DOCUMENTATION ISG-kernel

Manual
Kinematic transformations

Short Description:
KITRA

ISG Industrielle Steuerungstechnik GmbH
STEP, Gropiusplatz 10
D-70563 Stuttgart

www.isg-stuttgart.de
support@isg-stuttgart.de

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Preface

Legal information

This documentation was produced with utmost care. The products and scope of functions described are under continuous development. We reserve the right to revise and amend the documentation at any time and without prior notice.

No claims may be made for products which have already been delivered if such claims are based on the specifications, figures and descriptions contained in this documentation.

Personnel qualifications

This description is solely intended for skilled technicians who were trained in control, automation and drive systems and who are familiar with the applicable standards, the relevant documentation and the machining application.

It is absolutely vital to refer to this documentation, the instructions below and the explanations to carry out installation and commissioning work. Skilled technicians are under the obligation to use the documentation duly published for every installation and commissioning operation.

Skilled technicians must ensure that the application or use of the products described fulfil all safety requirements including all applicable laws, regulations, provisions and standards.

Further information

Links below (DE)

https://www.isg-stuttgart.de/produkte/softwareprodukte/isg-kernel/dokumente-und-downloads

or (EN)

https://www.isg-stuttgart.de/en/products/softwareproducts/isg-kernel/documents-and-downloads

contains further information on messages generated in the NC kernel, online help, PLC libraries, tools, etc. in addition to the current documentation.

Disclaimer

It is forbidden to make any changes to the software configuration which are not contained in the options described in this documentation.

Trade marks and patents

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General and safety instructions

Icons used and their meanings

This documentation uses the following icons next to the safety instruction and the associated text. Please read the (safety) instructions carefully and comply with them at all times.

Icons in explanatory text

➢ 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.

⚠ CAUTION

Personal injury and damage to machines!

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

Attention

Restriction or error

This icon describes restrictions or warns of errors.

Notice

Tips and other notes

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

Example

General example

Example that clarifies the text.

Programing Example

NC programming example

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

Release Note

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

List of figures

1 Introduction

Mandatory note on references to other documents

For the sake of clarity, links to other documents and parameters are abbreviated, e.g. [PROG] for the Programming Manual or P-AXIS-00001 for an axis parameter.

For technical reasons, these links only function in the Online Help (HTML5, CHM) but not in pdf files since pdfs do not support cross-linking.

Transformation types

The transformations listed below are 3, 4, 5 and 6-axis kinematic transformations. They are only required on machines with

- non-Cartesian axis arrangement or
- with rotary axes

to adjust orientation if programming takes place in the WCS (Workpiece Coordinate System). In general, this case results in non-linear equations that reflect the correlation between workpiece coordinates and machine coordinates.

Workpiece axes are axes that are located on the workpiece side in the kinematic chain. Tool axes are axes which are on the tool side.

A distinction is made between the following transformation types

- **RTCP Transformation (Rotation Tool Centre Point):** In this case, spatial positions are programmed in the WCS. The tool direction is set by programming the rotary machine axes (e.g. B and C are independent of the machine). Auxiliary functions permit automatic tool orientation to rotated coordinate systems in space.

  Example of NC program line: N10 X100 Y20 Z30 B0 C0

- **Complete transformation:** In this case, spatial curves and the tool machining orientation are programmed by position and orientation (point-vector sequences) and are always independent of the machine type with 6 coordinates (*).

  Example of NC program line: N10 X100 Y20 Z30 A0 B0 C1

(*) Depending on the degrees of freedom of a kinematic feature, only the position may be programmed by 3 coordinates (e. g. Tripod).

Notice

Transformations are additional options and subject to the purchase of a license.

Attention

When kinematic transformation is active, axis-specific tool offsets in *ax_versatz[<ax_index>]* (P-TOOL-00006) are only taken into consideration if axes are not influenced by the transformation function. Depending on the transformation type, they typically refer to all axes with index > 2 when RTCP is used.

The axis-specific tool offsets of the first three axes (index 0, 1, 2) are **not** taken into account when transformation is active. If tool offsets should also be effective for these axes when transformation is active, enter the values in the kinematic offsets of the tool (P-TOOL-00009) mentioned above.

The necessary kinematic-specific axis configuration setting must be entered in the channel parameters.

It is essential to use the correct axis index sequence for the selected transformation.

1.1 Specifying the kinematic ID, kinematic type and offset data

In order to use a kinematic, it must be explicitly specified by its kinematic ID (P-CHAN-00262) and kinematic type (P-CHAN-00829).

The purpose of the kinematic ID is to explicitly identify a configured kinematic from the list of all kinematics configured. A kinematic may not be configured multiple times.

The kinematic type determines the kinematic type and structure as classified in Overview [▶ 20].

Classification by means of kinematic ID and type is available as of CNC Build V3.1.3080.09. This has the advantage that several identical kinematic types with different offset data can be parameterised in the same configuration list and can be activated as required by using the kinematic ID.

Notice

If no kinematic type is specified (kinematic type 0), the value of the kinematic ID is automatically assigned to the kinematic type.

Kinematic type (as of V3.1.3080.09)

The number required to use a specific kinematic results from the specified kinematic type as follows:

KIN_TYP_1 1

KIN_TYP_2 2

etc.

In CNC Builds < V3.1.3080.09, the specified kinematic ID is identical with the kinematic type to be used.

Attention

As of Version V3.00.3012.00, the structures *kin_step[i].trafo[j].** or *trafo[j].** **replace** the definition of kinematic data programmed with *kinematik[i].**.

The previous structure *kinematik[i].** is no longer supported.

