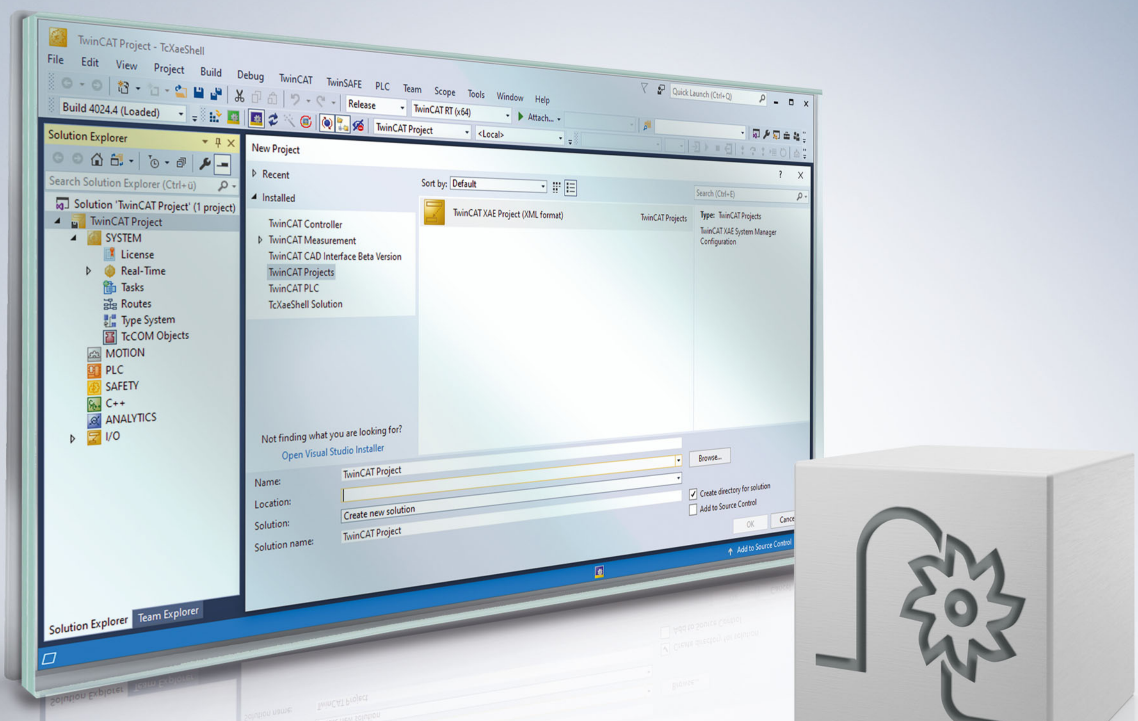
BECKHOFF New Automation Technology

Manual | EN

TF5200 | TwinCAT 3 CNC

Commissioning of the kinematic transformation



12/19/2023 | Version: 1.05

Notes on the documentation

This description is only intended for the use of trained specialists in control and automation engineering who are familiar with the applicable national standards.
It is essential that the documentation and the following notes and explanations are followed when installing and commissioning the components.
It is the duty of the technical personnel to use the documentation published at the respective time of each installation and commissioning.

The responsible staff must ensure that the application or use of the products described satisfy all the requirements for safety, including all the relevant laws, regulations, guidelines and standards.

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The documentation has been prepared with care. The products described are, however, constantly under development.
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1. Indicates an action.

⇨ Indicates an action statement.

⚠ DANGER

Acute danger to life!

If you fail to comply with the safety instruction next to this icon, there is immediate danger to human life and health.

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If you fail to comply with the safety instruction next to this icon, it may result in personal injury or damage to machines.

NOTICE

Restriction or error

This icon describes restrictions or warns of errors.

Tips and other notes

This icon indicates information to assist in general understanding or to provide additional information.

General example

Example that clarifies the text.

NC programming example

Programming example (complete NC program or program sequence) of the described function or NC command.

Specific version information

Optional or restricted function. The availability of this function depends on the configuration and the scope of the version.

Table of contents

Notes on the documentation ... **3**

General and safety instructions ... **4**

1 Machines with kinematic transformation ... **8**

1.1 Commissioning of the transformation ... 8

1.2 General approach for machine commissioning ... 8

1.2.1 Activating transformation ... 9

1.2.2 Implicit selection/cancelation of kinematic transformation ... 10

1.2.3 Parameterising the kinematics via the NC program ... 10

1.2.4 Checking the settings in the case of five-axis kinematics ... 11

2 Examples for machine kinematics ... **12**

2.1 Transformation for 5-axis machine with rotary table ... 12

2.1.1 Kinematic structure ... 12

2.1.2 Aligning the axis systems ... 13

2.2 Transformation for Tripod strut kinematic with fixed strut length ... 16

2.2.1 Kinematic structure ... 16

2.3 Transformation for articulated robot ... 18

2.3.1 Kinematic structure, Axis configuration ... 18

2.3.2 Translatory kinematic offsets ... 20

2.3.3 Rotary kinematic offsets ... 21

2.3.4 Tool offsets ... 23

2.3.5 Sample parameterisation for a KUKA KR150 ... 23

Index ... **25**

List of figures

Fig. 1 Kinematic structure of the single-column bed machine ... 12
Fig. 2 Coordinate systems and motion directions ... 13
Fig. 3 Kinematic offsets ... 14
Fig. 4 Tripod kinematics ... 16
Fig. 5 Offset dimensions of strut kinematics ... 17
Fig. 6 Axis configuration of the kinematic ... 19
Fig. 7 Example for param[13]=0 degrees, param[14]=0 degrees ... 21
Fig. 8 Example for param[13]=-90 degrees, param[14]=90 degrees ... 22

1 Machines with kinematic transformation

1.1 Commissioning of the transformation

Phases of commissioning

The following phases must be run through when commissioning a kinematic transformation:

1. Identifying the kinematic structure (comparison with structures in [KITRA])
2. Determining kinematic offsets
3. Parameterising the kinematics
4. Verification (checking on the basis of machine axis movements)

1.2 General approach for machine commissioning

Basic steps

1. Unless already done: Commission the axis systems and mechanically align the machine's axes according to the machine structure. In particular, pay attention to the correct motion direction of the machine axes so that the machine behaves during conventional operation (2.5D) in the way the user is accustomed to. (e.g. X100 leads to position 100 in WCS).
2. Select a suitable kinematic transformation according to the kinematic structure of the machine [TRAFO].
3. In keeping with the description of the kinematic structure (5-axis arrangement X, Y, Z, C, A), the continuous axis configuration of the machine must be created via the channel-specific list.
4. Measure the kinematic offsets and enter them into the assigned transformation parameters (channel parameter list).
5. Define default kinematics (channel parameter list).
6. After RPF→ selection of the kinematic transformation and programming of the orientation (e.g. rotatory axes A30, B45), the tool tip position must remain fixed in space.

