROBROOT	

RCS orientation	Description
TOOL	Reference coordinate systems with the orientation of the TOOL coordinate system are dependent on the orientation of the tool. (>>> 2.4.2 "RCS orientation: TOOL" Page 15)
TTS	Reference coordinate systems with the orientation of the TTS are only relevant for superposed force/torque control. (>>> 2.4.3 "RCS orientation: TTS" Page 15)

2.4.1 RCS orientation: BASE

Description

The orientation of the reference coordinate system corresponds to the orientation of the current BASE coordinate system. It is independent of the orientation of the tool.

The origin of the reference coordinate system is the current TCP.

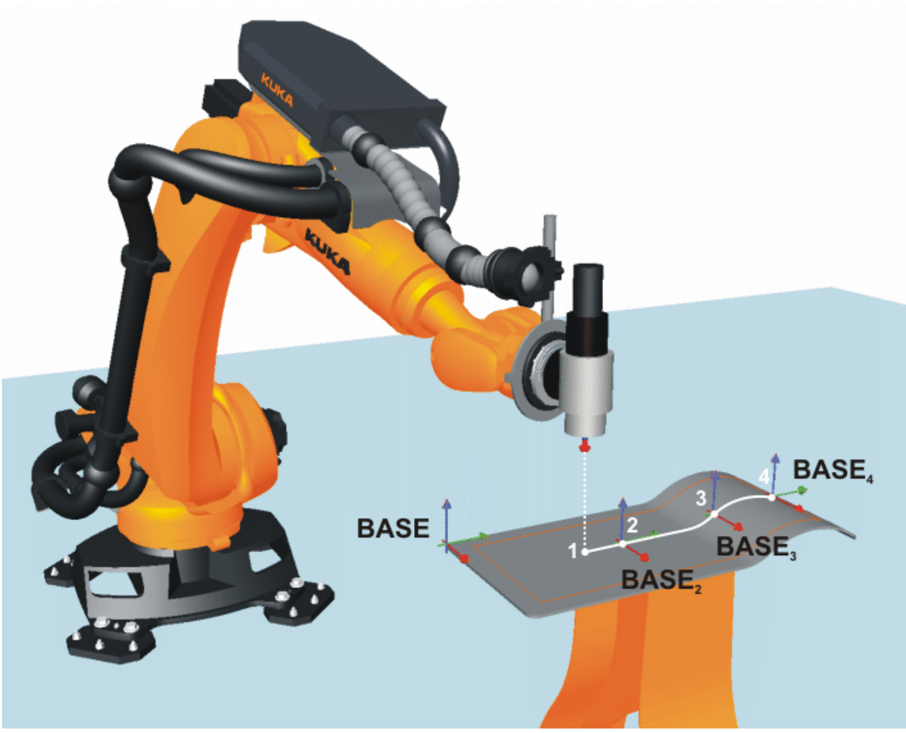

Fig. 2-6: RCS orientation: BASE

Example

- Grinding at a stationary abrasive belt

  Irrespective of the orientation of the TOOL coordinate system, the workpiece is pressed perpendicularly against the abrasive belt.

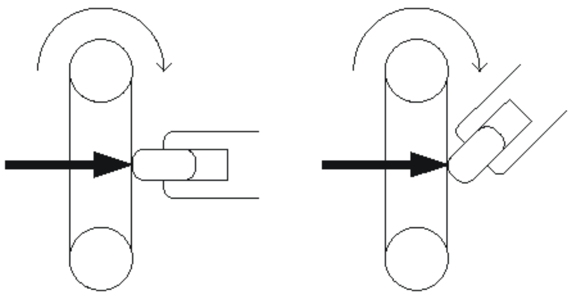

Fig. 2-7: Example – stationary abrasive belt

2.4.2 RCS orientation: TOOL

Description The orientation of the reference coordinate system corresponds to the orientation of the current TOOL coordinate system. It is dependent on the orientation of the tool.

The origin of the reference coordinate system is the current TCP.

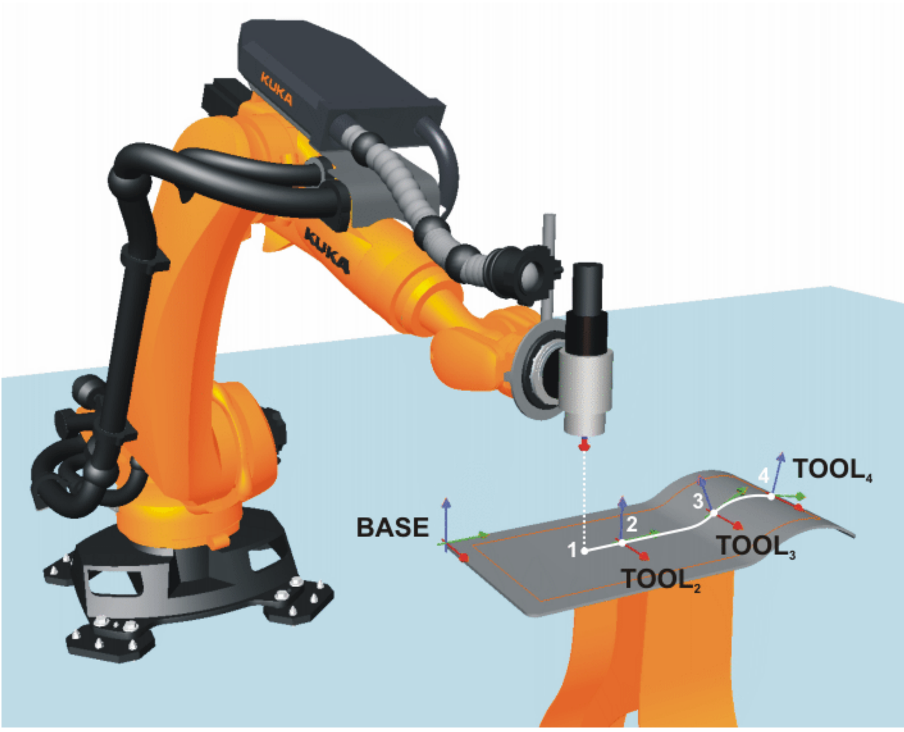

Fig. 2-8: RCS orientation: TOOL

Examples

- Handling
- Assembly
- Force/torque control in the tool direction

2.4.3 RCS orientation: TTS

Description The orientation of the reference coordinate system corresponds to the direction of motion of the TCP of the current tool.

The origin of the reference coordinate system is the current TCP.

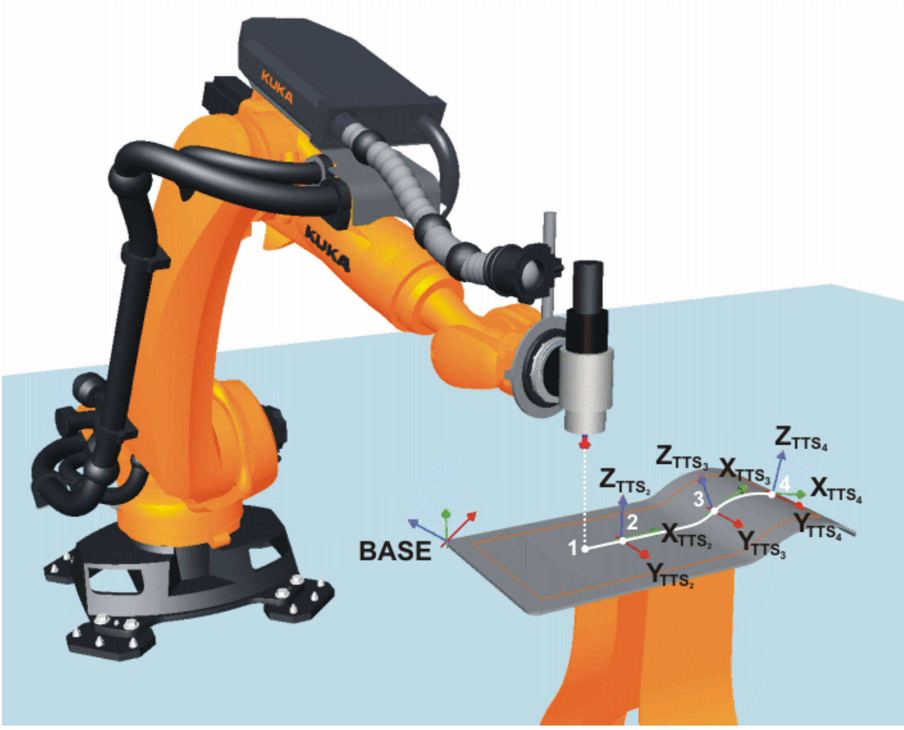

Fig. 2-9: RCS orientation: TTS

TTS

The TTS is a coordinate system that moves along the path with the robot. It is calculated for each CP motion. The TTS is derived from the path tangent, the +X axis of the TOOL coordinate system ($+X_{TOOL}$ = tool direction) and the resulting normal vector.

- X_{TTS}: path tangent
- Y_{TTS}: normal vector to the plane derived from the path tangent and $+X_{TOOL}$
- Z_{TTS}: normal vector of the right-angled system derived from X_{TTS} and Y_{TTS} (= negative tool direction)

> The path tangent and the tool direction must not be parallel, otherwise the TTS cannot be calculated and the robot controller displays an error message.

Example

- Force-controlled roll hemming

  The roll is pressed against the metal sheet perpendicularly to the direction of motion of the TCP.

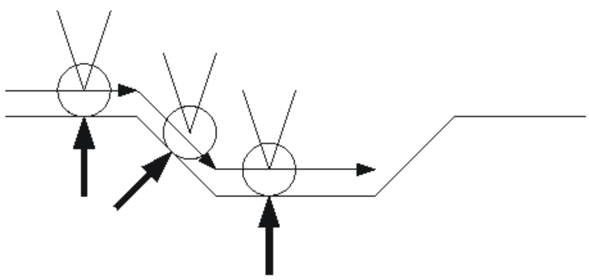

Fig. 2-10: Example – force-controlled roll hemming

2.4.4 RCS origin TCP, exemplified by RCS orientation BASE or TOOL

Description The origin of the reference coordinate system is always the current TCP.

Example The following parameters are configured for force/torque control.

Fx [N]	Fy [N]	Fz [N]	Tx [Nm]	Ty [Nm]	Tz [Nm]
- - -	- - -	50	- - -	0	- - -

In the following figure, the workpiece moves from top to bottom. When one point of the workpiece has reached force F_Z = 50 N on the surface, the workpiece rotates until torque T_Y = 0 is reached. The direction of rotation of the workpiece depends on the orientation of the TCP.

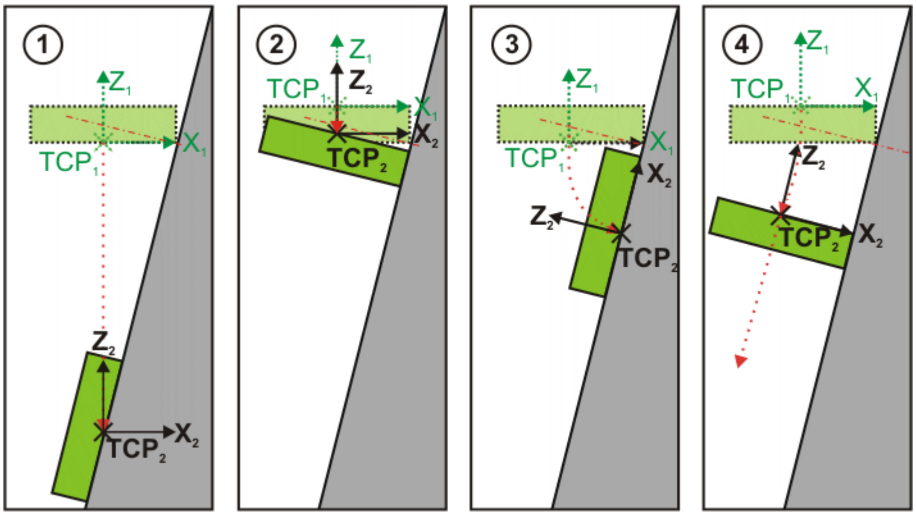

Fig. 2-11: RCS origin: TCP

Item	Description
1	RCS orientation: BASE, TCP below perpendicular When the workpiece rotates about the TCP, the orientation of the reference coordinate system does not change. Because the TCP is below the perpendicular to the surface, the workpiece rotates.
2	RCS orientation: BASE, TCP above perpendicular When the workpiece rotates about the TCP, the orientation of the reference coordinate system does not change. Because the TCP is above the perpendicular to the surface, the workpiece rotates upwards until torque T_Y = 0 is reached.
3	RCS orientation: TOOL, TCP at bottom When the workpiece rotates about the TCP, the orientation of the reference coordinate system changes. Because the TCP is below the perpendicular to the surface, the workpiece rotates downwards until torque T_Y = 0 is reached.
4	RCS orientation: TOOL, TCP at top When the workpiece rotates about the TCP, the orientation of the reference coordinate system changes. Because the TCP is above the perpendicular to the surface, the workpiece rotates upwards until torque T_Y = 0 is reached.