Example

Specifying the kinematic ID, kinematic type and offset parameters

As of Build V3.00 **the kinematic** must be specified as follows:

```
trafo[0].id                    9000
trafo[0].type                  9
trafo[0].param[0]              5000000
trafo[0].param[1]              0
trafo[0].param[2]              0
trafo[0].param[3]              0
```

with an additional transformation, e.g. kinematic ID 60 (no type is specified here, so it is automatically assigned with the value 60)

```
trafo[1].id                    60
trafo[1].param[0]              2000000
trafo[1].param[1]              0
```

The same entry of the kinematic with ID 9 to specify a multi-step transformation looks like this:

```
kin_step[0].trafo[0].id            9
kin_step[0].trafo[0].type          9
kin_step[0].trafo[0].param[0]      5000000
kin_step[0].trafo[0].param[1]      0
kin_step[0].trafo[0].param[2]      0
kin_step[0].trafo[0].param[3]      0
```

with a second transformation step, the kinematic specification would look like this:

```
kin_step[1].trafo[0].id            1
kin_step[1].trafo[0].type          20
kin_step[1].trafo[0].param[0]      3000000
```

Configuring two transformations of the same type, e.g. kinematic type 9 and two different data records:

```
trafo[0].id                    9000
trafo[0].type                  9
trafo[0].param[0]              5000000
trafo[0].param[1]              1000
…
trafo[1].id                    8000
trafo[1].type                  9
trafo[1].param[0]              4550000
trafo[1].param[1]              7500
…
```

Notice

The HDi offsets of a kinematic correspond to the kinematic offsets in the channel parameters for trafo[idx].param[i-1].

Alternatively, these offsets can be entered in the corresponding value of the tool parameters (P-TOOL-00009).

The offset parameter units are 1.0 E-4 mm for translatory offsets and 1.0 E-4° for rotary offsets.

1.1.1 Kinematic ID and offset data - CNC Build <V300

Kinematic ID

The ID required to use a specific kinematic feature results from the specified kinematic type as follows:

KIN_TYP_1 1

KIN_TYP_2 2

etc.

Example

Specifying the kinematic ID and offset parameters

The kinematic ID and the offset parameters (HD offsets) of a kinematic are specified as follows:

```
kinematik[9].param[0]          500000
kinematik[9].param[1]          0
kinematik[9].param[2]          0
kinematik[9].param[3]          0
```

with an additional transformation, e.g. kinematic ID 60

```
kinematik[60].param[0]          200000
kinematik[60].param[1]          0
```

Notice

The HDi offsets of a kinematic correspond to the kinematic offsets in the channel parameters for kinematik[ID].param[i-1].

Alternatively, these offsets can be entered in the corresponding value of the tool parameters (P-TOOL-00009).

The offset parameter units are 1.0 E-4 mm for translatory offsets and 1.0 E-4° for rotary offsets.

1.2 Rotary axes and direction of rotation

The figure below shows the positive rotation directions of rotary axes. The base is a right-handed Cartesian coordinate system.

Rotation is referred to as positive if it is counter-clockwise when viewed in the direction of the arrowhead of the coordinate system axis. If the rotary axis rotates around the X axis, it is referred to as the "A axis"; when it rotates around the Y axis, it is referred to as the "B axis" and so on. If not separately stated, these rotation directions are used in kinematic transformations involving rotary axes.

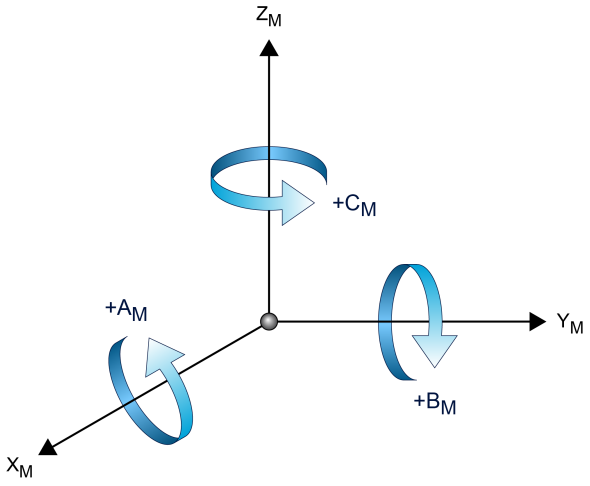


Fig. 1: Coordinate systems and motion directions

1.3 Linear axes and motion direction

The motion directions of linear axes must be adjusted so that the relative motion between tool and workpiece is the same as in 2.5 D mode. This means that when linear axes move the workpiece, the motion direction is opposite to the directions of the exs of the workpiece coordinate system.

1.4 Kinematic singularities

Kinematic singularities are specific axis positions of a kinematic.

In singular positions, the kinematic is unable to execute movements in certain Cartesian directions or rotations about specific spatial axes. A simple example is a fully extended robot arm which cannot move any further outwards (outside the work space).

Singularities have no impact on purely axis movements (e.g. with #PTP).

Singularities become critical if movements are executed in the vicinity of the programming coordinate system (PCS). Extremely fast axis movements may occur in these zones despite slow TCP movements.

However, since axis dynamics are limited, the TCP path velocity can be greatly reduced in the vicinity of a singularity.

It should be noted that these effects are a direct result of the physical kinematics. The controller can only minimise these effects or use alternative strategies, but they are not completely avoidable.

Robot singularities

See Singularities with a six-axis articulated robot kinematic [▶ 188]

Singularity with complete five-axis kinematics

In complete kinematics, the tool orientation is mapped in angular notation in a tool direction vector which is then used to map the ACS axis angle. This is dependent on P-CHAN-00247.

On the other hand, with RTCP kinematics, the tool orientation is derived directly from the programmed ACS machine angles.

With complete kinematics, the controller can no longer map the unambiguous position of the tool direction vector to an unambiguous position of the ACS orientation axes. With a complete five-axis kinematic, there are either two or an infinite number of possible ACS angle pairs for a given tool direction vector. The latter is referred to as the kinematic singularity of the structure.

In standard CA kinematics, the singular tool direction vector is ori = (0.0, 0.0, 1.0) and the corresponding ACS angular position is A_{ACS}=0. The C_{ACS} angle can assume any value in the motion range of this axis without any change in tool orientation.