1.2.1 Activating transformation

Possibilities of selection

After referencing of the machine (if necessary), the required transformation can be selected and cancelled via the NC program as follows.

Example 1

```
N10 #TRAFO ON
N20 X100 Y100 A0
N30 Z10 C0
N40 #TRAFO OFF
```

If different kinematics are possible for a machine (e.g. tool heads that can be changed in), the kinematic can be selected via the tool selection or can be explicitly programmed in the NC program. In the case of selection via the tool (e.g. D1 T1), the tool must be assigned a kinematics ID != 0 in the tool list.

Example 2

```
N05 #KIN ID[5]
N10 #TRAFO ON
N20 X100 Y100 A0
N30 Z10 C0
N40 #TRAFO OFF
```

Example 3:

```
N05 D1 T1
N10 #TRAFO ON
N20 X100 Y100 A0
N30 Z10 C0
N40 #TRAFO OFF
```

1.2.2 Implicit selection/cancelation of kinematic transformation

Configuring implicit selection/cancelation

For some machine types, it makes sense to only program movement in the WCS. Programmed selection/cancelation within the NC program can be dropped by means of implicit selection/cancelation in the CNC controller. Automatic selection/cancelation is achieved via the following channel-specific parameter list entries:

```
auto_enable_kin_trafo 1....automatic selection
auto_disable_kin_trafo 0 automatic cancellation
```

1.2.3 Parameterising the kinematics via the NC program

Change kinematics offsets in the NC program

When transformation is inactive, all kinematics offsets can also be influenced via the NC program. For safety reasons, however, this should be left to well-versed users.

Example 4:

```
N05 #KIN ID[12]
N10 V.G.KIN[12].PARAM[0]= 500000 (* WZ offset *)
N10 #TRAFO ON
N20 X100 Y100
N30 Z20
N40 #TRAFO OFF
```

1.2.4 Checking the settings in the case of five-axis kinematics

1.2.4.1 Zero setting the rotatory B axis in the tool

1. Clamp long centre point (125mm) into spindle.
2. Allow dial gauge (90 increments offset by z) to touch the tool close to the clamping-in point.
3. Move machine up in positive Z position. When the tool stands straight, there must be no noteworthy deviation recognizable on the dial gauge (a 0.1 degree angular error produces a 0.1745 mm position error in the case of a 100 mm tool length).

1.2.4.2 Setting the zero position of the rotatory C axis in the tool

1. Axis A or B in 90 degrees position.
2. Position dial gauge on tool as mentioned in 1.2.4.1.
3. Depending on the axis, move in the case of B -> Y axis or A ->X axis and check deviations on the dial gauge.

1.2.4.3 Zero setting the rotatory C axis in the workpiece

1. Clamp in a cuboid workpiece with parallel side faces
2. Secure a dial gauge on the tool carrier and lean it against the side face of the workpiece.
3. Move the machine in the X or Y direction and check the deviation on the dial gauge.

2 Examples for machine kinematics

2.1 Transformation for 5-axis machine with rotary table

2.1.1 Kinematic structure

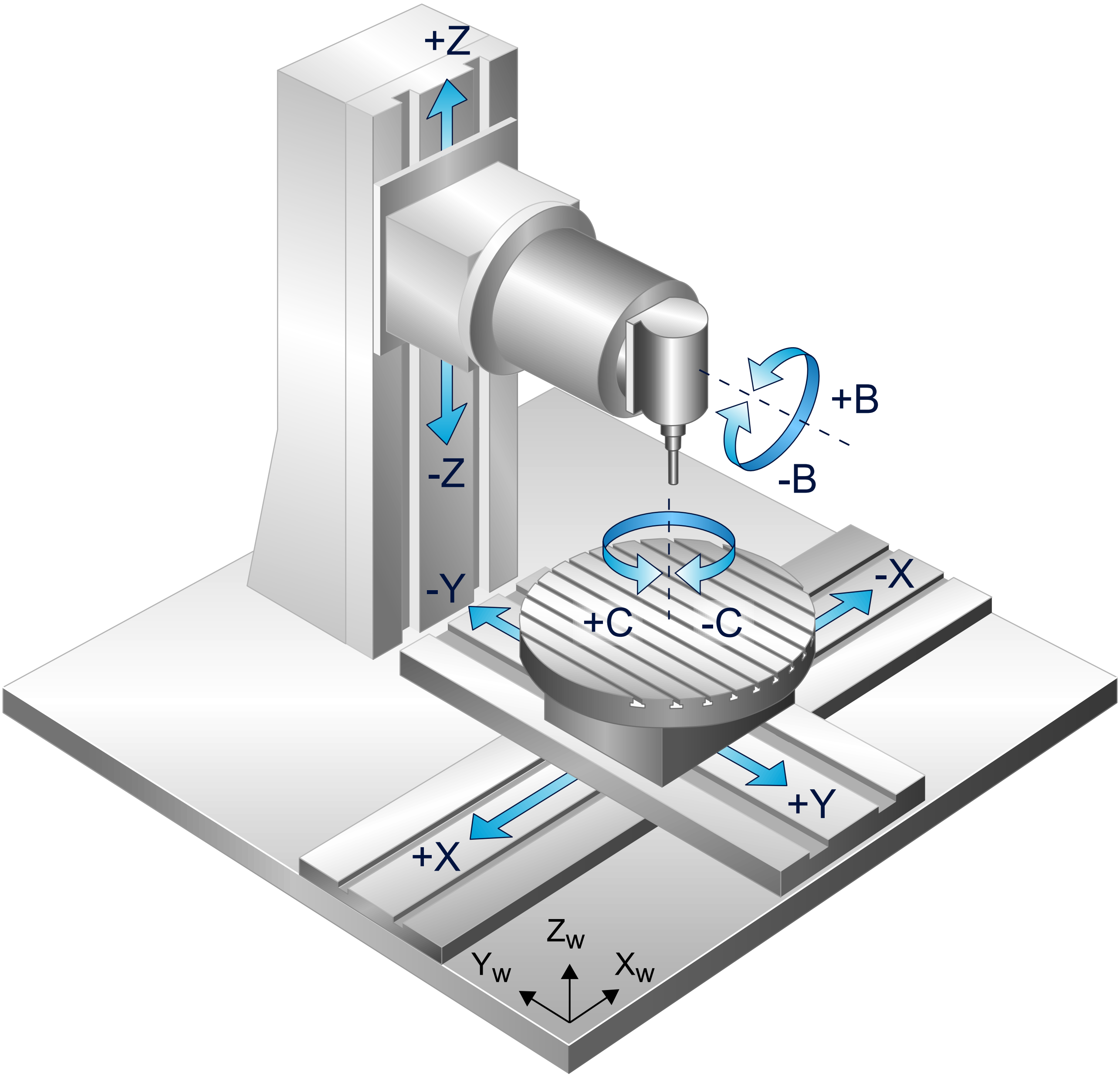


Fig. 1: Kinematic structure of the single-column bed machine

Machine type: 5-axis machine (5 axes + spindle)