2.5 Monitoring of force/torque control

Overview

The monitoring of force/torque control can be configured. ForceTorqueControl ends force/torque control if the configured load or sensor correction limits are exceeded.

- Exceeding of the maximum sensor load that may be exerted on the sensor in the sensor coordinate system. This may be due to external process forces and/or the weight of the tool.

  Configuration: **Load range** page (configuration of the sensor system)
- Exceeding of the maximum load that may be exerted externally on the tool in the reference coordinate system RCS.

  Configuration: (>>> 8.2.8 "“Monitoring functions” page" Page 52)
- Exceeding of the maximum sensor correction.

  Configuration: (>>> 8.2.7 "“Correction limit” page" Page 51)

For a sensor-guided motion, a break condition is always defined together with a break mode. As the break condition, one or more ranges can be defined which the measured sensor value must enter.

ForceTorqueControl ends sensor-guided motion when the break condition is satisfied, or on expiry of a defined maximum time if the break condition is not satisfied within this time.

- The break mode defines the time at which sensor-guided motion is terminated:
  - **In the target range**: Termination as soon as the measured sensor value lies within the defined range.
  - **Hold time once within target range**: A timer starts once the measured sensor value lies within the defined range. Termination once the hold time has expired, irrespective of whether the measured value leaves a range again during this time.
  - **Hold time entirely within target range**: The timer is reset each time the measured value leaves a range. Termination when the measured value lies within the defined range for the entire hold time.
  - **Hold time entirely within target range and signal**: Termination when the measured value lies within the defined range for the entire hold time and a defined input is additionally set to TRUE.

  Configuration: (>>> 8.2.6 "“Break condition” page (sensor-guided motions)" Page 50)
- Maximum time expired.

  Configuration: (>>> 8.2.9 "“Miscellaneous” page (sensor-guided motion)" Page 52)

> The cause of termination of a sensor-guided motion can be evaluated using the variable FT_NIFBREAK.
> (>>> 9.4 "Return values of the variables FT_NIFBREAK" Page 64)

2.5.1 Maximum load exceeded

Description

Force/torque control is terminated if a maximum force or a maximum torque is exceeded. The reference coordinate system is the RCS.

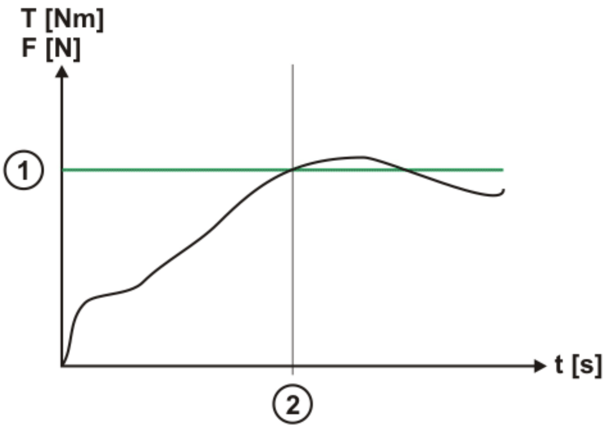

Fig. 2-12: Maximum load exceeded

Item	Description
1	Maximum force F_{Max} or torque T_{Max}
2	Maximum force F_{Max} or torque T_{Max} is exceeded. Force/torque control is terminated.

2.5.2 Maximum sensor correction exceeded

Description

The maximum sensor correction can be defined in a positive and negative direction for each activated component. The reference coordinate system is the RCS.

If the maximum sensor correction is exceeded during a sensor-guided motion, force/torque control is terminated.

If the maximum sensor correction is reached during a motion with superposed force/torque control, no further sensor corrections are carried out in this direction.

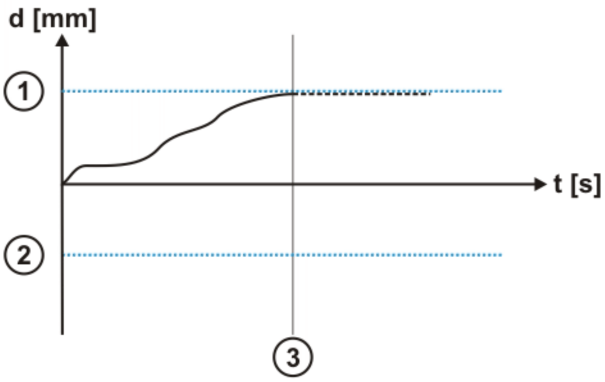

Fig. 2-13: Maximum sensor correction exceeded

Item	Description
1	Maximum sensor correction d_{Max} in the positive direction
2	Maximum sensor correction d_{Min} in the negative direction
3	Maximum sensor correction d_{Max} has been exceeded. A sensor-guided motion is terminated, and superposed force/ torque control is limited to the upper correction limit.

2.5.3 Break condition met and hold time expired

Description

Sensor-guided motion is terminated if the break condition is met and the timer for the hold time has expired.

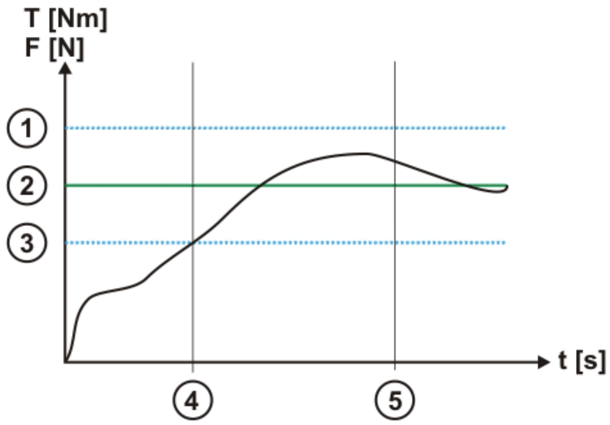

Fig. 2-14: Break condition met and hold time expired

Item	Description
1	Positive limit of the range
2	Specified force F_{Nom} or torque T_{Nom}
3	Negative limit of the range
4	Break condition is met. Timer for the hold time is started.
5	Timer for the hold time has expired. Sensor-guided motion is terminated.

2.5.4 Maximum time expired

Description

Sensor-guided motion is terminated if the timer for the maximum time has expired. The timer is started when sensor-guided motion is started.

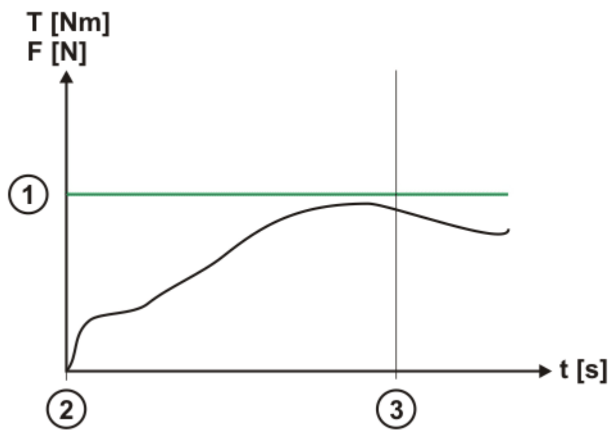

Fig. 2-15: Maximum time expired

Item	Description
1	Specified force F_{Nom} or torque T_{Nom}

Item	Description
2	Sensor-guided motion is started. Start is started.
3	Timer has expired. Sensor-guided motion is terminated.

3 Safety

This documentation contains safety instructions which refer specifically to the software described here.

The fundamental safety information for the industrial robot can be found in the “Safety” chapter of the Operating and Programming Instructions for System Integrators or the Operating and Programming Instructions for End Users.

> ⚠ The “Safety” chapter in the operating and programming instructions must be observed. Death to persons, severe injuries or considerable damage to property may otherwise result.

Sensor-assisted operation

- If used incorrectly, KUKA.ForceTorqueControl can cause personal injury and material damage.
- In sensor-assisted operation, the robot may move unexpectedly in the following cases:
  - Incorrectly configured force/torque control
  - Hardware fault (e.g. incorrect cabling, break in the sensor cable or sensor malfunction)
- Unexpected movements may cause serious injuries and substantial material damage. The system integrator is obliged to minimize the risk of injury to himself/herself and other people, as well as the risk of material damage, by adopting suitable safety measures, e.g. by means of workspace limitation.
- At the start of force/torque control, the safety controller generates the following acknowledgement message in T1 or T2 mode:

  !!! Caution - sensor correction is activated!!!

Workspace limitation

- The axis ranges of all robot axes are limited by means of adjustable software limit switches. These software limit switches must be set in such a way that the workspace of the robot is limited to the minimum range required for the process.
- The System Software allows the configuration of a maximum of 8 Cartesian and 8 axis-specific workspaces. The system integrator must configure the workspaces in such a way that they are limited to the minimum range required for the process. This reduces the risk of damage caused by unexpected movements in sensor-assisted operation to a minimum.

Sensor correction

- By default, KUKA.ForceTorqueControl limits the maximum sensor correction in the reference coordinate system to +/- 5 mm for translational direction corrections and 5° for axis angle corrections (= maximum rotational offset across all axis angles).

  If the preset range for sensor correction in the reference coordinate system is not sufficient, the maximum permissible correction range can be increased. The permissible range for sensor correction must always be limited to the minimum required range.

  (>>> 8.2.7 "“Correction limit” page" Page 51)

4 Planning

4.1 Geometry of the tool

Description

The torque load of the sensor is determined by the geometry of the tool. The following geometry must thus be observed when designing the tool in order to reduce the sensor load:

- Minimize distance from center of mass of tool to sensor system.
- Minimize length of lever arm of external process forces acting on the sensor system.

4.2 Selecting the sensor system

Description

The following criteria must be met:

1. Sensor load in normal operation is within the permissible measurement range of the sensor system.
2. Safety factor for peak loads is taken into consideration.