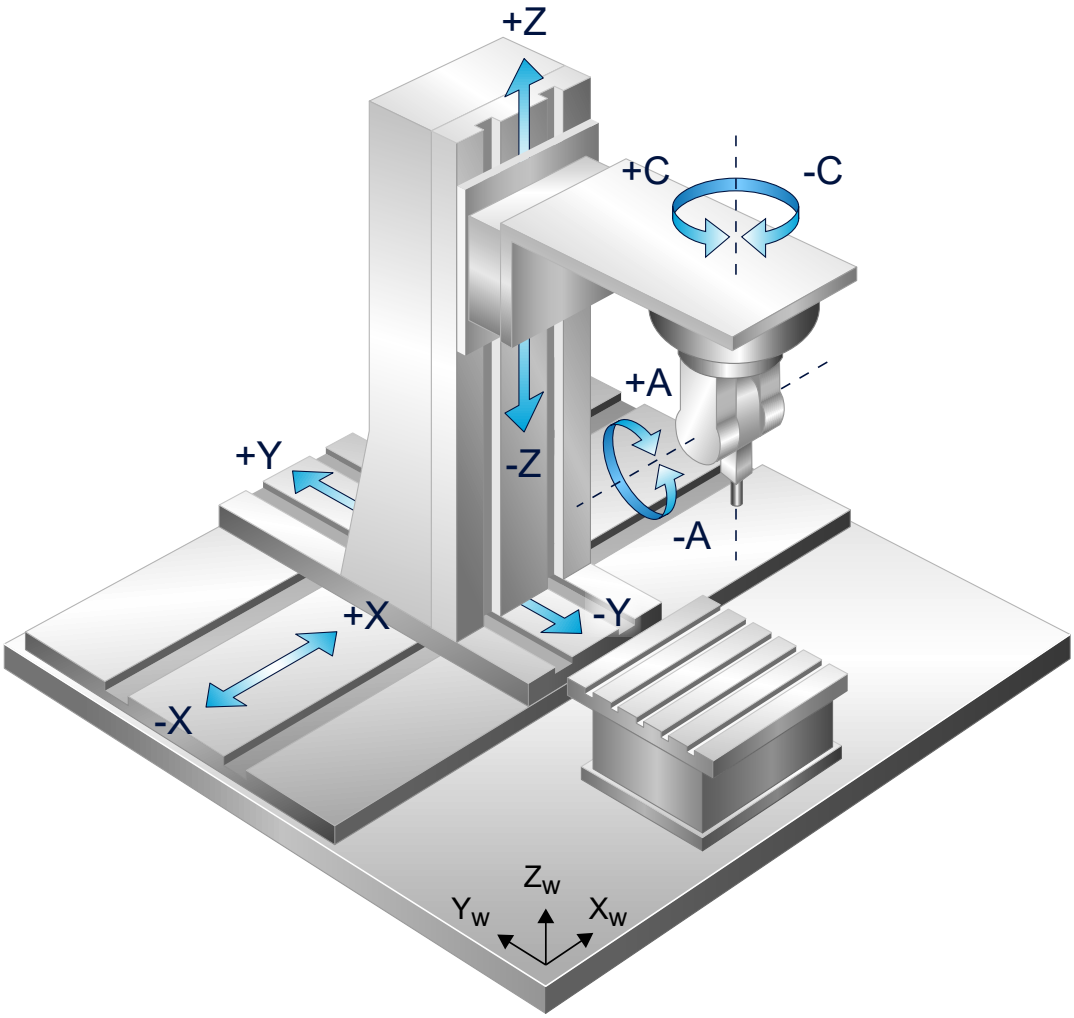


Fig. 2: Singular head position with CA five-axis kinematics, kinematic ID 9

The singularity at A_{ACS}=0 separates the two ACS angle solutions discussed above. With a CA head, for example, these angles are at orientation vector ori = (0.0, -0.7071, 0.7071)

1. C_{ACS}=0, A_{ACS}=45
2. or C_{ACS}=180 A_{ACS}=-45.

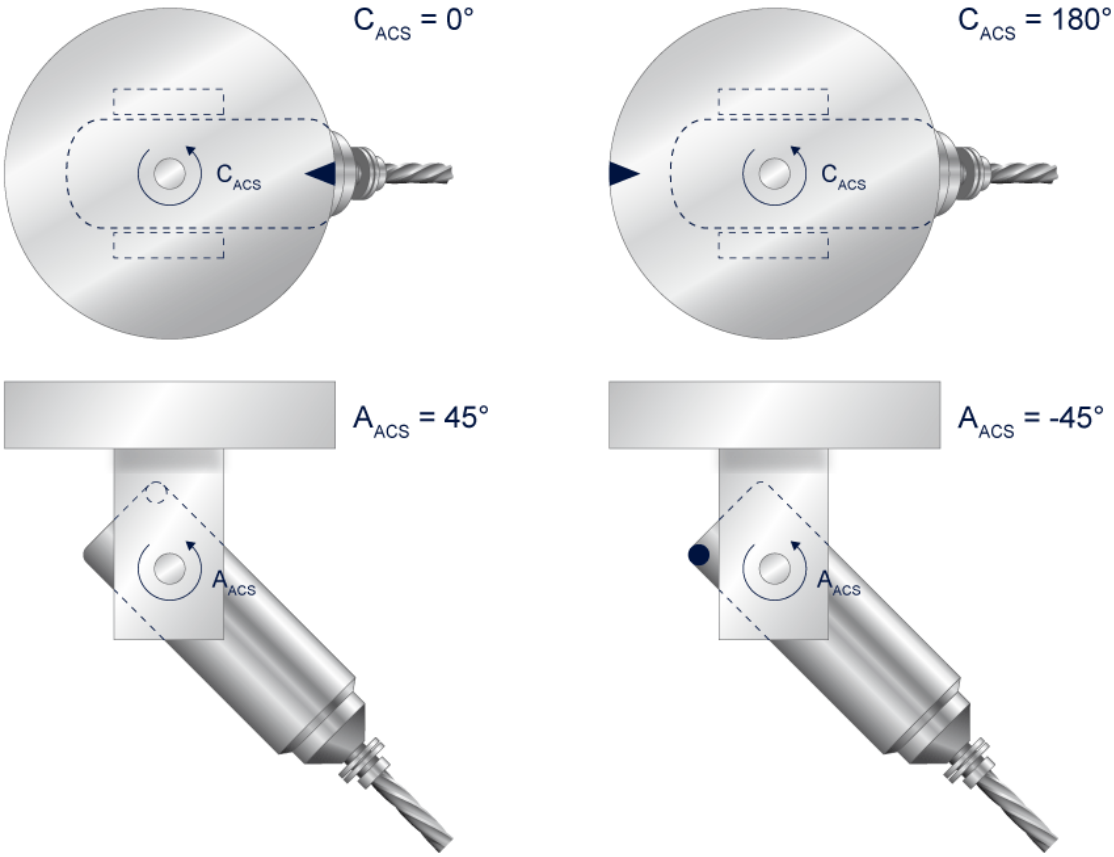


Fig. 3: Example position of a singularity

When moving out of the singularity, the controller selects the angular solution using the shortest path strategy.