Axis identifiers as per the machine labelling

Axes in the tool: Z, B, (spindle S)

Axes in the workpiece X, Y, C

Axis configuration in the sda_mds.lis: X, Y, Z, B, C

2.1.2 Aligning the axis systems

- Clamp centre point into spindle chuck.
- B axis zero point: Use a protractor or a try-square to align the rotatory axis B in the tool so that the centre point is oriented perpendicular to the turntable face of C.
- Zero point of X and Y axes: Position X and Y so that the centre point (clamped into the spindle) is flush with the rotary axis of C.
- Z axis zero point: The zero point of the Z axis cannot be approached. This transpires whenever the rotary axis of the B axis lies on the C axis. Place the centre point on the turntable via positioning of Z. Determine the offset from the turntable surface C up to the centre or the B axis. Subtract this offset from the current position→ results in the zero position in the current coordinate system.
- C axis zero point: This can be selected freely depending on the later turntable support with workpiece fastening (see turntable coordinate system). The easiest thing is to position fastening holes in the C axis to a flush position with the direction of the X or Y machine axes.
- Figure 2 shows the resulting positive motion direction of the translatory machine axes and the rotation direction of the rotatory machine axes. Note that the machine can also be moved correctly in the conventional 2.5 D mode. For example, the turntable with the workpiece moves to the left when X100 is programmed!