The required measurement range of the sensor system is derived from the following resulting forces:

- Weight of mounted tool at sensor system
- Maximum process force
- Maximum acceleration force

Simplified formula for dimensioning of the sensor system:

```
Mmax = FGw * dMs + FPmax * dKPmax
```

Element	Description
M_{max}	Maximum torque in Nm
F_{Gw}	Weight of tool in N
d_{Ms}	Distance from center of mass to sensor origin in m
F_{Pmax}	Maximum process force in N
d_{KPmax}	Maximum distance contact point to sensor origin in m

NOTICE Selection of the wrong sensor system can result in damage to the sensor system and other material damage.
The correct sensor system can only be selected with detailed knowledge of the real process.
Consultation with KUKA Roboter GmbH is required here. (>>> 10 "KUKA Service" Page 65)

Example

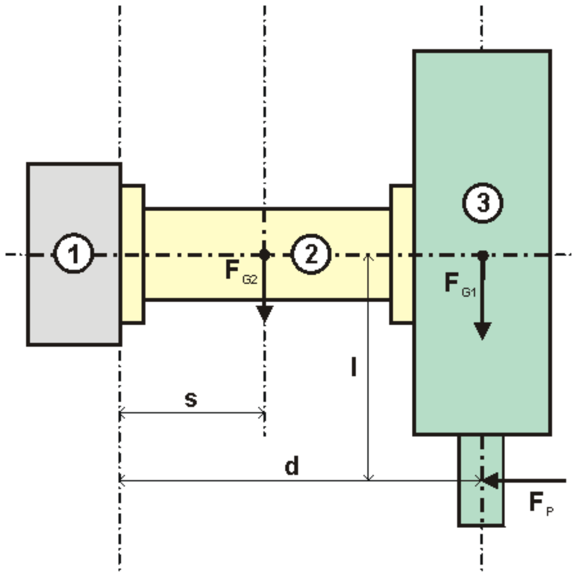

Fig. 4-1: Example of sensor system selection

Item	Description
1	Sensor
2	Mount
3	Spindle
F_{G1}	Weight of spindle, e.g. 50 N
F_{G2}	Weight of holder, e.g. 10 N
F_P	Process force, e.g. 100 N
s	Center of gravity of holder, e.g. 0.15 m
d	Center of gravity of spindle, e.g. 0.40 m
l	Lever arm, e.g. 0.25 m

The required measurement range of the sensor system is derived from the sum of the following torques acting on the sensor:

- Torque resulting from the weight of mounted tool at sensor system:
  $M1 = F_{G1} * d + F_{G2} * s = 50\ N * 0.40\ m + 10N * 0.15\ m = 21.5\ Nm$
- Torque resulting from the maximum process force:
  $M2 = F_P * l = 100\ N * 0.25\ m = 25.0\ Nm$

Sensor load in normal operation:

M1 + M2 = 46.5 Nm

Permissible torque from nominal load of the KR 16 robot and geometry of the tool:

M3 = 160 N * 0.4 m = 64 Nm

Sensor selection: ATI DAQ F/T Delta: Measurement range ±60 Nm, maximum load ±220 Nm

The following criteria are met:

1. Sensor load in normal operation is within the permissible measurement range of the sensor system.
   (-60 Nm < 46.5 Nm > +60 Nm)
2. Safety factor for peak loads is taken into consideration.
   Safety factor = 220 Nm/64 Nm = 3.5

Disadvantage of this choice of sensor:

- Although the sensor load during normal operation is within the permissible measuring range of the sensor system, the measuring range to be used for the planned application could be too small.

  M4 = 60 Nm - (M1 + M2) = 60 Nm - 46.5 Nm = 13.5 Nm

> Recommendation: Select the sensor system so that its measuring range is at least twice as large as the sensor load during normal operation.

4.3 ATI DAQ F/T sensor system

Overview

These hardware components are required for operating the sensor system with ForceTorqueControl:

- ATI F/T-DAQ sensor
- Intermediate flange between robot mounting flange and sensor
- Power supply box
- For sensors of type Gamma or larger:
  - 3-piece cable set, sensor - power supply box (5 m, 6 m, 15 m)
- EtherCAT bus system

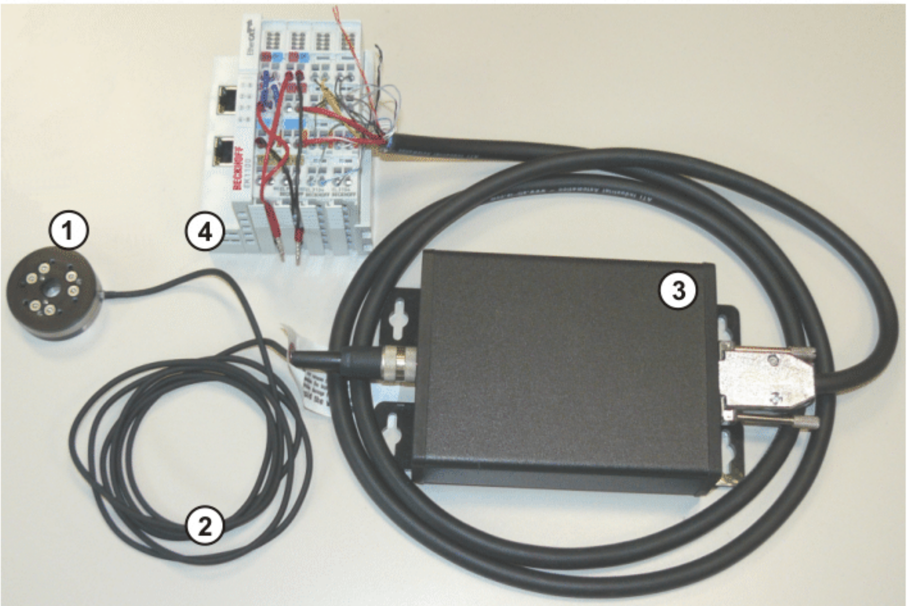

Fig. 4-2: ATI DAQ F/T sensor system (example with mini-sensor)

1	F/T-DAQ sensor	3	Power supply box
2	Sensor cable	4	EtherCAT bus system

EtherCAT bus system

We recommend using the EtherCAT bus coupler from Beckhoff. The following components are required:

- EL9505 power supply terminal 24 V —» 5 V
- EK1100 EtherCAT bus coupler
- 2 EL3104 4-channel analog input terminals, -10 V to 10 V

4.4 ATI NET F/T sensor system

Overview

These hardware components are required for operating the sensor system with ForceTorqueControl:

- ATI F/T-NET sensor

- Intermediate flange between robot mounting flange and sensor
- Sensor cable
- Ethernet cable
- ATI NET box or KUKA FT-NET controller box

> The ATI NET box must be grounded and supplied with power in accordance with the sensor system documentation. The required cables must be assembled by the user.

> The KUKA FT-NET controller box is a compact control cabinet with its own power supply, which comprises all the necessary components for operating the NET F/T sensor system.
> (>>> 4.4.1 "KUKA FT-NET controller box" Page 28)

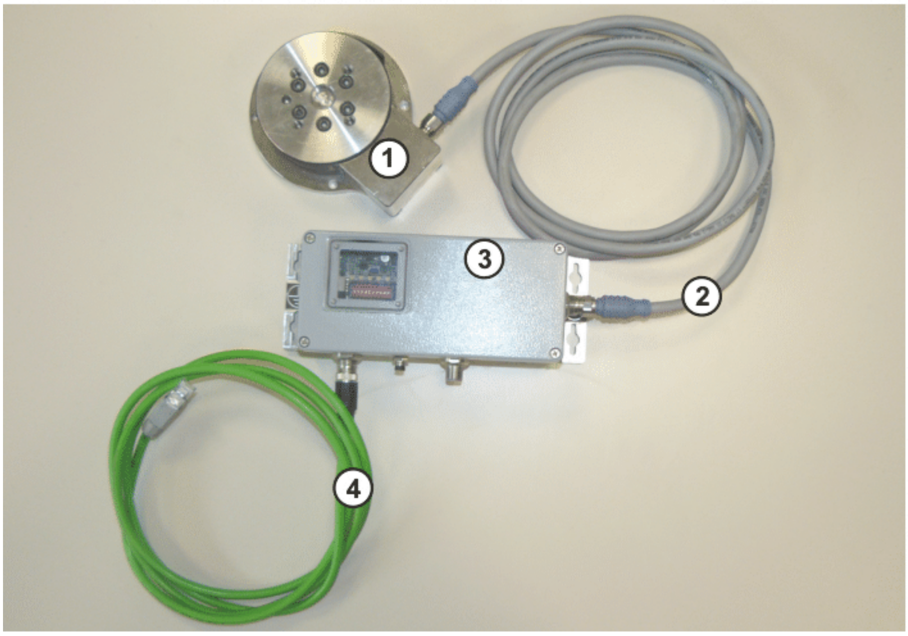

Fig. 4-3: ATI NET F/T sensor system (example)

1 F/T-NET sensor
2 Sensor cable, F/T-NET sensor – NET box
3 NET box
4 Ethernet cable, NET box – robot controller KLI

4.4.1 KUKA FT-NET controller box

The KUKA FT-NET controller box comprises all the necessary components for operating the ATI NET F/T sensor system:

- Power supply unit
- Evaluation electronics for the sensor for conditioning the measured values and making them available for Ethernet
- Power connection and connections for sensor and Ethernet cables

> The KUKA FT-NET controller box is not included in the scope of supply for ForceTorqueControl and can be ordered.

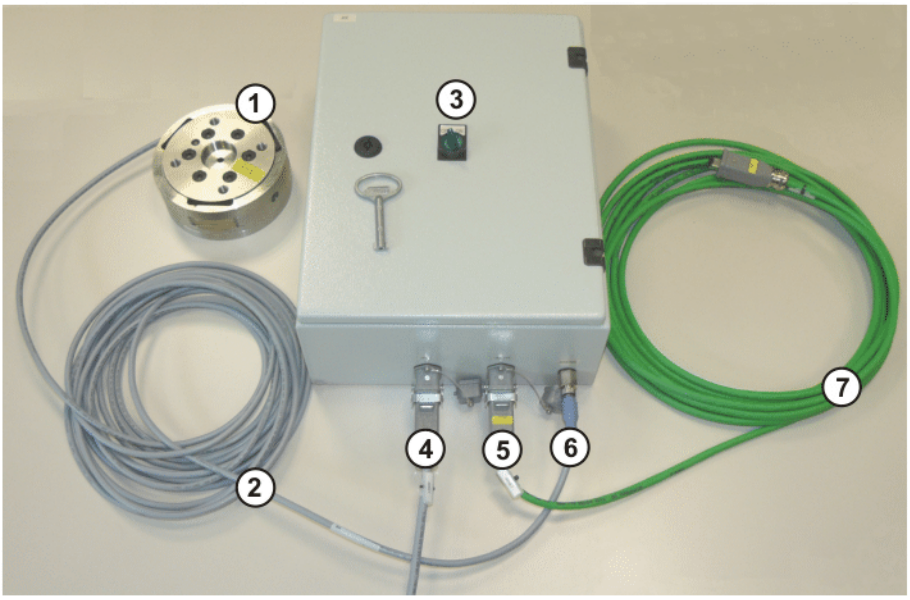

Fig. 4-4: KUKA FT-NET controller box

1 F/T-NET sensor
2 Sensor cable, F/T-NET sensor – controller box
3 Main switch for switching the controller box on and off
4 Connection for 230 V power supply
5 Connection for Ethernet cable
6 Connection for sensor cable
7 Ethernet cable, controller box – robot controller KLI

4.5 Intermediate flange between robot mounting flange and sensor

Description

The sensor cannot be mounted directly on the robot flange. An intermediate flange is required between the mounting flange of the robot and the sensor. Depending on the sensor type, the intermediate flange may consist of one or two plates.

Example

Intermediate flange with 2 plates

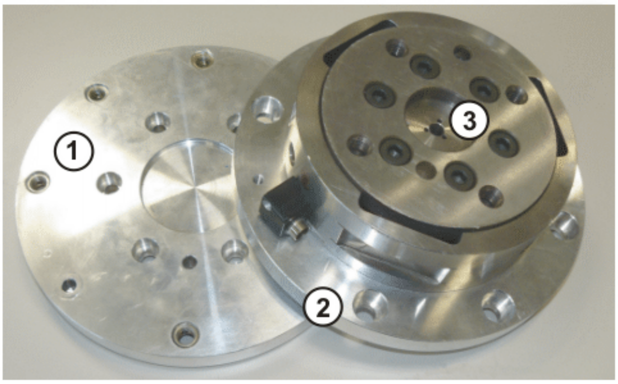

Fig. 4-5: Sensor with intermediate flange – flange plates separated

1 Plate 1
2 Plate 2 with sensor
3 Sensor

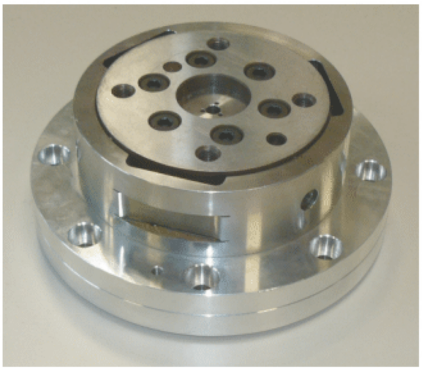

Fig. 4-6: Sensor mounted with intermediate flange

5 Installation

5.1 System requirements

Hardware

- KR C4

Software

- KUKA System Software 8.2

5.2 Installing or updating ForceTorqueControl

It is advisable to archive all relevant data before updating a software package.

Preparation

- Copy software from CD to KUKA USB stick.

  The software must be copied onto the stick with the file Setup.exe at the highest level (i.e. not in a folder).

NOTICE Recommendation: Always use KUKA sticks. Data may be lost if sticks from other manufacturers are used.