Enormous dynamic stresses can occur depending on the change in orientation in the vicinity of this singular axis position. This can lead to high axis speeds of rotary axes, although the TCP path velocity (relative velocity of the TCP between tool and workpiece) is relatively low at these positions.

For certain technologies, such as laser cutting, a sufficient distance to the critical area of the singularity of this structure can be achieved with alternative tool head structures.
For example, an AB tool head that has the singularity at tool direction vector ori = (0.0, 1.0, 0.0) and ori = (0.0, -1.0, 0.0). The critical range can be avoided by using the technically required restriction of the chamfer angle of the rotary axes, e.g. B_{ACS}=+-50°.

Optimum velocity curves are obtained for positioning movements in the singularity range using special CNC functions (e.g. #PTP).

1.5 Further documentation concerning transformations

The function description [FCT-M5] describes transformations for tube machining.

Transformation ID	Description
15	Round tube, lateral surface (3/4-axis)
78	Round tube, projection (3/4-axis)
79	Polygonal tube, profiled tube (3/4-axis)
90	Round tube, lateral surface (5/6-axis)
93	Polygonal tube, profiled tube (5/6-axis)

The function description [FCT-C27] describes the Universal Kinematics using ID 91.

The function description [FCT-C35] contains the functionality of the couple kinematic with ID 210.

The integration of user-defined transformations is described in the description of the transformation interface [McCOM-TRAFO].

2 Kinematic transformations

2.1 KIN_TYP_1 – 5-axis kinematics/single-column bed machine

Kinematic structure

The kinematic structure of this machine consists of 2 translatory axes and 1 rotary axis in the workpiece as well as 1 translatory axis and 1 rotary axis in the tool.

Axis configuration in NC channel		
Axis identifier	X,Y, Z, B, C	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	Z, B	X, Y, C