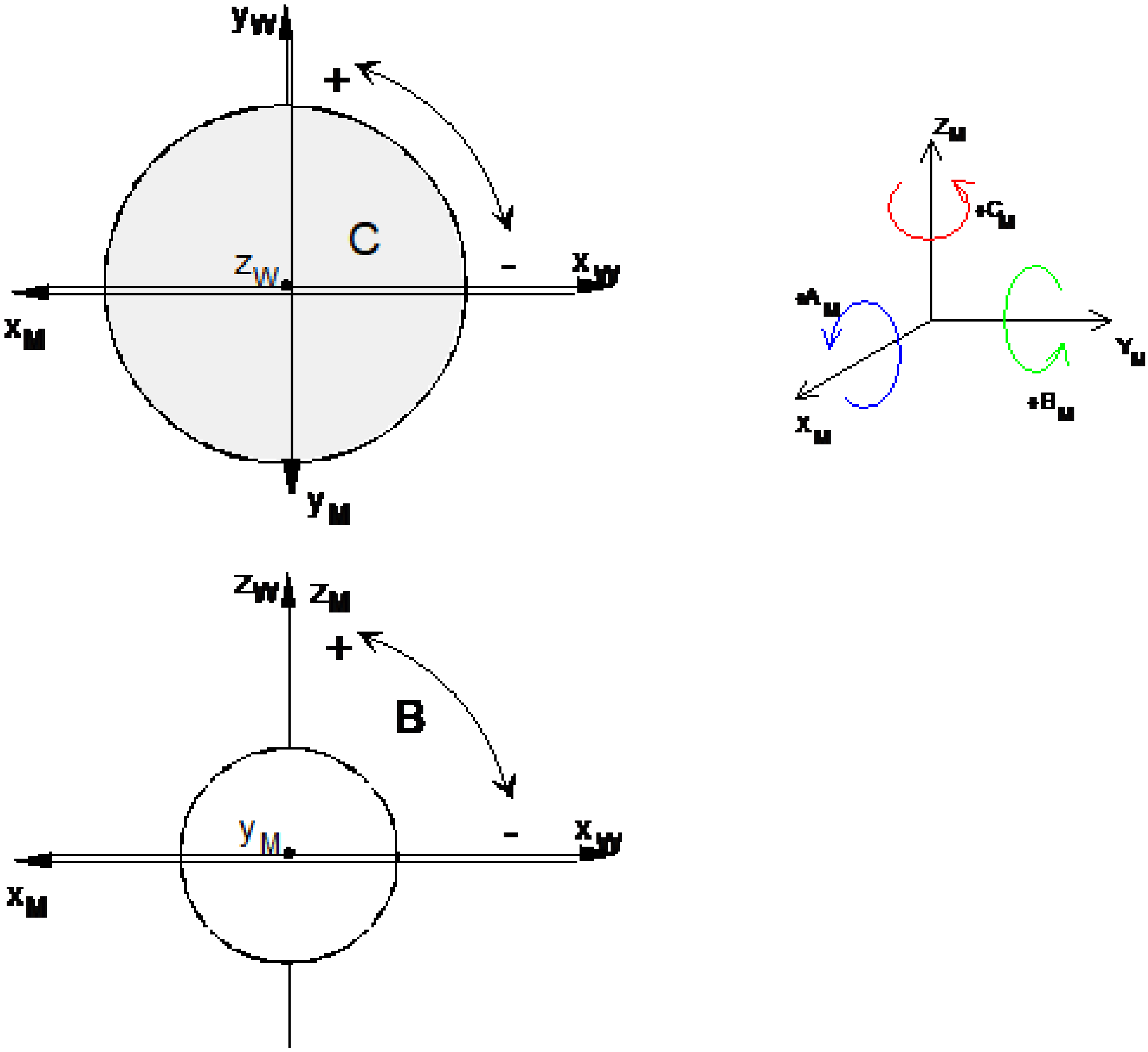


Fig. 2: Coordinate systems and motion directions

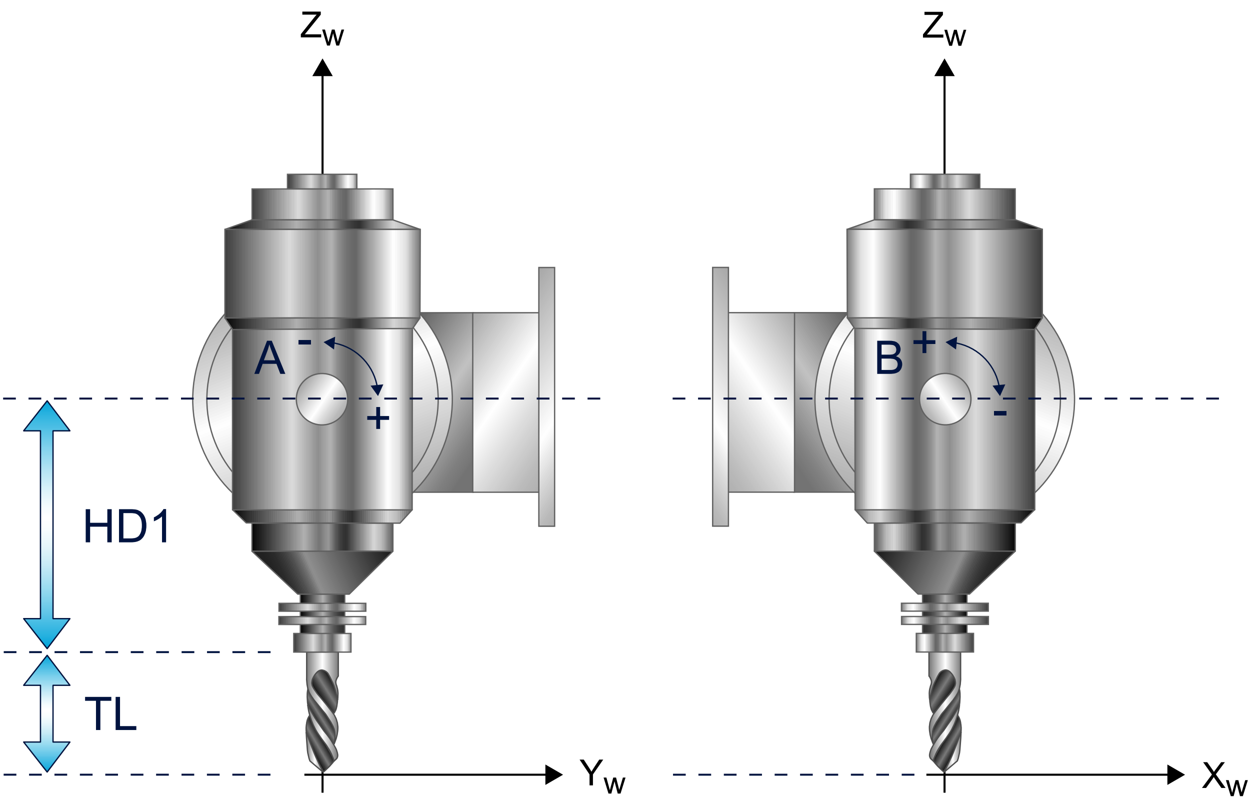


Fig. 3: Kinematic offsets

Kinematics ID	Axis sequence	
1	X, Y, Z, B, C	
Offset parameters	**List parameters**	**Meaning**
HD1	kinematik[1].param[0]	z axis offset zero point until rotation point B axis

Axis configuration and kinematic offsets

Excerpt from the parameter list of the channel:

```
# Define axis configuration
# ==================================

gruppe[0].achse[0].log_achs_nr 1
gruppe[0].achse[0].bezeichnung X
#
gruppe[0].achse[1].log_achs_nr 2
gruppe[0].achse[1].bezeichnung Y
#
gruppe[0].achse[2].log_achs_nr 3
gruppe[0].achse[2].bezeichnung Z
#
gruppe[0].achse[3].log_achs_nr 4
gruppe[0].achse[3].bezeichnung B
#
gruppe[0].achse[4].log_achs_nr 5
gruppe[0].achse[4].bezeichnung C
#


# Define kinematic parameters
# ==================================
kinematik_id  1 5ax model machine

# Offsets in 0.1 æm
#
```

```
kinematik[1].param[0]  1450000 /* Tool clamping point offset to rotation point B axis */
kinematik[1].param[1]  0
kinematik[1].param[2]  0
kinematik[1].param[3]  0
kinematik[1].param[4]  0
kinematik[1].param[5]  0
kinematik[1].param[6]  0
.....
.....
....
```

2.2 Transformation for Tripod strut kinematic with fixed strut length

2.2.1 Kinematic structure

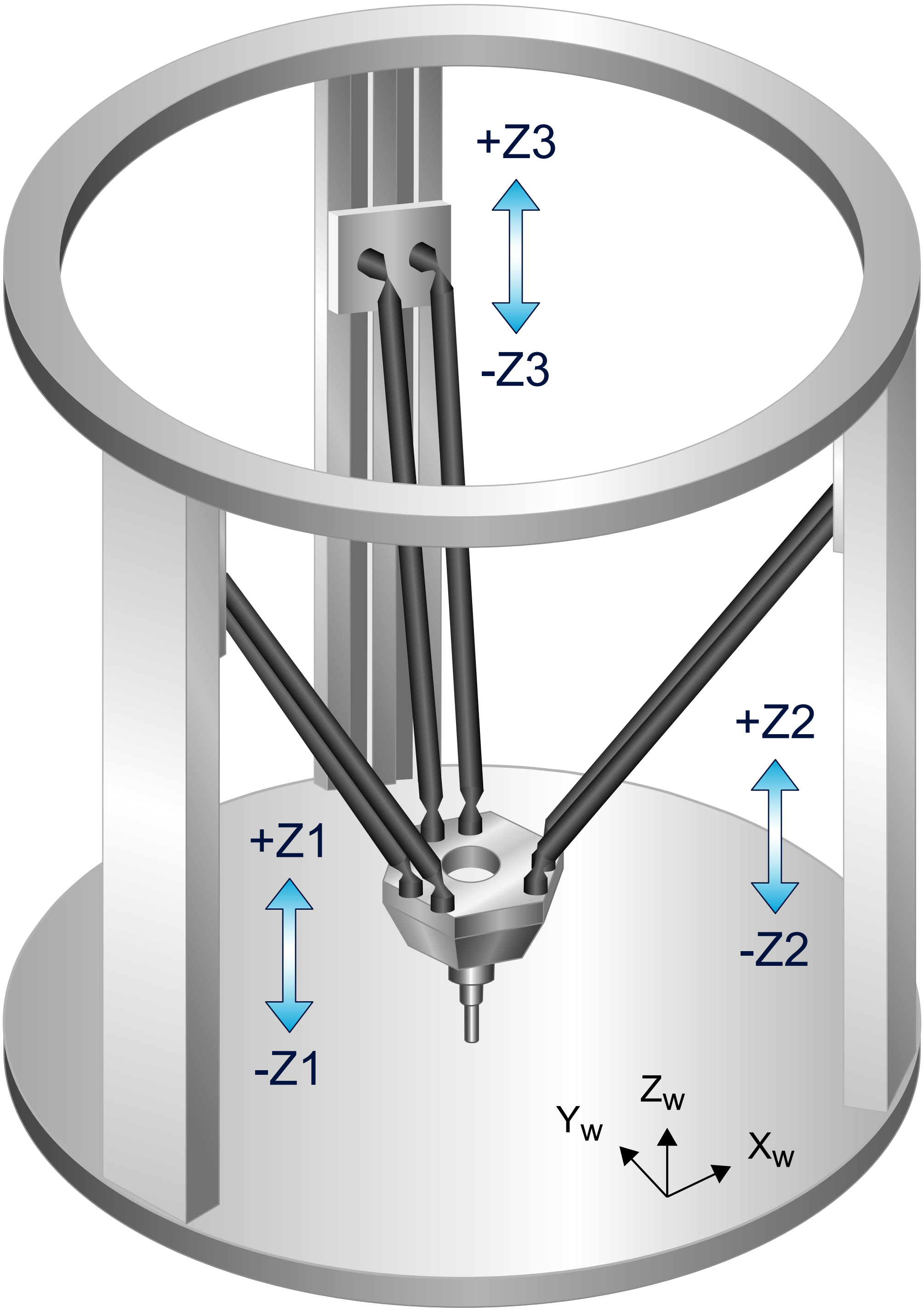


Fig. 4: Tripod kinematics

Machine type: 3-axis machine (3 axes + spindle)