Precondition

- “Expert” user group

Procedure

1. Connect the USB stick to the robot controller or smartPAD.
2. In the main menu, select **Start-up** > **Additional software**.
3. Press **New software**. The entry **Force Torque Control** must be displayed in the **Name** column and drive **E:** or **K:** in the **Path** column.

   If not, press **Refresh**.
4. If the specified entries are now displayed, continue with step 5.

   If not, the drive from which the software is being installed must be configured first:
   - Press the **Configuration** button. A new window opens.
   - Select a line in the **Installation paths for options** area.

     Note: If the line already contains a path, this path will be overwritten.
   - Press **Path selection**. The available drives are displayed.
   - Select **E:**. (If stick connected to the robot controller.)

     Or select **K:**. (If stick connected to the smartPAD.)
   - Press **Save**. The window closes again.

   The drive only needs to be configured once and then remains saved for further installations.
5. Select the entry **Force Torque Control** and press **Install**. Answer the request for confirmation with **Yes**.
6. Several reboot prompts are displayed consecutively. Confirm each prompt by pressing **OK**.
7. Remove the stick.
8. Reboot the robot controller.

LOG file

A LOG file is created under C:\KRC\ROBOTER\LOG.

5.3 Licensing ForceTorqueControl

ForceTorqueControl must be activated using a license key.

5.3.1 Requesting a license key

Precondition

- "Expert" user group

Procedure

1. In the main menu, select **Configuration** > **FTCtrl** > **Sensor**. The configuration window is opened.
2. Select the **License** page.
3. Press **Request**.
4. In the Navigator, select the storage location, e.g. USB stick or network drive, and confirm with **OK**. The license request FTCtrl.ROB is created.
5. Send the license request FTCtrl.ROB together with the additional information to the following address: FTCtrl@kuka-roboter.de

   The following additional information is required for processing the request:

   - Serial number of the robot
   - Version of the installed ForceTorqueControl software
   - Order number of the installed ForceTorqueControl software

The license key is requested and KUKA Roboter returns the license file FTCtrl.LIC.

5.3.2 Activating ForceTorqueControl

Precondition

- "Expert" user group
- The license file FTCtrl.LIC is available, e.g. on a USB stick or network drive.

Procedure

1. In the main menu, select **Configuration** > **FTCtrl** > **Sensor**. The configuration window is opened.
2. Select the **License** page.
3. Press **Import**.
4. In the Navigator, navigate to the license file FTCtrl.LIC, select the file and load it with **Open**.

   ForceTorqueControl is now licensed and can be started.

5.4 Uninstalling ForceTorqueControl

> It is advisable to archive all relevant data before uninstalling a software package.

Description

To uninstall the ForceTorqueControl technology package completely, the following components must be uninstalled:

- ForceTorqueControl
- RobotSensorInterface
- UserTech

> Only uninstall components if it has been ascertained that they are not being used by another technology package!

Precondition

- "Expert" user group

Procedure

1. In the main menu, select **Start-up** > **Additional software**. All additional programs installed are displayed.

2. Select the entry **FTCtrl** and press **Uninstall**. Reply to the request for confirmation with **Yes**. Uninstallation is prepared.
3. Repeat step 2 to prepare further software components for uninstallation.
4. Reboot the robot controller. Uninstallation is resumed and completed.

LOG file

A LOG file is created under C:\KRC\ROBOTER\LOG.

6 Operation

6.1 Menus

The following menus and commands are specific to this technology package:

Main menu:

- **Configuration** > **FTCtrl**
  - **Sensor**
  - **Application**

Menu sequence:

- **Commands** > **FTCtrl**
  - **Sensor-guided**
    - **Init**
    - **On**
  - **Superposed**
    - **Init**
    - **On**
    - **Off**

6.2 Navigation bar

The navigation bar can be used to switch to the individual configuration pages.

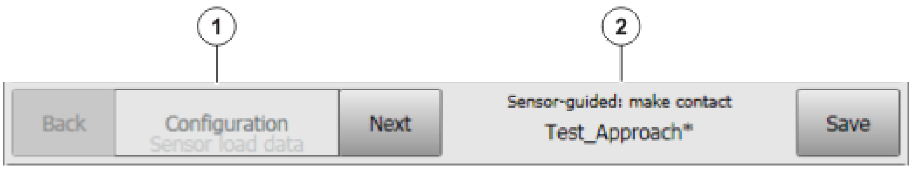

Fig. 6-1: Navigation bar – Configuration

Item	Description
1	Name of the configuration page currently being displayed. Pressing the display opens a menu. In this menu, the user can select the pages individually. Precondition: “Expert” user group
2	Name of the task that is currently open (only displayed when configuring force/torque control)

The following buttons are available:

Button	Description
Next	Switches to the next page.
Back	Switches to the previous page.
Save	Saves the configuration.

7 Start-up and configuration

> This chapter contains overviews of the most important steps for the start-up of sensor systems supported by ForceTorqueControl. The precise sequence depends on the application, the manipulator type, the sensor type, the technology packages used and other customer-specific circumstances.
> For this reason, the overview does not claim to be comprehensive.

7.1 Start-up and configuration – NET F/T sensor system

Step	Description
1	Mount the sensor on the robot. The sensor cannot be mounted directly on the robot flange. An intermediate flange is required between the mounting flange of the robot and the sensor. Depending on the sensor type, the intermediate flange may consist of one or two plates.
2	Mount the tool on the sensor. **Note**: Tighten the fastening screws to the defined tightening torque in diagonally opposite sequence in accordance with the sensor system documentation. The maximum tightening torque and the maximum penetration depth of the fastening screws must not be exceeded, otherwise the sensor could be damaged.
3	Mount the KUKA FT-NET controller box externally. (The box is powered independently from the robot controller.) **Alternatively**: Mount the ATI NET box on the mounting plate for customer components in the robot controller and install it in accordance with the sensor system documentation.
4	Connect the connecting cables. Attention must be paid to the following: ■ The sensor cable from the sensor to the FT-NET controller box must be correctly routed using an energy supply system. The energy supply system ensures that the cables are guided with minimum stress despite the high load on the sensor cable caused by the robot motion. ■ The Ethernet cable must be connected to the robot controller KLI. (>>> 7.1.1 "Network connection via the KLI of the robot controller" Page 37)
5	Configure the Ethernet sensor network. (>>> 7.1.2 "Configuring the Ethernet sensor network – IP address of the robot controller" Page 38)
6	Configure the sensor system. (>>> 7.1.3 "Configuring the ATI NET F/T sensor system" Page 38)
7	Determine the sensor load data. (>>> 7.4 "Determining sensor load data" Page 43)

7.1.1 Network connection via the KLI of the robot controller

Description

A network connection must be established via the KLI of the robot controller in order to exchange data via Ethernet.

The following Ethernet interfaces are available as options at the customer interface of the robot controller, depending on the specification:

- Interface X66 (1 slot)

- Interface X67.1-3 (3 slots)

> Further information on the Ethernet interfaces can be found in the operating or assembly instructions for the robot controller.

7.1.2 Configuring the Ethernet sensor network – IP address of the robot controller

Precondition

- “Expert” user group
- Network connection via the KLI of the robot controller

Procedure

1. In the main menu, select **Start-up** > **Service** > **Minimize HMI**.
2. Select **All Programs** > **RSI-Network** in the Windows Start menu.

   The **Network Setup** window appears. The network connections already set up are displayed in the tree structure under **Other Installed Interfaces**.
3. Select the entry **New** under **RSI Ethernet** in the tree structure and press **Edit**.
4. Enter the IP address of the robot controller and confirm with **OK**.

> The IP addresses of the sensor (default: 192.168.1.1) and the robot controller must be in the same network segment, i.e. the addresses must differ only in the last of the 4 ranges.

> The IP address range 192.168.0.x is blocked for the configuration of the network connection.

5. Reboot the robot controller with a cold restart.

7.1.3 Configuring the ATI NET F/T sensor system

Precondition

- The sensor system is installed and connected.
- The Ethernet sensor network is configured.

Procedure

1. In the main menu, select **Configuration** > **FTCtrl** > **Sensor**. The configuration window is opened.
2. On the **Sensor type** page, select the sensor **ATI NET/FT sensor**.
3. Press **Next** to switch to the **Connection** page and enter the IP address of the connected sensor.

> The IP addresses of the sensor (default: 192.168.1.1) and the robot controller must be in the same network segment, i.e. the addresses must differ only in the last of the 4 ranges.

> If the preset IP address of the sensor cannot be used, it must be modified in accordance with the sensor system documentation.

4. Modification only by the administrator and after consultation with KUKA Roboter GmbH:
   - **Sampling time**
   - **Low-pass cut-off frequency**
5. Press **Next** to switch to the **Mounting** page. Enter the **Offset X**, **Y**, **Z** and the **Rotational offset A**, **B**, **C** of the sensor coordinate system relative to the reference coordinate system.

The sensor is installed by default on the mounting flange. The reference coordinate system for the sensor coordinate system is the FLANGE coordinate system.

6. Press **Next** to switch to the **Load range** page and enter the permissible sensor load. ForceTorqueControl terminates control if the permissible sensor load is exceeded.

> The permissible sensor load must lie within the measuring range of the sensor. Information on the measuring range can be found in the sensor system documentation.

> **NOTICE** If the values entered for the permissible sensor load are too high, this can damage the sensor system, resulting in damage to property.
> The system integrator is responsible for analyzing the real processes and the conditions of the sensor application and determining the values for the permissible sensor load on the basis of this analysis. It is generally advisable to allow an additional safety factor when using the measured range specified by the sensor manufacturer.

7. Press **Next** to switch to the **License** page and license KUKA.ForceTorqueControl.

   (>>> 5.3 "Licensing ForceTorqueControl" Page 31)

8. Save the configuration with **Save**.

7.2 Start-up and configuration – DAQ F/T sensor system

Step	Description
1	Mount the sensor on the robot. The sensor cannot be mounted directly on the robot flange. An intermediate flange is required between the mounting flange of the robot and the sensor. Depending on the sensor type, the intermediate flange may consist of one or two plates.
2	Mount the tool on the sensor. **Note**: Tighten the fastening screws to the defined tightening torque in diagonally opposite sequence in accordance with the sensor system documentation. The maximum tightening torque and the maximum penetration depth of the fastening screws must not be exceeded, otherwise the sensor could be damaged.
3	Mount the power supply box of the sensor on the mounting plate for customer components in the robot controller or externally. The precise mounting position of the power supply box depends on the configuration variant of the robot controller and the specific requirements of the overall system.
4	Connect the EtherCAT bus module directly to the CIB (connector X44) or via a switch on the robot controller. **Note**: Information about the EtherCAT connection on the CIB can be found in the assembly and operating instructions of the robot controller and in the assembly and operating instructions **Optional Interfaces** for KR C4.
5	Connect the cables between the power supply box and the EtherCAT bus module in accordance with the sensor system documentation.

Step	Description
6	Connect the connecting cables. Attention must be paid to the following: ■ The sensor cable from the sensor to the power supply box must be correctly routed using an energy supply system. The energy supply system ensures that the cables are guided with minimum stress despite the high load on the sensor cable caused by the robot motion.
7	Configuration in WorkVisual 1. Transfer the project to WorkVisual 2. Connect the analog input terminals of the EtherCAT bus coupler to X44. (>>> 7.2.1 "Configuring the KUKA Extension Bus (SYS-X44) in WorkVisual" Page 40) 3. Then transfer the project from WorkVisual back to the robot controller. **Note**: Information about bus configuration and project deployment can be found in the **WorkVisual** documentation.
8	Configure the sensor system. (>>> 7.2.2 "Configuring the ATI DAQ F/T sensor system" Page 40)
9	Determine the sensor load data. (>>> 7.4 "Determining sensor load data" Page 43)

7.2.1 Configuring the KUKA Extension Bus (SYS-X44) in WorkVisual

Precondition

- The robot controller has been set as the active controller.