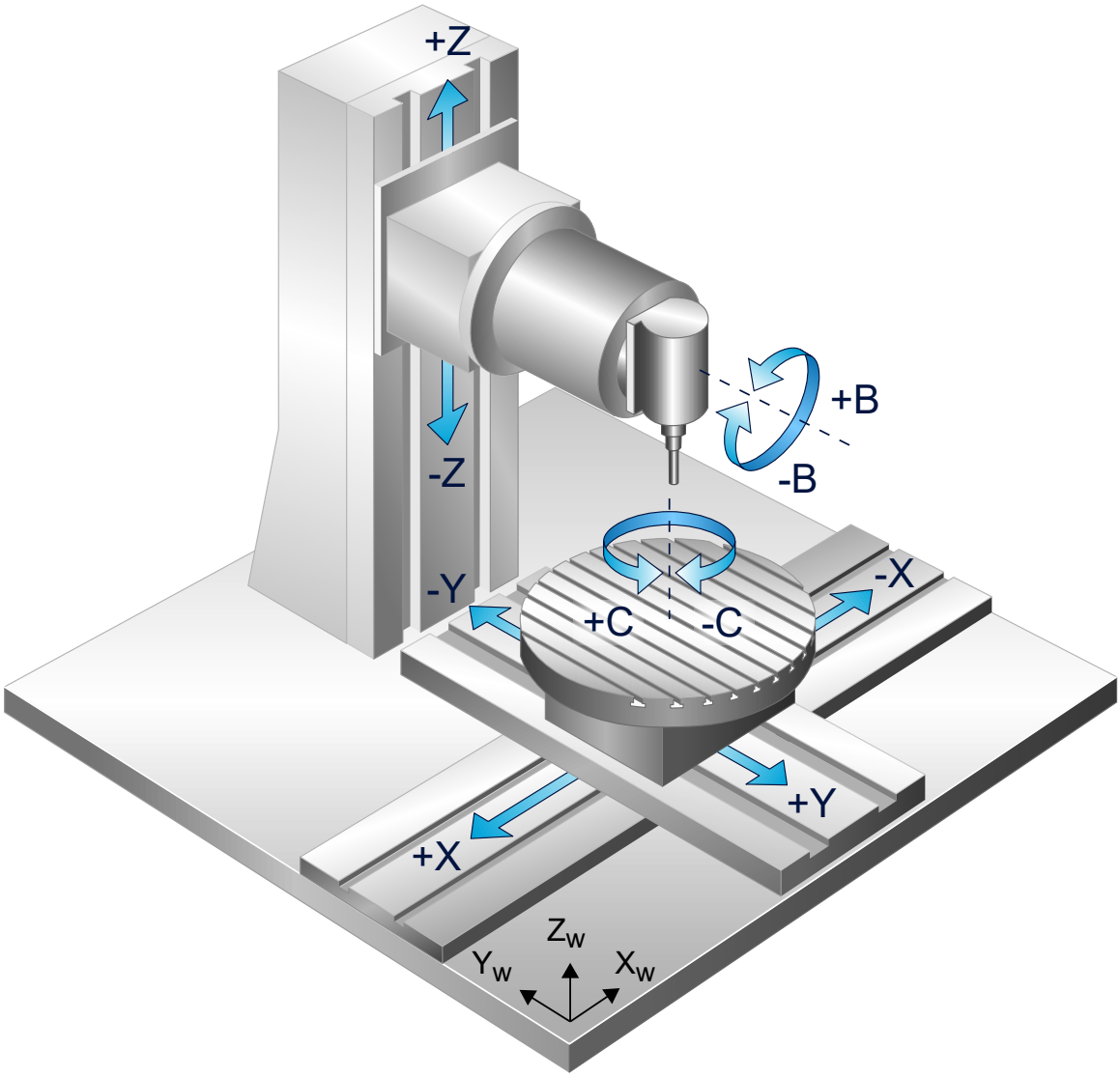


Fig. 4: Kinematics of the single-column bed machine

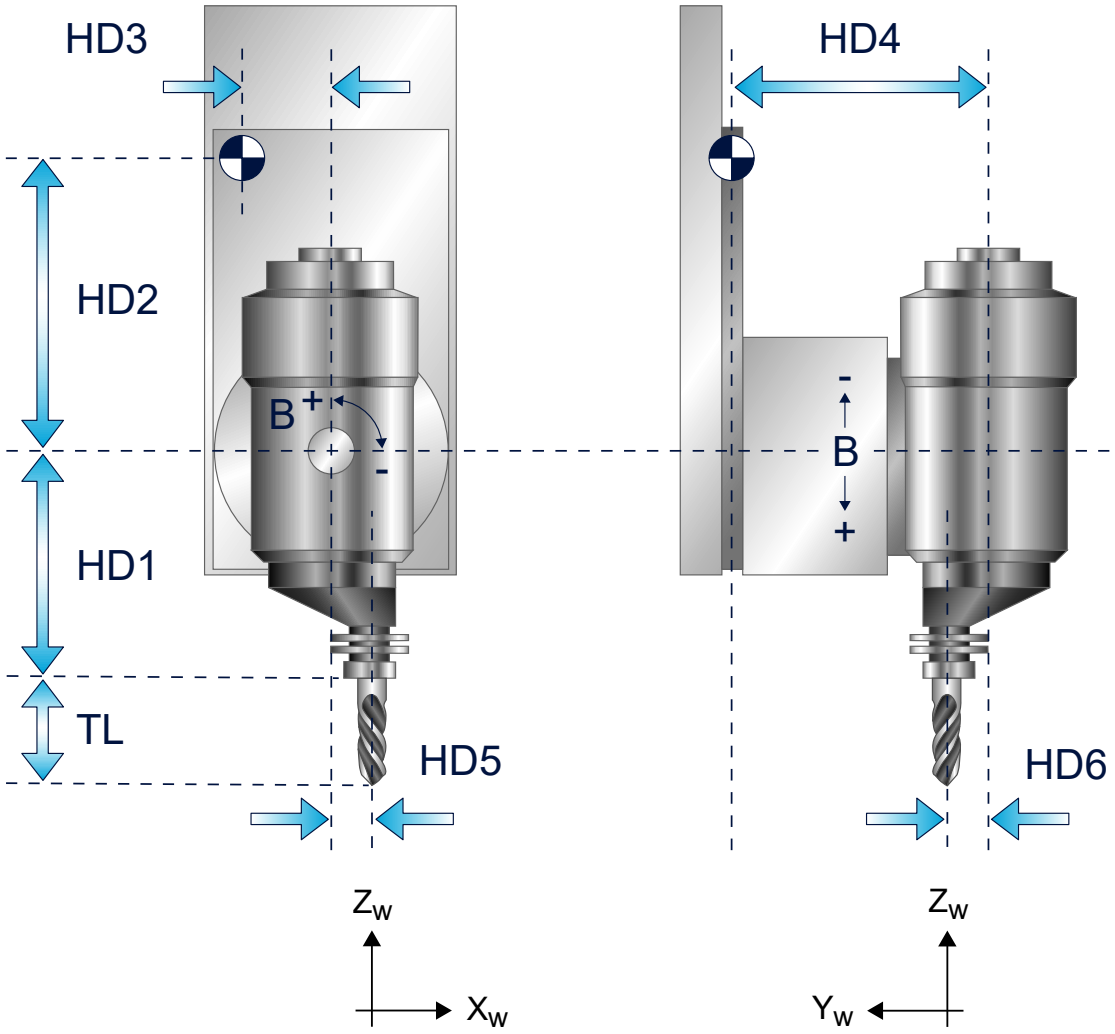


Fig. 5: Offsets in tool head

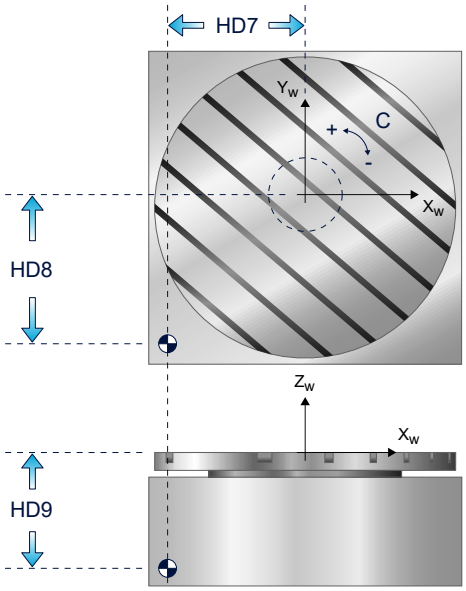


Fig. 6: Offsets on workpiece holder

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset tool holding device to rotation point B axis	1.0 E-4 mm
HD2	1	Z offset rotation point B-axis to reference point tool slide	1.0 E-4 mm
HD3	2	X offset reference point tool slide to rotation point B axis	1.0 E-4 mm
HD4	3	Y offset reference point tool slide to rotation point B axis	1.0 E-4 mm
HD5	4	X offset rotation point B axis to tool holding device	1.0 E-4 mm
HD6	5	Y offset rotation point B axis to tool holding device	1.0 E-4 mm
HD7	6	X offset machine origin MZP to rotary axis C	1.0 E-4 mm
HD8	7	Y offset machine origin MZP to rotary axis C	1.0 E-4 mm
HD9	8	Z offset machine origin MZP to rotary axis C	1.0 E-4 mm
HD10	9	Rotary offset rotary axis B	1.0 E-4 mm
HD11	10	Rotary offset rotary axis C	1.0 E-4 mm
HD13	12	Rotation direction B axis (*), 0: negative, 1positive	[-]
HD14	13	Rotation direction C axis, 0 positive, 1 negative	[-]

(*) The rotation direction of the B axis is mathematically negative.

2.2 KIN_TYP_2 – 5-axis kinematics with rotary/swivel head

Kinematic structure

The kinematic structure of this machine consists of 3 translatory axes and 2 rotary axes in the tool (rotary/swivel head).