Axis identifiers as per the machine labelling

Axes in the tool: Z1, Z2, Z3,(Spindle B)

Axes in the workpiece -

Axis configuration in the sda_mds.lis: X, Y, Z

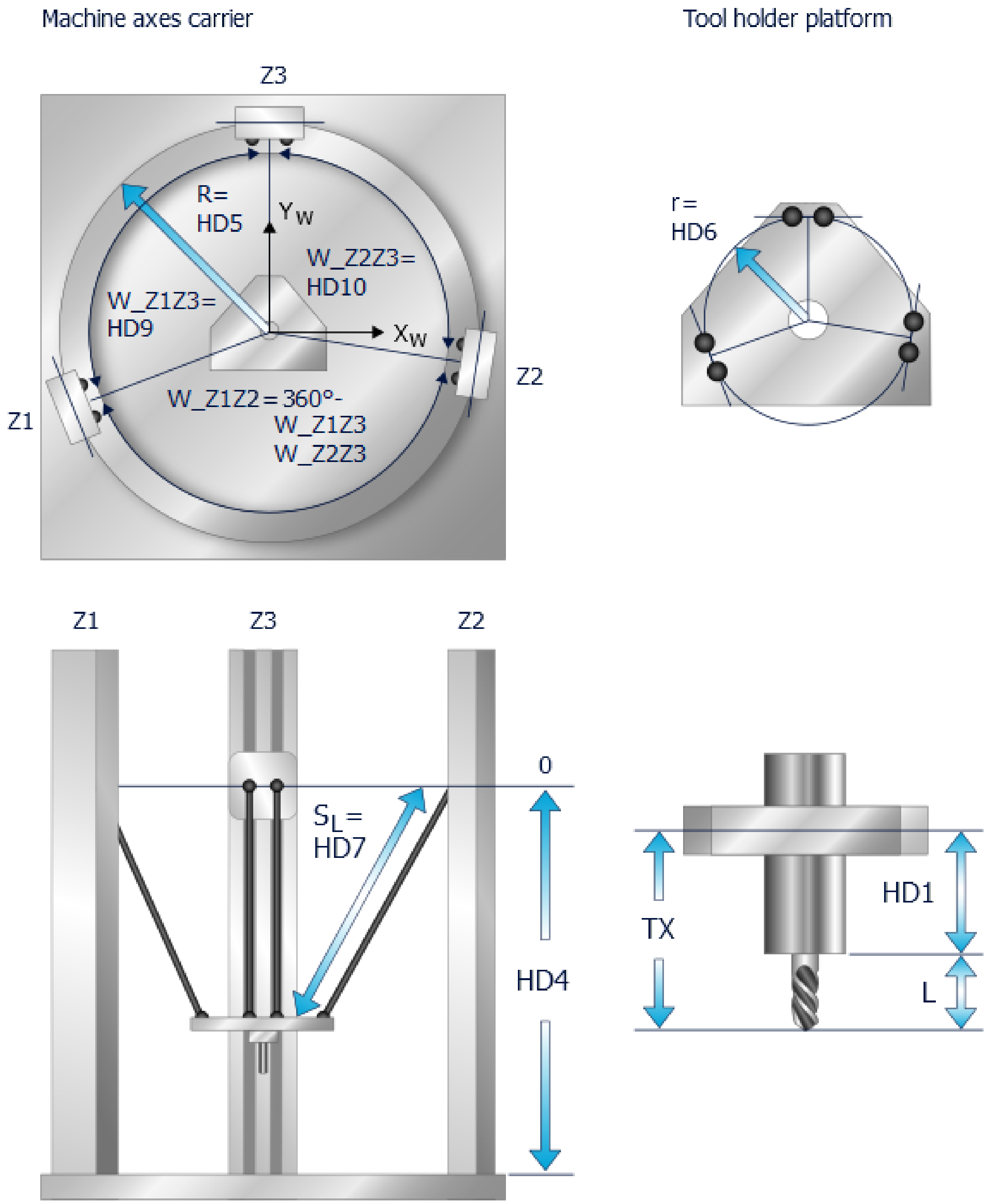


Fig. 5: Offset dimensions of strut kinematics

Kinematics ID	Axis sequence
12	X, Y, Z (Z1, Z2, Z3)
Parameter	

Offset	List	Meaning
HD1	kinematik[12].param[0]	z offset tool
HD2	kinematik[12].param[1]	x offset tool
HD3	kinematik[12].param[2]	y offset tool
HD4	kinematik[12].param[3]	z offset machine axis zero point.
HD5	kinematik[12].param[4]	Radius to connecting line joint centre points drive columns
HD6	kinematik[12].param[5]	Radius to connecting line joint centre points Steward platform.
HD7	kinematik[12].param[6]	Strut length to each joint centre point
HD8	kinematik[12].param[7]	Switch for switching to non-ideal tripod (enable HD9 / HD 10)
HD9	kinematik[12].param[8]	Angle column / joint 3 to column / joint 1
HD10	kinematik[12].param[9]	Angle column / joint 3 to column / joint 2

Axis configuration and kinematic offsets

Excerpt from the channel parameter list:

```
# Define axis configuration
# =================================
gruppe[0].achse[0].log_achs_nr 1
gruppe[0].achse[0].bezeichnung X
#
gruppe[0].achse[1].log_achs_nr 2
gruppe[0].achse[1].bezeichnung Y
#
gruppe[0].achse[2].log_achs_nr 3
gruppe[0].achse[2].bezeichnung Z
#
# Define kinematic parameters
# =================================
kinematik_id  12 Tripod
#
# Offsets in 0.1 æm
# Tripod
kinematik[12].param[0] 500000
kinematik[12].param[1] 0
kinematik[12].param[2] 0
kinematik[12].param[3] 9100000
kinematik[12].param[4] 4585000
kinematik[12].param[5] 725900
kinematik[12].param[6] 7020000
```