Procedure

1. Insert the KUKA Extension Bus (SYS-X44) in the controller bus (window **Project structure** > tab **Hardware** > **Bus structure**).
2. Add the EK1100 EtherCAT coupler under SYS-X44.
3. Add the EL9505 5V power supply terminal under **EK1100**.
4. Add 2 EL3104 4-channel analog inputs under **EK1100**.
5. Connect the analog inputs to the field buses **EL3104 1** and **EL3104 2**.
   - $ANIN[1] to AI Standard Channel 1.Value / terminal 1
   - …
   - $ANIN[4] to AI Standard Channel 4.Value / terminal 1
   - $ANIN[5] to AI Standard Channel 1.Value / terminal 2
   - …
   - $ANIN[8] to AI Standard Channel 4.Value / terminal 2

7.2.2 Configuring the ATI DAQ F/T sensor system

Precondition

- The sensor system is installed and connected.
- The EtherCAT bus system has been configured in WorkVisual and the configuration has been transferred from WorkVisual to the robot controller.
- The file FT<XXXX>.CAL with the sensor calibration data is available, e.g. on a USB stick or network drive.

Procedure

1. In the main menu, select **Configuration** > **FTCtrl** > **Sensor**. The configuration window is opened.
2. On the **Sensor type** page, select the sensor **ATI-DAQ system**.
3. Press **Next** to switch to the **Connection** page and, under **$ANIN[]**, specify the inputs of the robot controller via which the EtherCAT bus system reads in the sensor values **Fx**, **Fy**, **Fz** and **Tx**, **Ty**, **Tz**.

4. Press **Import** and navigate in the Navigator to the CAL file with the sensor calibration data. Select the file and load it with **Open**.
5. Press **Next** to switch to the **Mounting** page. Enter the **Offset X**, **Y**, **Z** and the **Rotational offset A**, **B**, **C** of the sensor coordinate system relative to the reference coordinate system.

   The sensor is installed by default on the mounting flange. The reference coordinate system for the sensor coordinate system is the FLANGE coordinate system.
6. Press **Next** to switch to the **Load range** page and enter the permissible sensor load. ForceTorqueControl terminates control if the permissible sensor load is exceeded.

The permissible sensor load must lie within the measuring range of the sensor. Information on the measuring range can be found in the sensor system documentation.

NOTICE If the values entered for the permissible sensor load are too high, this can damage the sensor system, resulting in damage to property.
The system integrator is responsible for analyzing the real processes and the conditions of the sensor application and determining the values for the permissible sensor load on the basis of this analysis. It is generally advisable to allow an additional safety factor when using the measured range specified by the sensor manufacturer.

7. Press **Next** to switch to the **License** page and license KUKA.ForceTorqueControl.

   (>>> 5.3 "Licensing ForceTorqueControl" Page 31)
8. Save the configuration with **Save**.

7.3 Start-up and configuration – user-specific sensor system

Step	Description
1	Mount the sensor on the robot. The sensor cannot be mounted directly on the robot flange. An intermediate flange is required between the mounting flange of the robot and the sensor. Depending on the sensor type, the intermediate flange may consist of one or two plates.
2	Mount the tool on the sensor. **Note**: Tighten the fastening screws to the defined tightening torque in diagonally opposite sequence in accordance with the sensor system documentation. The maximum tightening torque and the maximum penetration depth of the fastening screws must not be exceeded, otherwise the sensor could be damaged.
3	Connect the connecting cables.
4	Configuration in WorkVisual 1. Transfer the project to WorkVisual 2. Configure the field bus in WorkVisual. 3. Then transfer the project from WorkVisual back to the robot controller. **Note**: Information about bus configuration and project deployment can be found in the **WorkVisual** documentation.

Step	Description
5	Configure the sensor system. (>>> 7.3.1 "Configuring the user-specific sensor system" Page 42)
6	Determine the sensor load data. (>>> 7.4 "Determining sensor load data" Page 43)

7.3.1 Configuring the user-specific sensor system

Precondition

- The sensor system is installed and connected.
- The field bus has been configured in WorkVisual and the configuration has been transferred from WorkVisual to the robot controller.

Procedure

1. In the main menu, select **Configuration** > **FTCtrl** > **Sensor**. The configuration window is opened.
2. On the **Sensor type** page, select the sensor used:
   - **Sensor on analog input**: For sensors which supply the measured value as an analog output
   - **Sensor on digital input**: For sensors which supply the measured value as a digital output
3. Press **Next** to switch to the **Connection** page and set the following parameters:
   - Specify the inputs of the robot controller via which the field bus reads in the sensor values **Fx**, **Fy**, **Fz** and **Tx**, **Ty**, **Tz**. Depending on the sensor used, either specify analog inputs under **$ANIN[]**, or digital inputs under **Index**.
   - If required, the input signal can be adapted with the aid of **Offset** and **Scaling**. This produces the measured values actually supplied by the sensor. The adaptation is made using the following formula:

     Measured value = (Input signal + **Offset**) x **Scaling**

     Example: A sensor delivers a signal between 4 mA and 20 mA. This is to correspond to measured values between -400 N and +400 N. Consequently, the following values for **Offset** and **Scaling** are to be selected:

     Offset = -12 mA

     Scaling = 50 N/mA

     If, for example, the sensor delivers an input value of 15 mA, according to the above formula the following measured value results:

     (15 mA - 12 mA) x 50 N/mA = 150 N
   - Only for sensors which supply the measured value as a digital output: Specify the **Data width** of the sensor value for each digital input.
4. Press **Next** to switch to the **Mounting** page. Enter the **Offset X**, **Y**, **Z** and the **Rotational offset A**, **B**, **C** of the sensor coordinate system relative to the reference coordinate system.

   The sensor is installed by default on the mounting flange. The reference coordinate system for the sensor coordinate system is the FLANGE coordinate system.
5. Press **Next** to switch to the **Load range** page and enter the permissible sensor load. ForceTorqueControl terminates control if the permissible sensor load is exceeded.

> The permissible sensor load must lie within the measuring range of the sensor. Information on the measuring range can be found in the sensor system documentation.

NOTICE If the values entered for the permissible sensor load are too high, this can damage the sensor system, resulting in damage to property.
The system integrator is responsible for analyzing the real processes and the conditions of the sensor application and determining the values for the permissible sensor load on the basis of this analysis. It is generally advisable to allow an additional safety factor when using the measured range specified by the sensor manufacturer.

6. Press **Next** to switch to the **License** page and license KUKA.ForceTorqueControl.

   (>>> 5.3 "Licensing ForceTorqueControl" Page 31)

7. Save the configuration with **Save**.

7.4 Determining sensor load data

Description

The sensor load data can be determined automatically using the program R1\Program\FTCtrl\FTCtrl_LDD.SRC.

The program FTCtrl_LDD.SRC contains 6 predefined measurement poses with different robot orientations. During load data determination, the robot moves to these measurement poses. From the measurements, a calculation is made of the total load on the sensor and the center of gravity of the sensor load relative to the origin of the sensor coordinate system.

The sensor load data are not the same as the payload data (= load data of the sensor and tool relative to the FLANGE coordinate system) which must be entered in the robot controller and assigned to the correct tool.

To determine the sensor load data, the robot needs to move to at least 2 measurement poses. It is recommended to move to all of the measurement poses, if possible, as this produces a more accurate measurement result.

Preparation

1. Check whether there is enough workspace to be able to move to the individual measurement poses.
2. If it is not possible to move to a measurement pose, change the measurement position in the program or deactivate the measurement. To do this, comment out the relevant lines in the program.

Precondition

- Operating mode T1

Procedure

- Select and execute the program FTCtrl_LDD.SRC to the end of the program.

  The measurement result and the sensor load and sensor load center of gravity are displayed in a message.

8 Programming

Overview

Step	Description
1	Create the configuration for the force/torque control and define the task that is to be executed. (>>> 8.1 "Creating a configuration and defining a task" Page 45)
2	Call, start and terminate the configuration (task) in a KRL program via inline forms. (>>> 8.4 "Instructions – Sensor-guided motion" Page 56) (>>> 8.5 "Instructions – Superposed force/torque control" Page 58)

8.1 Creating a configuration and defining a task

Procedure

1. In the main menu, select **Configuration** > **FTCtrl** > **Application**. The configuration window is opened.
2. On the **Configuration** page, enter a name for the configuration.
3. Press **Create** and then select the task that is to be defined from the **Task selection** menu.

   (>>> "Task selection" Page 46)

   The next configuration page opens automatically.
4. Work through this page and all the subsequent pages, configuring the parameters as required.

   (>>> 8.2 "Configuration parameters" Page 46)
5. Press **Save**. The configuration is saved.
6. Close the configuration window using the **Close** symbol.

Description

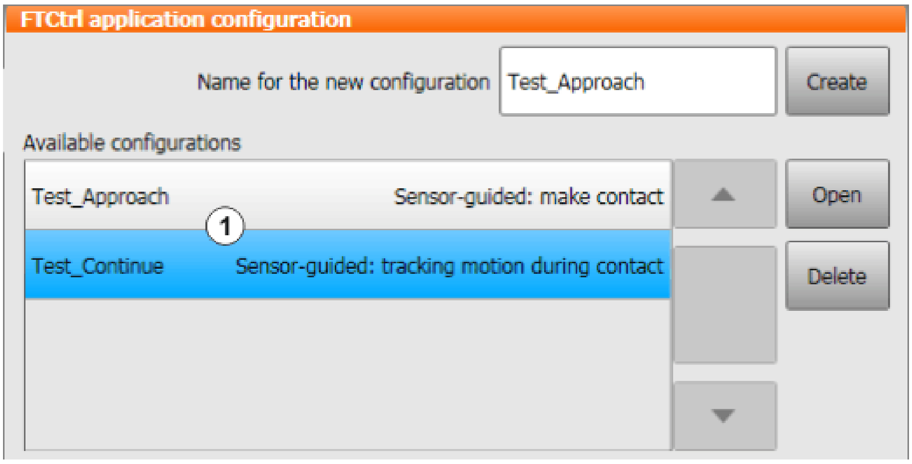

Fig. 8-1: “Configuration” page – Task selection

1 Configuration list

Buttons

The following buttons are available on the **Configuration** page:

Button	Description
Create	Opens the **Task selection** menu. After task selection, a new configuration is created with default values. This configuration is not yet saved.
Open	Opens the configuration selected in the configuration list. The name of an opened configuration can be re-entered and the configuration can be saved under this new name.
Delete	Deletes the configuration selected in the configuration list.

Task selection

The following tasks can be defined for a sensor-guided motion:

- **Sensor-guided**
  - **Sensor-guided: make contact**

    The robot has no contact with the environment. It is possible to define in which direction and at what velocity the robot moves until contact is made.
  - **Sensor-guided: tracking motion during contact**

    The robot is in contact. New setpoint values can be defined.

The following tasks can be defined for superposed force/torque control:

- **Superposed**
  - **Superposed: make contact**

    The robot has no contact with the environment. Control is performed in parallel with the robot motion. Contact is made via control.
  - **Superposed: tracking motion during contact**

    The robot is in contact. Control is performed in parallel with the robot motion. New setpoint values can be defined.
  - **Superposed: velocity change**

    The robot has no contact with the environment. Control is performed in parallel with the robot motion. Contact is made via control. In addition, the velocity on the programmed path can be adapted as a function of the measured process force.

8.2 Configuration parameters

8.2.1 “Sensor load data” page

The sensor load data are not the same as the payload data (= load data of the sensor and tool relative to the FLANGE coordinate system) which must be entered in the robot controller and assigned to the correct tool.

Parameter	Description
Sensor load [N]	Enter the sum of the loads mounted on the sensor.
Cent. of grav. [mm]	Enter the position of the sensor load center of gravity relative to the origin of the sensor coordinate system in the boxes **X**, **Y**, **Z**.

Buttons

The following buttons are available on the **Sensor load data** page:

Button	Description
Import messages	Automatically reads in the load data determined using the program FTCtrl_LDD.SRC. (>>> 7.4 "Determining sensor load data" Page 43)

8.2.2 “RCS” page

Parameter	Description
Reference coordinate system	Select the Cartesian coordinate system to which the force/torque control refers. ■ **World** ■ **Base** ■ **RobRoot** ■ **Tool** ■ **TTS** Default: **Tool** It is advisable to select a reference coordinate system that requires the activation of as few components as possible. (>>> 2.4 "Reference coordinate system: RCS" Page 13)

8.2.3 “FT controller” page (make contact, velocity change)

⚠ WARNING The difference between the setpoint and actual values of the force/torque control influences the sensor correction and thus the velocity of the robot. Incorrect entries can result in unexpectedly fast robot motions and cause personal injury or material damage. The safety regulations must be observed.