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, B	-

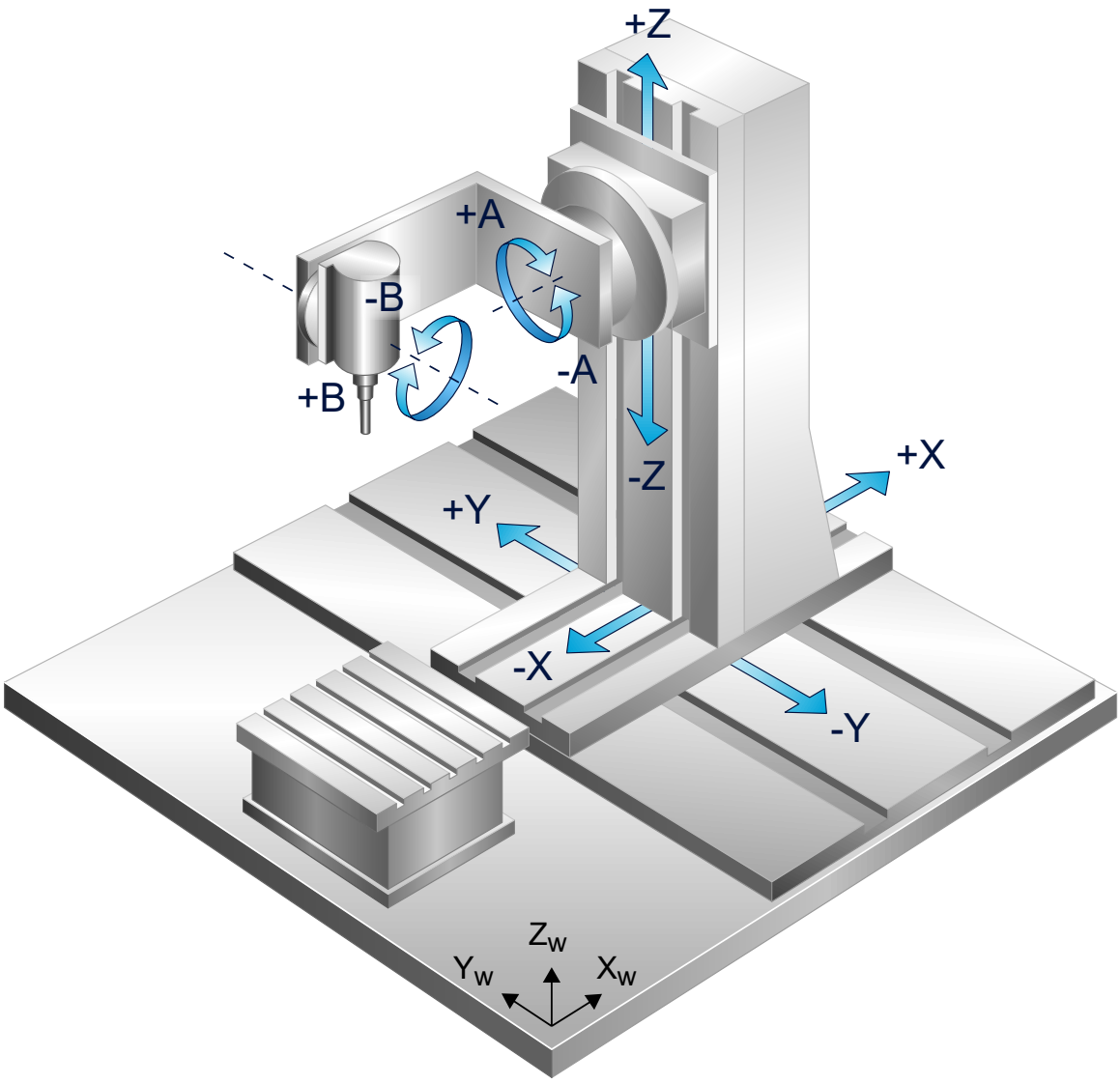


Fig. 7: Kinematics of the 5-axis milling machine with rotary/swivel head

The geometry constants HD1, HD2 and HD3 are required to describe the rotary/swivel head of the machine in the figure above. The figure below shows their application. The rotary/swivel head is shown in top view.

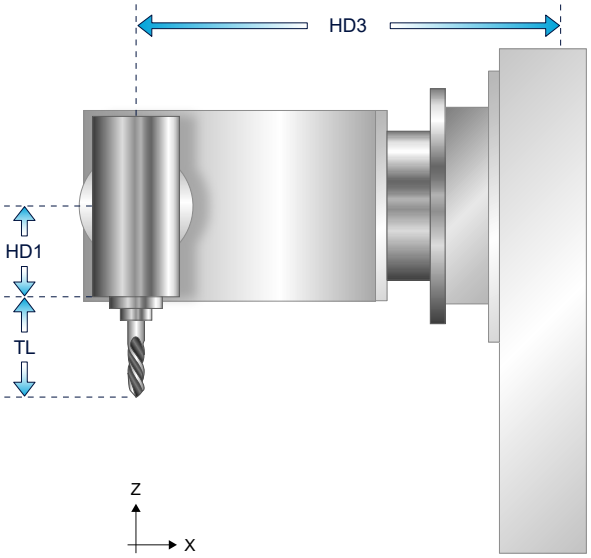


Fig. 8: Sizes L, TX, HD1, HD2 and HD3 of the rotary/swivel head

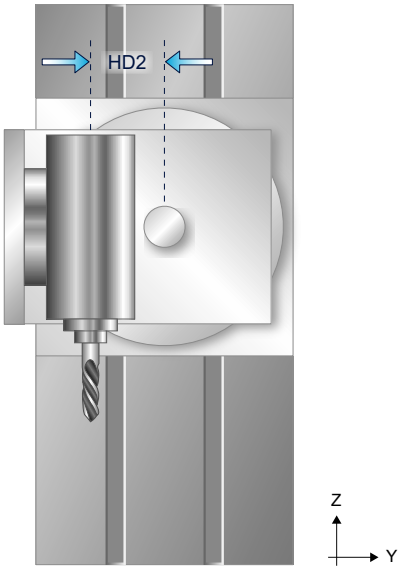


Fig. 9: Front view

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Offset tool holding device to rotation point B axis	1.0 E-4 mm
HD2	1	Y offset from B axis to A axis	1.0 E-4 mm
HD3	2	X offset from B axis to A axis	1.0 E-4 mm

2.3 KIN_TYP_3 - four-axis kinematics with double spindle head (top spindle)

Kinematic structure

The kinematic structure of the machine consists of 3 translatory axes and 1 rotary axis in the tool (double spindle head).