2.3 Transformation for articulated robot

2.3.1 Kinematic structure, Axis configuration

Kinematic ID	45

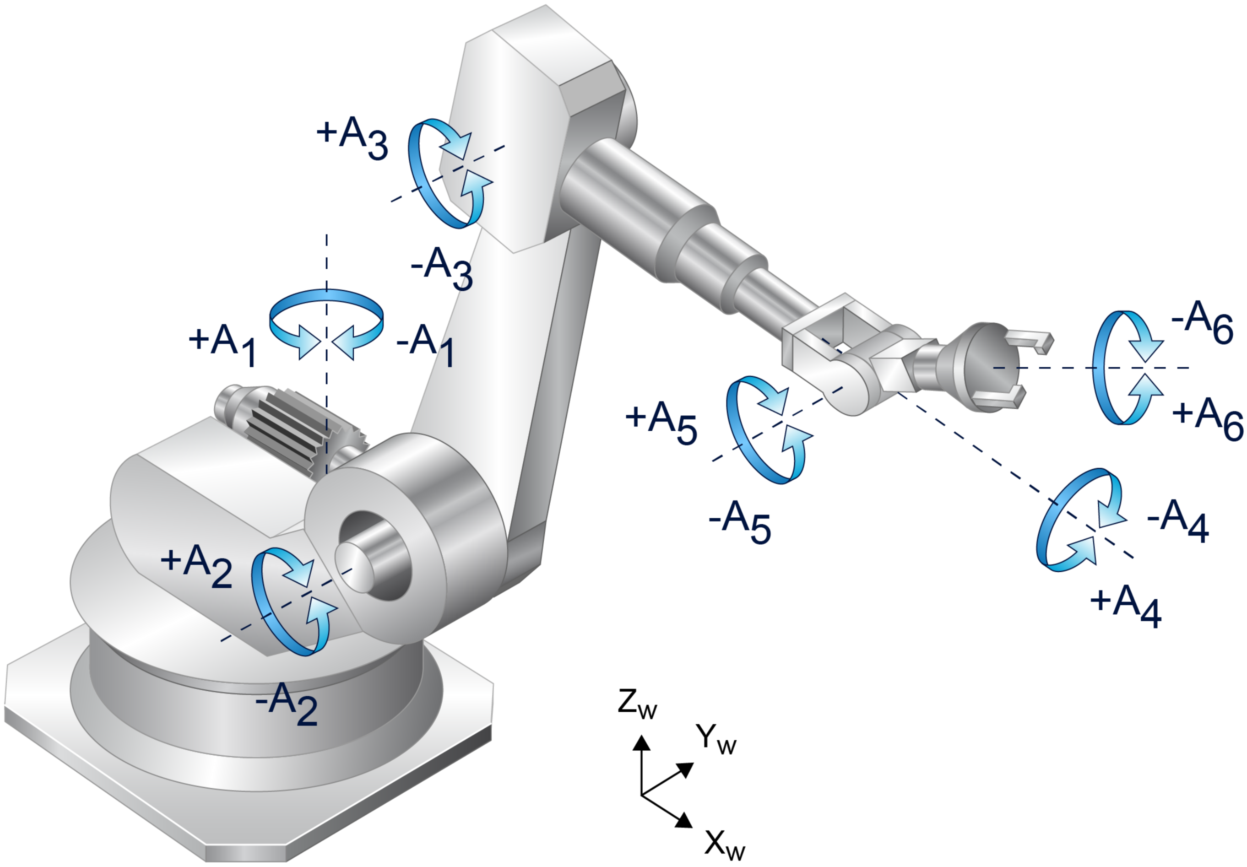


Fig. 6: Axis configuration of the kinematic

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B, C (G1, G2, G3, G4, G5, G6)	
Axis index	0, 1, 2, 3, 4.5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, B, C	-

Peculiarities

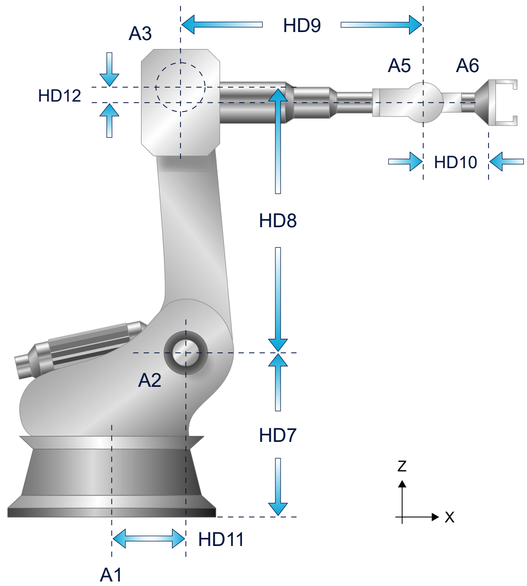
The articulated axes are numbered consecutively from 1 to 6 (starting with the first axis which rotates about the z axis of the Cartesian space coordinate system). The robot is in the zero position of the articulated axes.

Establish a continuous axis configuration with 6 axes X, Y, Z, A, B, C. corresponding to the axis sequence specified. Establish the correct mathematically positive rotation direction of the articulated axes according to the space coordinate system.

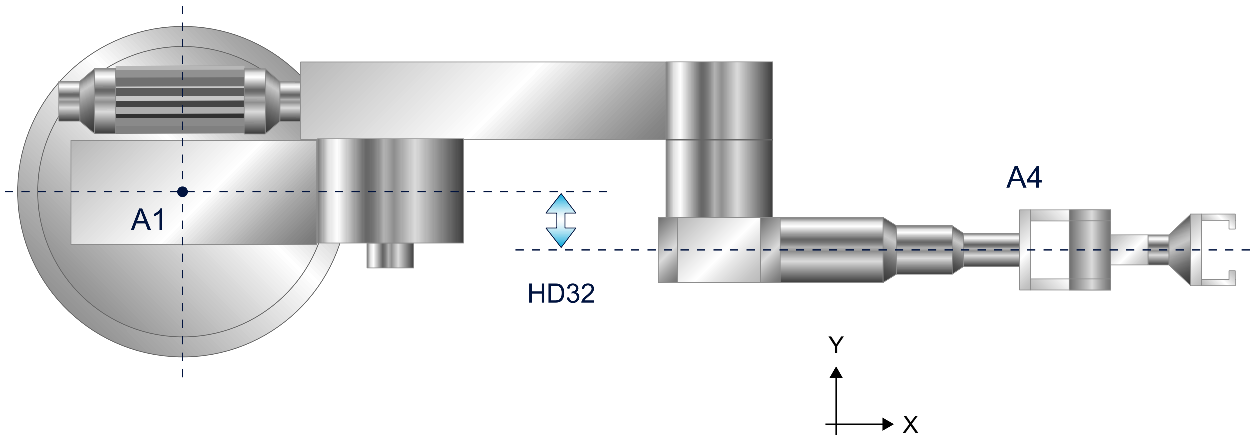
All articulated axes of the robot except for the hand axes A4 and A6 are linear axes. The axes G4 and G6 are modulo axes with ranges of 0 to 180, 0 to -180 degrees. If no trailing cables have to be taken into account, articulated axis G1 can also be set as a modulo axis.

Check whether the hand axes G4 to G6 are coupled mechanically via gearing. If this is the case, electronic gear compensation is necessary in the CNC!