Here a main direction is defined in which motion is performed in the reference coordinate system until contact is made, and a setpoint force or torque for this direction:

- In the case of sensor-guided motion, control is maintained in the selected main direction after contact is made, until the defined setpoint is reached. The robot then stops.
- In the case of superposed force/torque control, the robot moves on a programmed path. In parallel with this motion, the robot moves in the selected main direction until contact is made. Once the defined setpoint is reached, control is maintained in the main direction and the robot attempts to maintain the established force or torque along the programmed path.

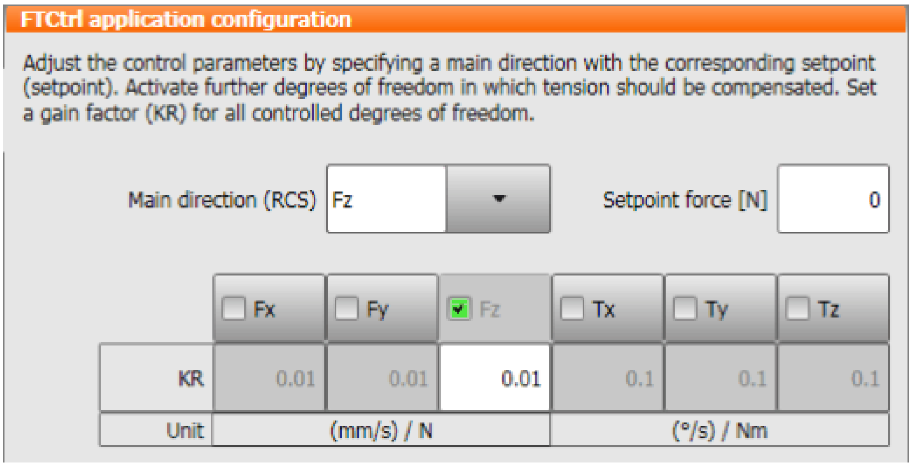

Fig. 8-2: “FT controller” page (make contact, velocity change)

Check boxes

Via the check boxes, further directions can be activated for force/torque control in addition to the main direction. The main direction is activated automatically.

The setpoint force or torque for the additionally activated directions are set by default to zero. If the sensor detects any contact in the additionally activated direction, the controller deviates in the opposite direction. This makes it possible to compensate for distortion.

Parameter	Description
Main direction (RCS)	Select the direction in which motion to contact is performed in the reference coordinate system specified on the **RCS** page. ■ **Fx**, **Fy**, **Fz**: Motion in X, Y or Z direction of the RCS ■ **Tx**, **Ty**, **Tz**: Rotation about the X, Y or Z axis of the RCS Default: **Fz** **Note**: In the case of superposed velocity adaptation, a force controller must be selected here.
Setpoint force [N]	If a force controller is activated for the main direction in the **Fx**, **Fy** or **Fz** direction, enter the desired setpoint force.
Setpoint torque [Nm]	If a torque controller is activated for the main direction in the **Tx**, **Ty** or **Tz** direction, enter the desired setpoint torque.
KR	Here a gain factor can be entered for the activated directions for force/torque control. The force/torque controller operates with these gain factors: Default values: ■ Gain factor for force controller: **0.01 (mm/s)/N** ■ Gain factor for torque controller: **0.1 (°/s)/Nm**

Example

(>>> 8.3.1 "Force control with gain" Page 53)

8.2.4 “FT controller” page (tracking motion during contact)

⚠ WARNING The difference between the setpoint and actual values of the force/torque control influences the sensor correction and thus the velocity of the robot. Incorrect entries can result in unexpectedly fast robot motions and cause personal injury or material damage. The safety regulations must be observed.

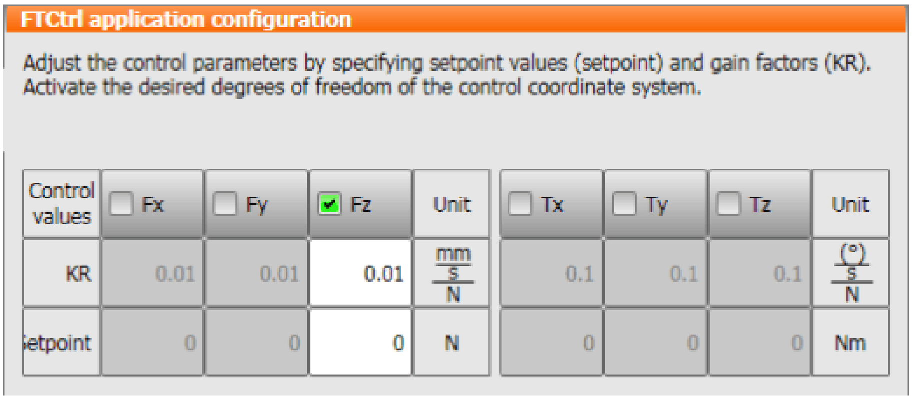

Fig. 8-3: “FT controller” page (tracking motion during contact)

Check boxes

Via the check boxes, activate the directions for force/torque control. By default, the force controller is active in the **Fz** direction.

Parameter	Description
Setpoint	Enter here for each activated force controller **Fx**, **Fy** or **Fz** the corresponding setpoint force and for each activated torque controller **Tx**, **Ty** or **Tz** the corresponding setpoint torque. The robot attempts to reach these setpoint values while it maintains contact with the workpiece.
KR	Here a gain factor can be entered for the activated directions. The force/torque controller operates with these gain factors: Default values: ■ Gain factor for force controller: **0.01 (mm/s)/N** ■ Gain factor for torque controller: **0.1 (°/s)/Nm**

Example

(>>> 8.3.1 "Force control with gain" Page 53)

8.2.5 “Approach motion” page (make contact, velocity change)

Here the maximum velocity is defined at which motion to contact is performed in the main direction of force or torque control. After this, the contact controller takes over control and attempts to reach the setpoint force or torque defined on the **FT controller** page.

NOTICE If the robot moves to contact at too fast a velocity, the controller will not be able to brake the robot quickly enough, which may result in damage to property. For this reason, an approach velocity is suggested, depending on the setpoint value to be reached during contact that is specified on the **FT controller** page.
To avoid damage to property, it is advisable to accept the suggested velocity initially and adjust it later if necessary.

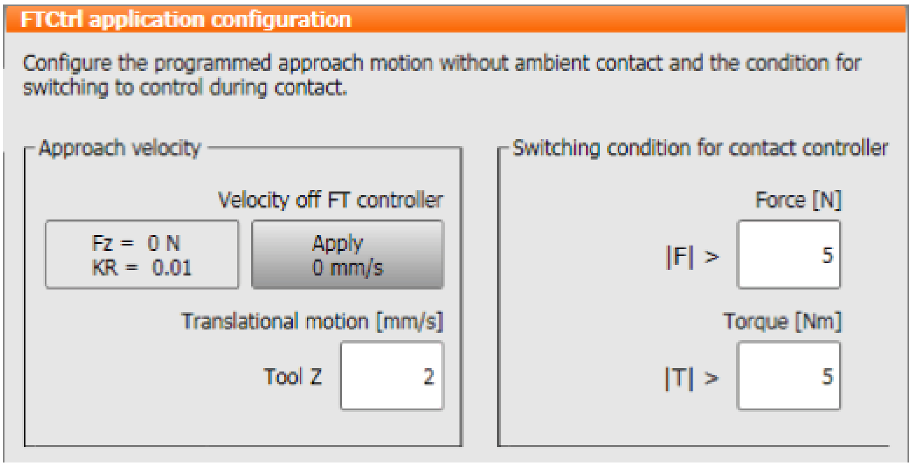

Fig. 8-4: "Approach motion" page (make contact, velocity change)

Parameter	Description
Approach velocity	Enter the maximum approach velocity or accept the suggested velocity as the approach velocity using the **Apply** button. ■ **Translational motion [mm/s]**: This velocity is used for motion to contact in the X, Y or Z direction of the RCS. ■ **Rotational motion [°/s]**: This velocity is used for rotation about the X, Y or Z axis of the RCS until contact is made. **Note**: The reference coordinate system selected on the **RCS** page and the main control direction set on the **FT controller** page are displayed automatically, here **Tool Z**.
Switching condition for contact controller	Enter the minimum values which the sensor must measure on contact in order to switch to contact control. ■ **Force |F| [N] >**: Minimum force that must be measured ■ **Torque |T| [Nm] >**: Minimum torque that must be measured

Buttons

The following buttons are available on the **Approach motion** page:

Button	Description
Apply	Copies the suggested maximum approach velocity Depending on the specified setpoint force or torque, the velocity is estimated for the selected controller. This suggestion can be accepted as the approach velocity using the **Apply** button.

8.2.6 "Break condition" page (sensor-guided motions)

For each controller component activated on the **FT controller** page, a break condition can be defined which terminates the sensor-guided motion. For this, the setpoint force or torque that the robot attempts to reach is monitored within a defined range.

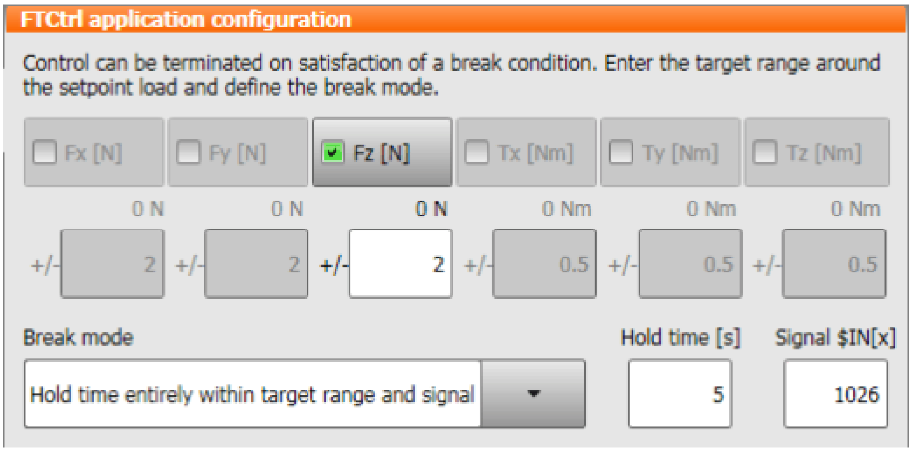

Fig. 8-5: "Break condition" page (sensor-guided motion)

Check boxes

Via the check boxes, activate the controller components which are to be monitored and enter the appropriate range.

Parameter	Description
Break mode	Select the break mode. ■ **In the target range**: When the range is entered for the first time, the task is considered as completed and the sensor-guided motion is terminated. ■ **Hold time once within target range**: When the range is entered for the first time, a timer is started. When the defined hold time has elapsed, the timer stops and the sensor-guided motion is terminated. ■ **Hold time entirely within target range**: When the range is entered for the first time, a timer is started. If the range is left again before the hold time has elapsed, the timer is reset and restarted the next time the range is entered. The sensor-guided motion is only terminated when the sensor values lie within the range throughout the hold time. ■ **Hold time entirely within target range and signal**: Behavior as for **Hold time entirely within target range**. In addition, the **Signal $IN[x]** must be set to TRUE in order to terminate the sensor-guided motion. Default: **In the target range**
Hold time [s]	Hold time for the timer. The timer is stopped when the hold time has elapsed. Default: **5 s** This box is not displayed for the break mode **In the target range**.
Signal $IN[x]	Number of the input which must be set to TRUE in order to terminate the sensor-guided motion Default: **1026** This box is only displayed for the break mode **Hold time entirely within target range and signal**.

8.2.7 "Correction limit" page

The maximum permissible sensor correction in the reference coordinate system is defined here. ForceTorqueControl monitors the correction limits from the start of control, and terminates control immediately if one of the limits is exceeded.

> The maximum sensor correction in the RCS must lie within the global correction limits that are defined on the **Correction monitoring** page.

Parameter	Description
X, Y, Z [mm]	Enter the maximum permissible Cartesian correction. ■ **Min**: Maximum Cartesian correction in the negative X, Y or Z direction Default: **-5 mm** ■ **Max**: Maximum Cartesian correction in the positive X, Y or Z direction Default: **5 mm**
Angle of rotation [°]	Enter the maximum permissible axis angle correction (= maximum rotational offset across all axis angles). Default: **5°**

8.2.8 “Monitoring functions” page

Here the maximum load is defined that may be exerted externally on the tool in the reference coordinate system. ForceTorqueControl monitors the load limits from the start of control onwards, and terminates control immediately if one of the limits is exceeded.