The KIN_TYP_4 selects the bottom spindle.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, B	-

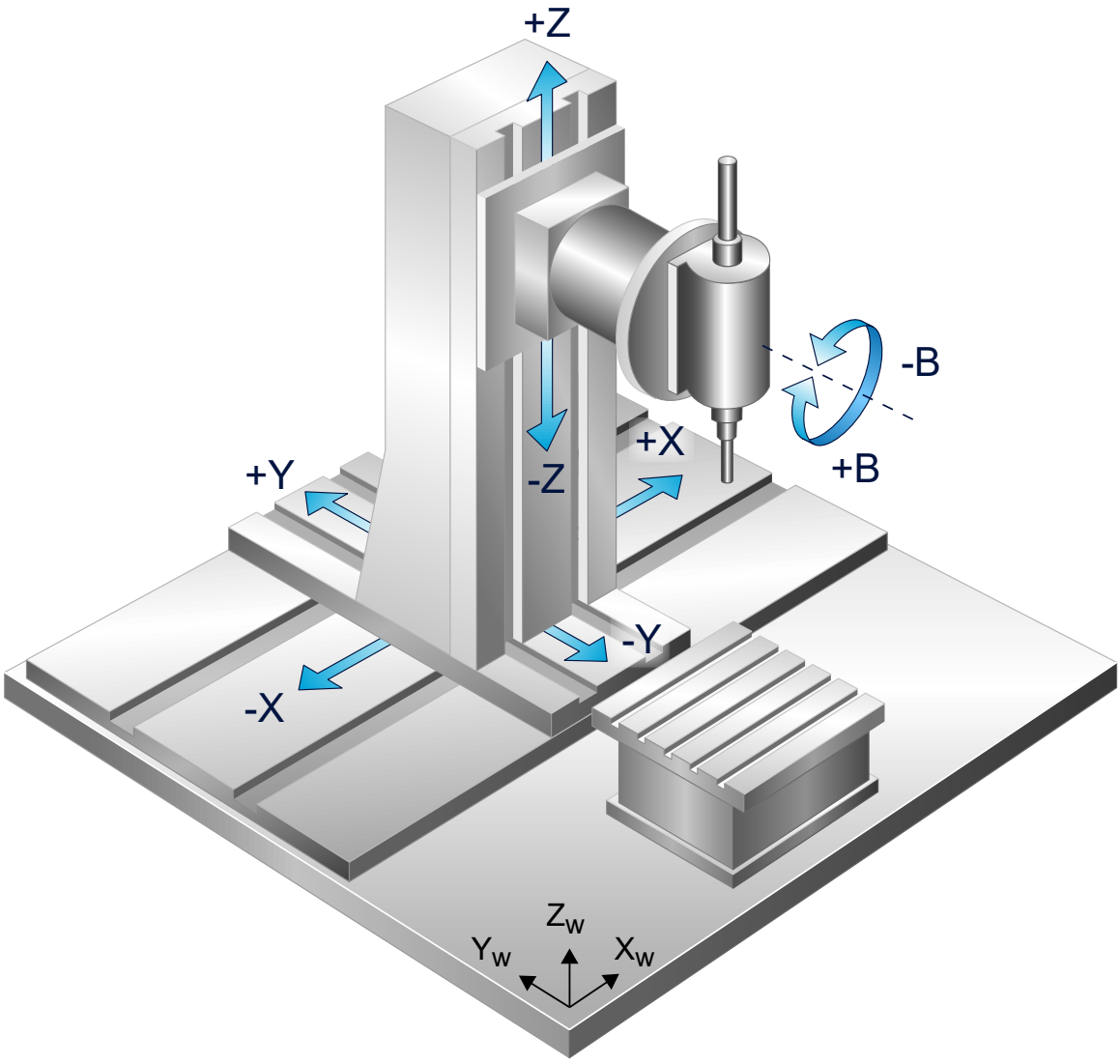


Fig. 10: Kinematic structure of the 4-axis milling machine with double spindle head

The top figure shows the structure of the milling head for the zero position of the B axis. It features 2 spindles (referred to in this document as *top* and *bottom* spindle irrespective of the current position of the B axis) so that 2 tools can be clamped rotated by 180° relative to each other.

A command in the NC program allows selection of the two spindles or which of the 2 tools is currently active.

If the top spindle is active, the programmed value for the B axis must be changed as follows:

$b_M=b_M+180°$

Thus, changing spindles means rotating the B axis through an angle of 180° and translatory shifts of all 3 linear axes. This is due to the geometry constants when RTCP is active.