2.3.2 Translatory kinematic offsets



List parameters	Meaning
kinematik[45].param[10]	X offset of origin of Cartesian space KS to rotation point articulated axis 2
kinematik[45].param[6]	Z offset of origin of Cartesian space KS to rotation point articulated axis 2 kinematik[45].param[6]
kinematik[45].param[31]	Y offset between rotary axis 4 and rotary axis 1
kinematik[45].param[7]	Z offset from rotary axis joint 2 to rotary axis joint 3
kinematik[45].param[11]	Z offset from rotary axis joint 3 to rotary axis joint 5
kinematik[45].param[8]	X offset from rotary axis joint 3 to rotary axis joint 5
kinematik[45].param[9]	X offset from manual axis joint 5 to flange surface on joint 6



2.3.3 Rotary kinematic offsets

2.3.3.1 Angle offset

These are needed to match the zero position of the internal robot model in the kinematic transformation with the physical zero position of the real robot. In the examples given below, the articulated axis positions are 0 in each case.

List parameters	Meaning
kinematik[45].param[13]	Rotary offset for zero position of robot joint axis 2
kinematik[45].param[14]	Rotary offset for zero position of robot joint axis 3

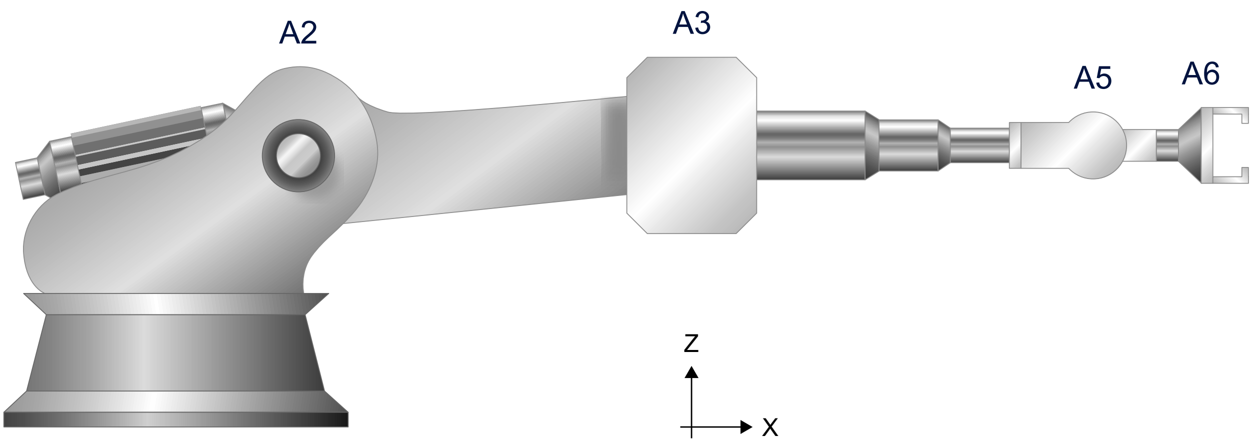


Fig. 7: Example for param[13]=0 degrees, param[14]=0 degrees

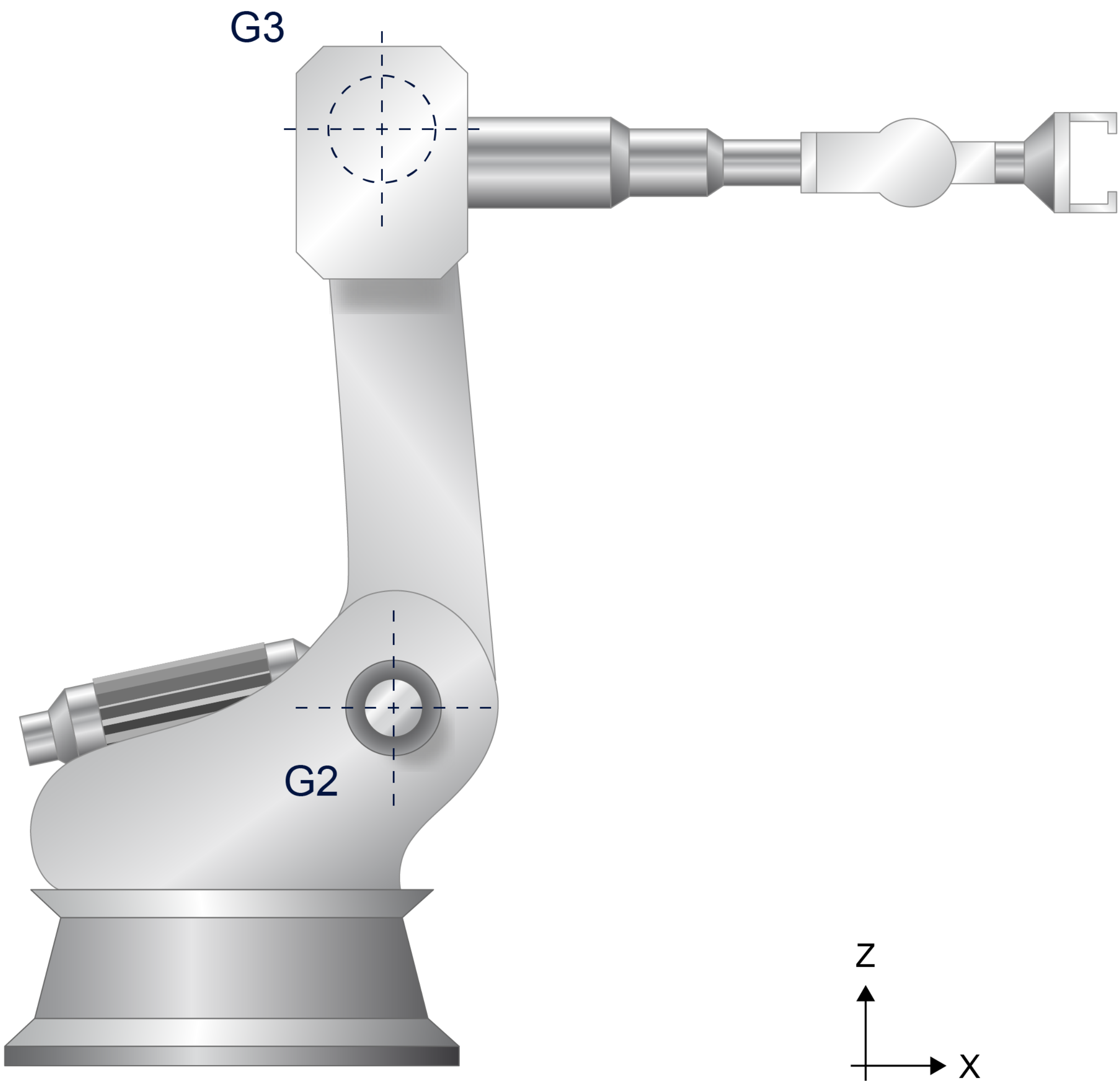


Fig. 8: Example for param[13]=-90 degrees, param[14]=90 degrees

2.3.3.2 Direction of rotation

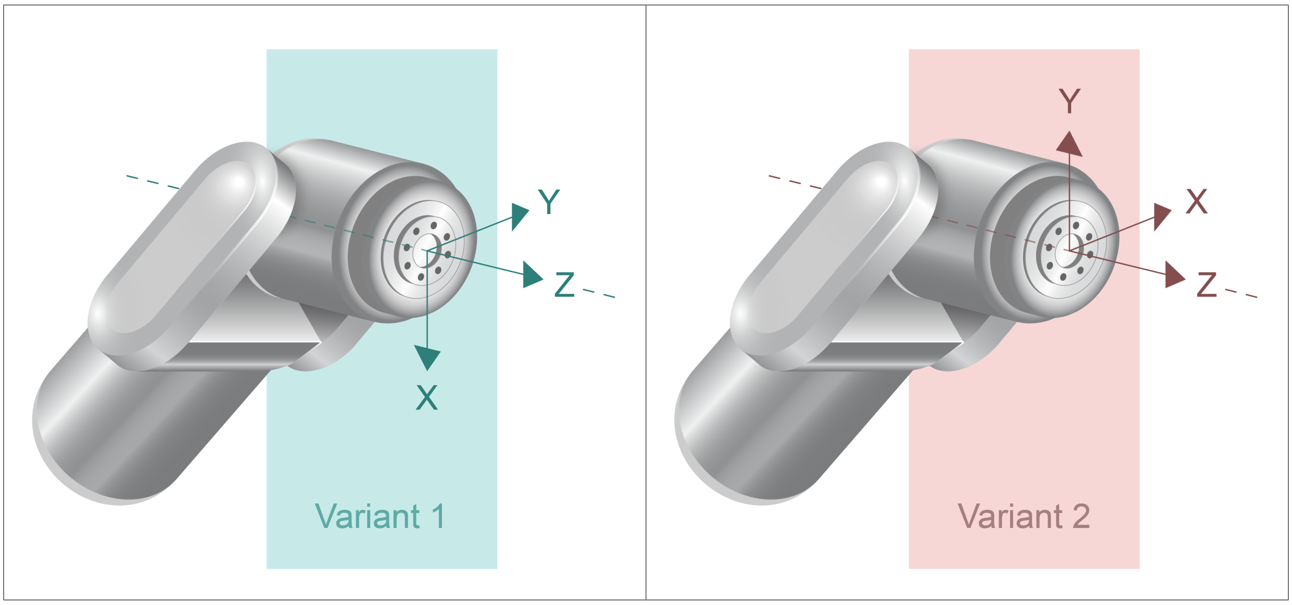
These were used for matching the rotation directions of the internal robot model in the kinematic transformation to the physical rotation directions of the actual robot. In default position, all the articulated axes in zero position of the robot rotate around the Cartesian y axis in a mathematically positive direction.

List parameters	**Meaning**
kinematik[45].param[20]	Rotation direction of C axis 1, 0: positive, 1: negative
kinematik[45].param[21]	Rotation direction of C axis 2, 0: positive, 1: negative
kinematik[45].param[22]	Rotation direction of C axis 3, 0: positive, 1: negative
kinematik[45].param[23]	Rotation direction of C axis 4, 0: positive, 1: negative
kinematik[45].param[24]	Rotation direction of C axis 5, 0: positive, 1: negative
kinematik[45].param[25]	Rotation direction of C axis 6, 0: positive, 1: negative

2.3.3.3 Flange coordinate system

For compatibility reasons, the orientation of the flange coordinate system can be changed back from variant 1 (standard) to variant 2.

List parameters	Meaning
kinematik[45].param[30]	0: Variant 1, default (KUKA, Stäubli) 1: Variant 2



2.3.4 Tool offsets

The following parameters are available for a tool flanged onto robot axis 6.