> The maximum load must lie within the measuring range of the sensor. Information on the measuring range can be found in the sensor system documentation.

Parameter	Description
Fx, Fy, Fz [N]	Enter the maximum permissible load that may be exerted externally on the tool in the X, Y, Z directions of the RCS.
Tx, Ty, Tz [Nm]	Enter the maximum torque that may be exerted externally on the tool about the X, Y, Z axes of the RCS.

8.2.9 “Miscellaneous” page (sensor-guided motion)

Sensor-guided motion is always terminated after the time specified here, if none of the conditions defined on the **Break condition** page have been safisfied by that time.

8.2.10 “Correction monitoring” page

The global limits for sensor correction are defined here:

- Maximum permissible translational offset from the start point of sensor correction (unit: mm)
- Maximum permissible rotational offset from the start point of sensor correction (unit: °)

The global limits refer to the overall correction system of the sensor, and must limit the sensor correction in such a way that the workpiece and other cell components are not damaged.

8.2.11 “Velocity change” page (velocity change)

Superposed velocity change can only be used if a setpoint force for contact is defined in the main direction selected on the **FT controller** page. For this setpoint force, 2 ranges can be defined to control the sensor override on the programmed path.

Parameter	Description
Force range around the setpoint force [N]	■ **F in**: If the sensor measured value enters this range, the motion is executed with a sensor override of 100%. ■ **F out**: If the sensor measured value leaves this range, the motion is executed with the set sensor override. **Note**: The force range **F out** must be larger than the force range **F in**.
Sensor override [%]	The sensor override can only be set for the force range **F out**. In the force range **F in**, the sensor override is always 100%. The sensor override refers to the program override $OV_PRO programmed for the start of motion. In the case of a velocity change via ForceTorqueControl, the start value for $OV_PRO is reduced by a specified percentage. **Example**: The program override is 50% at the start of motion. With a sensor override of 100%, the robot moves with an override of 50%. With a sensor override of 50%, the robot moves with an override of 25%.

> When superposed velocity change is active, ForceTorqueControl takes control of the program override $OV_PRO. Changes to the program override via the smartPAD or the KRL program are overwritten by ForceTorqueControl and have no effect.

8.3 Configuration examples

8.3.1 Force control with gain

The following values have been defined for force control on the **FT controller** page:

- Setpoint force: F_{Def} = 50 N
- Gain factor: KR = 0.02 (mm/s)/N

The sensor measures the following force in the RCS:

F_{RCS} = 125 N

Resulting control difference between measured force and setpoint force:

$F_{Diff} = F_{RCS} - F_{Def}$ = 125 N - 50 N = 75 N

The controller reacts to the control difference with the following velocity setpoint for the robot:

Vel = F_{Diff} * KR = 75 N * 0.02 (mm/s)/N = 1.5 mm/s

The robot deviates from the control difference with a motion of 1.5 mm per second, i.e. at a velocity of 1.5 mm/s.

8.3.2 Pressing a cube onto an inclined plane

Description

- Sensor-guided motion (make contact)
- Reference coordinate system TOOL

The cube moves in the negative Z direction until the lower right-hand side touches the inclined plane and a force setpoint F_Z of 50 N has been reached.

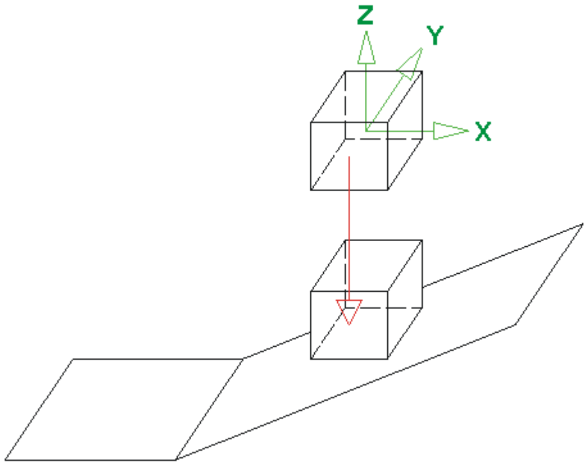

Fig. 8-6: Pressing a cube onto an inclined plane

The following parameters are configured for force/torque control.

Fx [N]	Fy [N]	Fz [N]	Tx [Nm]	Ty [Nm]	Tz [Nm]
- - -	- - -	50	- - -	- - -	- - -

8.3.3 Pressing a cube onto an inclined plane, orientation compensation

Description

- Sensor-guided motion (make contact)
- Reference coordinate system TOOL

The cube moves in the negative Z direction until the lower right-hand side touches the inclined plane and a force setpoint F_Z of 50 N has been reached. With constant force setpoint F_Z, the cube rotates about the Y axis until its surface is lying on the inclined plane and a torque setpoint T_Y of 0 Nm has been reached.

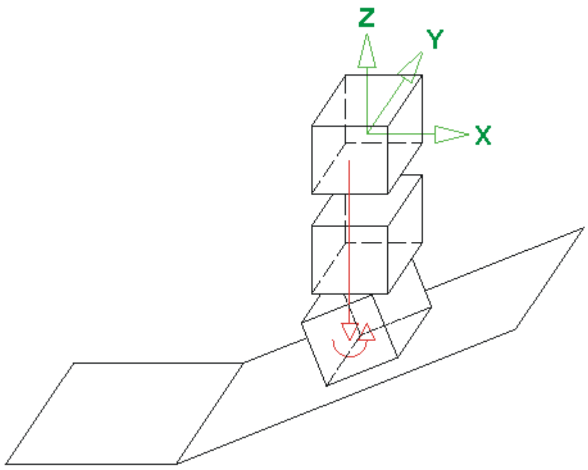

Fig. 8-7: Pressing a cube onto an inclined plane, orientation compensation

The following parameters are configured for force/torque control.

Fx [N]	Fy [N]	Fz [N]	Tx [Nm]	Ty [Nm]	Tz [Nm]
- - -	- - -	50	- - -	0	- - -

The orientation of the force/torque control is dependent on the defined reference coordinate system.

- If the TOOL coordinate system is set, the orientation of the force/torque control changes with that of the mounted tool. The cube rotates until a force setpoint of 50 N is reached. The TCP moves along an arc-shaped path.
- If the BASE, WORLD or ROBROOT coordinate system is set, the orientation of the force/torque control does not change. The cube rotates until a force setpoint of 50 N * sinα is reached. The TCP moves along a straight path.

8.3.4 Pressing a cube against a beveled edge

Description

- Sensor-guided motion (make contact)
- Reference coordinate system TOOL

The cube moves in the negative Z direction until the lower right-hand side touches the inclined plane and a force setpoint F_Z of 50 N has been reached. With constant force setpoint F_Z, the cube moves in the negative XY direction until its surface is lying on the inclined plane and a force setpoint F_X of 0 N has been reached.

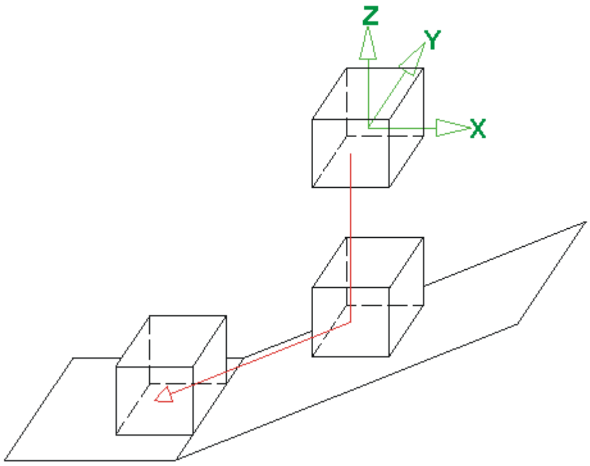

Fig. 8-8: Pressing a cube against a beveled edge

The following parameters are configured for force/torque control.

Fx [N]	Fy [N]	Fz [N]	Tx [Nm]	Ty [Nm]	Tz [Nm]
0	- - -	50	- - -	- - -	- - -

8.3.5 Pressing a cube against a beveled edge, orientation compensation

Description

- Sensor-guided motion (make contact)
- Reference coordinate system TOOL

The cube moves in the negative Z direction until the lower right-hand side touches the inclined plane and a force setpoint F_Z of 50 N has been reached.

With constant force setpoint F_Z, the following motions are executed simultaneously:

- The cube moves in the negative X direction until its surface is lying on the inclined plane and a force setpoint F_X of 0 N has been reached.
- The cube rotates about the Y axis until its surface is lying on the inclined plane and a torque setpoint T_Y of 0 Nm has been reached.

How far the cube moves on the inclined plane depends on the configuration of the individual controllers. The cube stops when both force/torque control conditions are met.

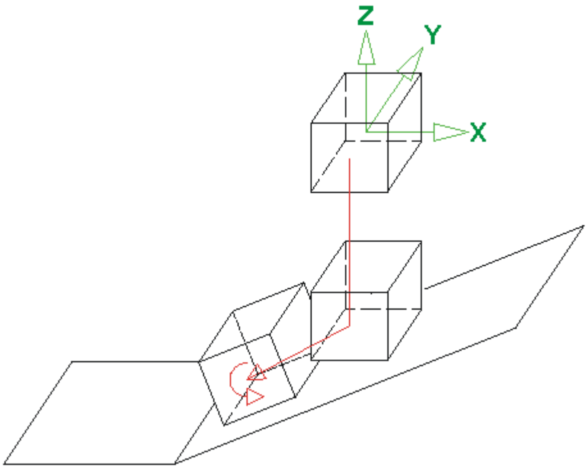

Fig. 8-9: Pressing a cube against a beveled edge, orientation compensation

The following parameters are configured for force/torque control.

Fx [N]	Fy [N]	Fz [N]	Tx [Nm]	Ty [Nm]	Tz [Nm]
0	- - -	50	- - -	0	- - -

8.4 Instructions – Sensor-guided motion

Call

- Select the menu sequence **Commands** > **FTCtrl** > **Sensor-guided** and select the desired inline form.

Overview

Inline form	Description
Init	Initialize sensor-guided motion with the data of the desired task. (>>> 8.4.1.1 "Inline form OnBreak_Init" Page 57)
On	Start sensor-guided motion. (>>> 8.4.1.2 "Inline form OnBreak_On" Page 57)

8.4.1 Programming sensor-guided motion

Precondition

- The task is defined.

Procedure

1. Only with “Make contact”: Program the start point of the sensor-guided motion.

There must not yet be any contact forces and torques acting on the sensor at the start point of the motion. The tool on the robot must have clearance on all sides.

2. Initialize sensor-guided motion.
3. Start sensor-guided motion.

   The sensor-guided motion is terminated automatically when the break condition defined in the configuration (task) is met or the defined maximum time has elapsed. The cause of termination of the sensor-guided motion can be evaluated using the variable FT_NIFBREAK.

Example Sensor-guided motion: Make contact

```
1   DEF Sensorguided_Approach( )
2   INI
3
4   PTP HOME  Vel= 100 % DEFAULT
5   FTCtrl.OnBreak_Init Config=Approach_1
6   FTCtrl.OnBreak_On Message=Quit
7   IF (FT_NIFBREAK <> FT_STOPSOLFZ) THEN
8      HALT
9   ENDIF
10  GRIPPER OPEN
```

Line	Description
4	Start point of the sensor-guided motion
5	The sensor-guided motion is initialized.
6	The sensor-guided motion is started. An acknowledgement message stating the cause of termination is generated when the sensor-generated motion is terminated.
7 … 9	Evaluation of the cause of termination with FT_NIFBREAK

8.4.1.1 Inline form OnBreak_Init

The instruction initializes the sensor-guided motion with the data from the configuration (task) selected in the inline form.