List parameters	Meaning
kinematik[45].param[0]	Tool offset in Z direction of effector
kinematik[45].param[1]	Tool offset in X direction of effector
kinematik[45].param[2]	Tool offset in Y direction of effector
kinematik[45].param[3]	Tool rotation about the X'' axis
kinematik[45].param[4]	Tool rotation about the Y' axis
kinematik[45].param[5]	Tool rotation about the Z axis

First rotate and then shift?

2.3.5 Sample parameterisation for a KUKA KR150

2.3.5.1 Axis configuration

```
gruppe[0].bezeichnung IPO_1
gruppe[0].achs_anzahl 6
gruppe[0].achse[0].log_achs_nr 1
gruppe[0].achse[0].bezeichnung X
gruppe[0].achse[1].log_achs_nr 2
gruppe[0].achse[1].bezeichnung Y
gruppe[0].achse[2].log_achs_nr 3
gruppe[0].achse[2].bezeichnung Z
gruppe[0].achse[3].log_achs_nr 4
gruppe[0].achse[3].bezeichnung A
gruppe[0].achse[4].log_achs_nr 5
```

```
gruppe[0].achse[4].bezeichnung B
gruppe[0].achse[5].log_achs_nr 6
gruppe[0].achse[5].bezeichnung C
```

2.3.5.2 Kinematics offsets

```
# Robot: 6-axis articulated robot based on the example of KR210 R2700-2
# ----------------------------------------------------------
# Offset from G3 to rotation sym. axis in beam arm -115 mm
# X offset from the origin to the rotation point G2 330 mm
# Z offset from the origin to the rotation point G2 645 mm
# Top arm length 2 1150 mm
# Bottom arm length G3 to G5 1120 mm
# Distance G5 to G6 215 mm
#

kinematik[45].param [0] 500000 Effector offset: Z
kinematik[45].param [1] 2500000 X
kinematik[45].param [2] 0 Y
kinematik[45].param [3] 0 Effector rotation: X''
kinematik[45].param [4] 900000 Y'
kinematik[45].param [5] 0 Z
kinematik[45].param [6] 6450000 Z offset from G1 to G2
kinematik[45].param [7] 11500000 Z offset from G2 to G3
kinematik[45].param [8] 12200000 X offset from G3 to G5
kinematik[45].param [9] 2150000 X offset from G5 to G6
kinematik[45].param [10] 3300000 X offset from G1 to G2
kinematik[45].param [11] -1150000 Z offset from G3 to G5

kinematik[45].param [13] 0 Angle offset zero position G2
kinematik[45].param [14] 0 Angle offset zero position G3

kinematik[45].param [20] 1 Rotation direction G1 negative
kinematik[45].param [21] 0 Rotation direction G2 negative
kinematik[45].param [22] 0 Rotation direction G3 negative
kinematik[45].param [23] 1 Rotation direction G4 negative
kinematik[45].param [24] 0 Rotation direction G5 negative
kinematik[45].param [25] 1 Rotation direction G6 negative

kinematik[45].param [30] 0 Old orientation of flange coordinate system
kinematik[45].param [31] 0 Y offset from G4 to G1
```

Index

More Information:
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