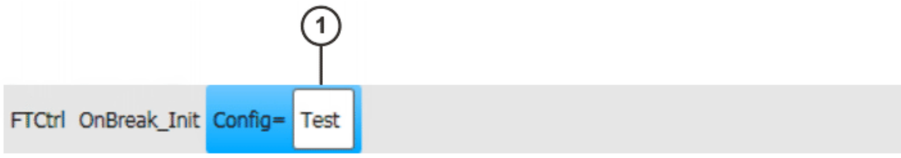

Fig. 8-10: Inline form OnBreak_Init

Item	Description
1	Name of the configuration (task)

8.4.1.2 Inline form OnBreak_On

The instruction starts a sensor-guided motion. When the break condition defined in the configuration (task) is met, the sensor-guided motion is terminated. A message giving the cause of termination can be generated.

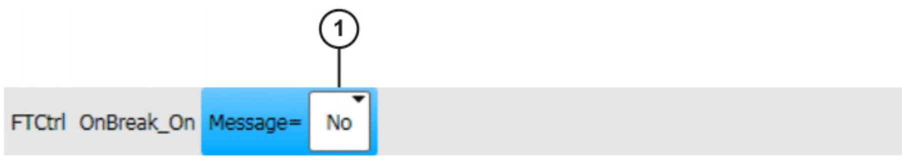

Fig. 8-11: Inline form OnBreak_On

Item	Description
1	Message type ■ **No**: No message ■ **Info**: Notification message ■ **Quit**: Acknowledgement message

8.5 Instructions – Superposed force/torque control

Call

- Select the menu sequence **Commands** > **FTCtrl** > **Superposed** and select the desired inline form.

Overview

Inline form	Description
Init	Initialize superposed force/torque control with the data of the desired task. (>>> 8.5.1.1 "Inline form OnPath_Init" Page 58)
On	Start superposed force/torque control. (>>> 8.5.1.2 "Inline form OnPath_On" Page 59)
Off	Terminate superposed force/torque control. (>>> 8.5.1.3 "Inline form OnPath_Off" Page 59)

8.5.1 Programming superposed force/torque control

Precondition

- The task is defined.

Procedure

1. Only with “Make contact” or “Velocity change”: Teach the start point for superposed force/torque control.

> There must not yet be any contact forces and torques acting on the sensor at the start point of the motion. The tool on the robot must have clearance on all sides.

2. Initialize superposed force/torque control.
3. Start superposed force/torque control.
4. Teach CP motions with superposed force/torque control.
5. Terminate superposed force/torque control.

Example

Superposed force/torque control: Make contact

```
 1  DEF Sensorimposed_Approach( )
 2  INI
 3
 4  PTP HOME  Vel= 100 % DEFAULT
 5  PTP P1 Vel 100 % PDAT1 Tool[1] Base[1]
 6  FTCtrl.OnPath_Init Config=Approach_2
 7  FTCtrl.OnPath_On
 8  LIN P2 Vel= 0.8 m/s CPDAT1 Tool[1] Base[1]
 9  LIN P3 Vel= 0.8 m/s CPDAT1 Tool[1] Base[1]
10  LIN P4 Vel= 0.8 m/s CPDAT1 Tool[1] Base[1]
11  FTCtrl.OnPath_Off
12  ENDIF
```

Line	Description
5	Start point for superposed force/torque control
6	Superposed force/torque control is initialized.
7	Superposed force/torque control is started.
8 … 10	Motion with superposed force/torque control
11	Superposed force/torque control is terminated.

8.5.1.1 Inline form OnPath_Init

The instruction initializes superposed force/torque control with the data from the configuration (task) selected in the inline form.

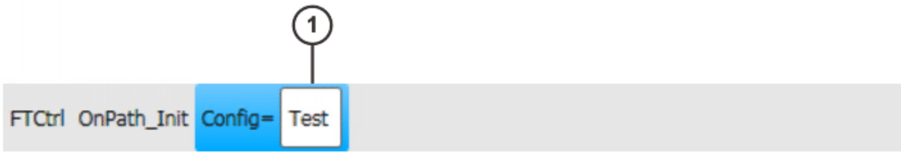

Fig. 8-12: Inline form OnPath_Init

Item	Description
1	Name of the configuration (task)

8.5.1.2 Inline form OnPath_On

The instruction starts superposed force/torque control. All subsequent motions are executed with superposed force/torque control.

Fig. 8-13: Inline form OnPath_On

8.5.1.3 Inline form OnPath_Off

The instruction terminates superposed force/torque control.

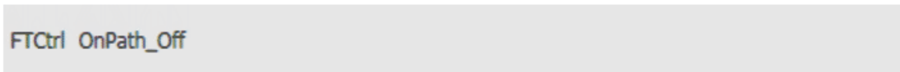

Fig. 8-14: Inline form OnPath_Off

9 Diagnosis

9.1 Signal display with the RSI monitor

Call

- In the main menu, select **Configuration** > **FTCtrl** > **Application** and select the **Signal display** page.

Overview

Fig. 9-1: RSI monitor

The following buttons are available:

Button	Description
Setup	The signal properties for the signal recording can be defined. (>>> 9.1.1 "Setting signal properties" Page 62)
File	The recorded signal diagram can be saved in a file or a file can be loaded.
Config	To display the force/torque control signals, the default RSI channel 1 must be used. This button is only available to the user group “Expert” or higher.
Zoom	The displayed time frame can be increased or decreased in size using a slide controller. The visible time frame can be shifted by dragging it horizontally in the monitor display window.

9.1.1 Setting signal properties

Description

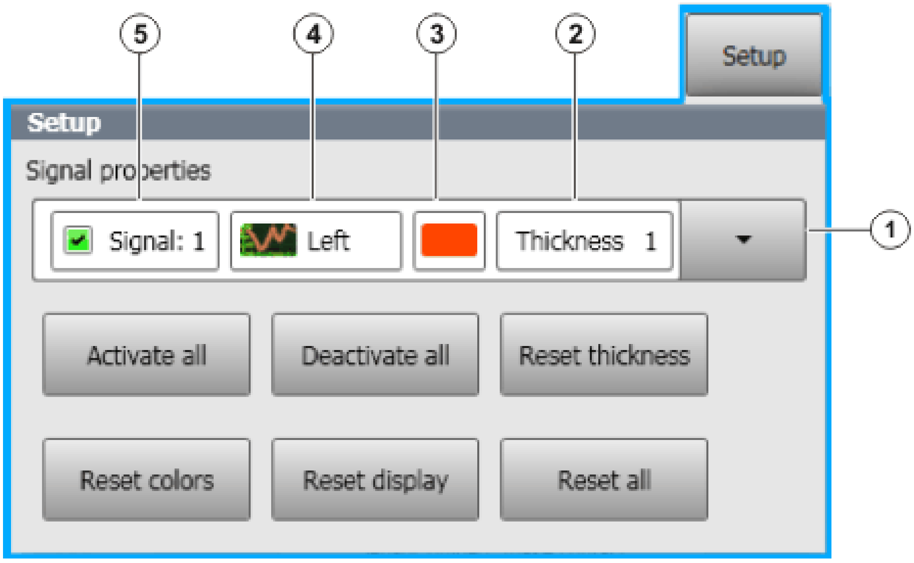

Fig. 9-2: RSI monitor – signal properties

Item	Description
1	List box with the signals 1 … 24
2	Line thickness of the signal ■ **Line thickness1 … 4** Default: **Line thickness 1**
3	Signal color of the signal
4	Ordinate along which the signal is scaled ■ **Left**: Scaling on the left-hand ordinate ■ **Right**: Scaling on the right-hand ordinate Default: **Left**
5	The check box must be activated to display a signal in the monitor. Default: Check box for **Signal 1 … 6** activated.

The following buttons are available:

Button	Description
Activate all	Activates all signals.
Deactivate all	Deactivates all signals.
Reset thickness	Resets the line thicknesses of the signals to the default line thickness 1.
Reset colors	Resets the signal colors to the default colors.
Reset monitor	Resets the time window to the default size (cancel zoom).
Reset all?	Resets all signal properties to the default properties.

9.1.2 Displaying a signal diagram

Procedure

1. Press **Setup** and open the list box with the signals.
2. Activate the desired signals for the recording and change the signal properties if required.
3. Select and execute the program.

Description

The following signals can be displayed and recorded using the RSI monitor:

Signal	Description
1 … 6	Process forces and torques in the RCS (transformed sensor values) ■ Signal 1: Fx ■ Signal 2: Fy ■ Signal 3: Fz ■ Signal 4: Tx ■ Signal 5: Ty ■ Signal 6: Tz
7 … 12	Corrections in the RCS (distance traveled) ■ Signal 7: Correction in the X direction ■ Signal 8: Correction in the Y direction ■ Signal 9: Correction in the Z direction ■ Signal 10: Correction of angle A (rotation about the Z axis) ■ Signal 11: Correction of angle B (rotation about the Y axis) ■ Signal 12: Correction of angle C (rotation about the X axis)
13 … 18	Process forces and torques in the sensor coordinate system (raw sensor values) ■ Signal 13: Fx ■ Signal 14: Fy ■ Signal 15: Fz ■ Signal 16: Tx ■ Signal 17: Ty ■ Signal 18: Tz
19	Correction status ■ **0**: No correction possible ■ **1**: Correction active ■ **>1**: Correction in limitation

9.1.3 Saving a signal trace

Procedure

1. Activate the **File** check box.
2. Enter a file name for the trace in the **Save file** box and press **Save**.

   The trace is saved as a DAT file in the directory C:\KRC\ROBOTER\LOG\SensorInterface\MONITOR.

9.1.4 Loading a signal trace into the monitor

Procedure

1. Activate the **File** check box.
2. Select the desired file in the **Load file** box and press **Load**.

   All traces saved in the directory C:\KRC\ROBOTER\LOG\SensorInterface\MONITOR are available for selection.

9.2 Displaying diagnostic data about ForceTorqueControl

Procedure

1. In the main menu, select **Diagnosis** > **Diagnostic monitor**.
2. Select the **Force Torque Control (FTCtrl)** module in the **Module** box.

9.3 Error protocol (logbook)

The error messages of the RSI interface are logged by default in a LOG file under C:\KRC\ROBOTER\LOG\SensorInterface.

9.4 Return values of the variables FT_NIFBREAK

The cause of termination of a sensor-guided motion can be evaluated using the global KRL variable FT_NIFBREAK (type: INT).

Return value	Constant	Description
1	FT_STOPBREAKOK	Break condition met
10	FT_STOPSOLFX	Maximum force that the sensor can measure in the X direction has been exceeded
11	FT_STOPSOLFY	Maximum force that the sensor can measure in the Y direction has been exceeded
12	FT_STOPSOLFZ	Maximum force that the sensor can measure in the Z direction has been exceeded
13	FT_STOPSOLTX	Maximum torque that the sensor can measure in the X direction has been exceeded
14	FT_STOPSOLTY	Maximum torque that the sensor can measure in the Y direction has been exceeded
15	FT_STOPSOLTZ	Maximum torque that the sensor can measure in the Z direction has been exceeded
16	FT_STOPROLFX	Maximum permissible force in the X direction of the RCS exceeded
17	FT_STOPROLFY	Maximum permissible force in the Y direction of the RCS exceeded
18	FT_STOPROLFZ	Maximum permissible force in the Z direction of the RCS exceeded
19	FT_STOPROLTX	Maximum permissible torque about the X axis of the RCS exceeded
20	FT_STOPROLTY	Maximum permissible torque about the Y axis of the RCS exceeded
21	FT_STOPROLTZ	Maximum permissible torque about the Z axis of the RCS exceeded
22	FT_STOPMAXTIME	Time limit for the force/torque control exceeded
23	FT_STOPMAXCORR	Maximum permissible overall Cartesian correction exceeded

10 KUKA Service

10.1 Requesting support

Introduction

The KUKA Roboter GmbH documentation offers information on operation and provides assistance with troubleshooting. For further assistance, please contact your local KUKA subsidiary.

Information

The following information is required for processing a support request:

- Model and serial number of the robot
- Model and serial number of the controller
- Model and serial number of the linear unit (if applicable)
- Model and serial number of the energy supply system (if applicable)
- Version of the KUKA System Software
- Optional software or modifications
- Archive of the software

  For KUKA System Software V8: instead of a conventional archive, generate the special data package for fault analysis (via **KrcDiag**).
- Application used
- Any external axes used
- Description of the problem, duration and frequency of the fault

10.2 KUKA Customer Support

Availability

KUKA Customer Support is available in many countries. Please do not hesitate to contact us if you have any questions.

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