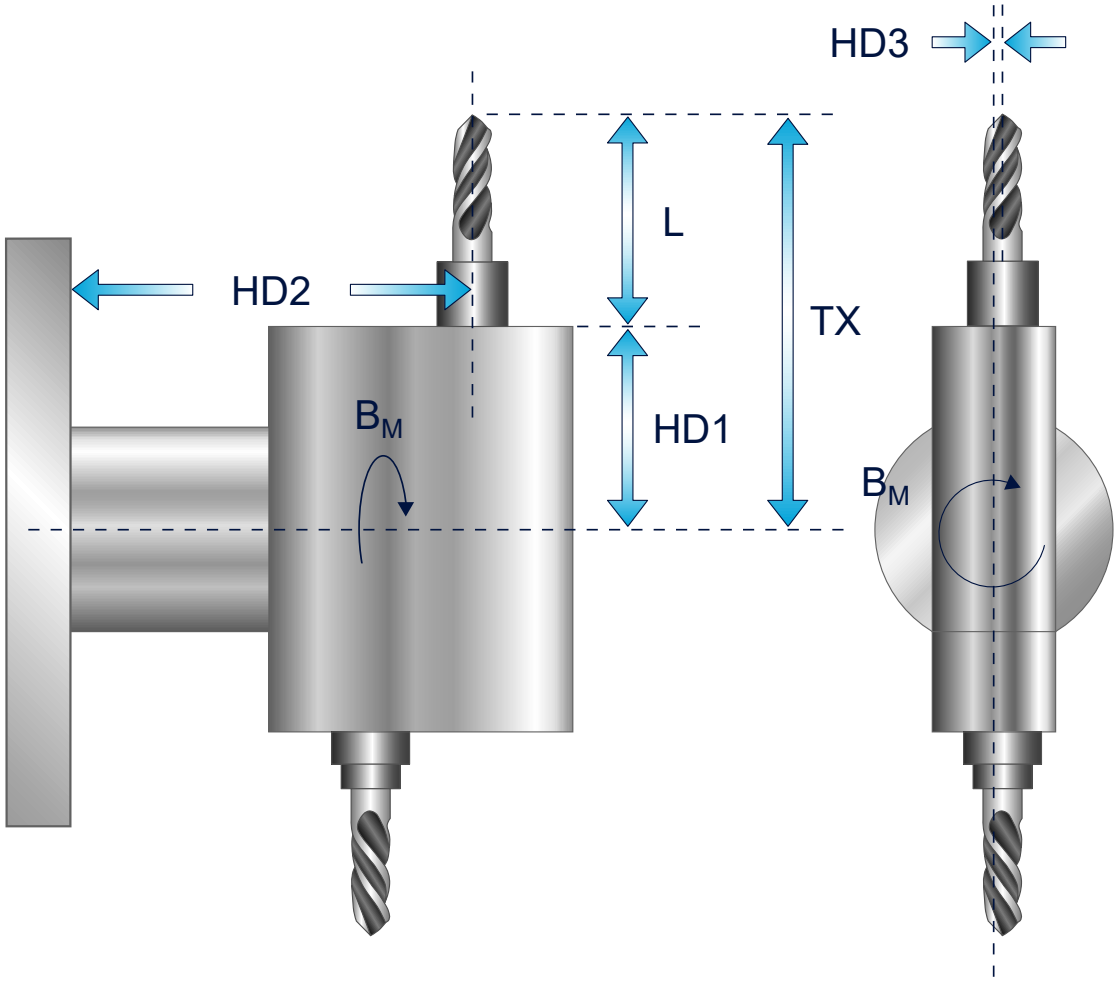


Fig. 11: Side view and front view of the double spindle head (upper spindle)

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Offset tool holding device to rotation point B axis	1.0 E-4 mm
HD2	1	Y offset tool head	1.0 E-4 mm
HD3	2	X offset from tool holding device to B axis	1.0 E-4 mm

2.4 KIN_TYP_4 - four-axis kinematics with double spindle head (top spindle)

Kinematic structure

The kinematic structure of the machine consists of 3 translatory axes and 1 rotary axis in the tool (double spindle head).

The KIN_TYP_3 selects the top spindle.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, B	-

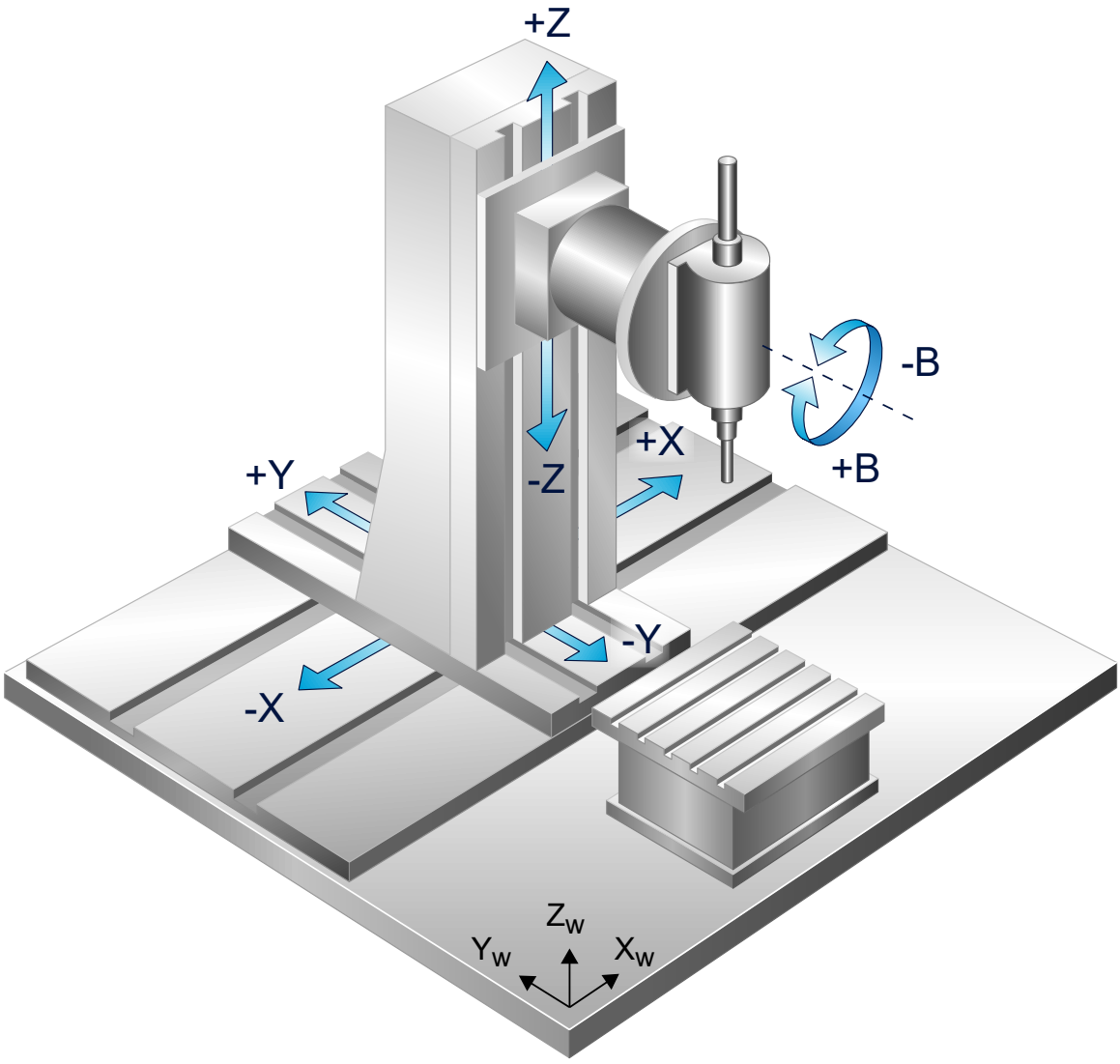


Fig. 12: Kinematic structure of the 4-axis milling machine with double spindle head

The top figure shows the structure of the milling head for the zero position of the B axis. It features 2 spindles (referred to in this document as *top* and *bottom* spindle irrespective of the current position of the B axis) so that 2 tools can be clamped rotated by 180° relative to each other.

A command in the NC program allows selection of the two spindles or which of the 2 tools is currently active.

If the top spindle is active, the programmed value for the B axis must be changed as follows:

$b_M=b_M+180°$

Thus, changing spindles means rotating the B axis through an angle of 180° and translatory shifts of all 3 linear axes. This is due to the geometry constants when RTCP is active.

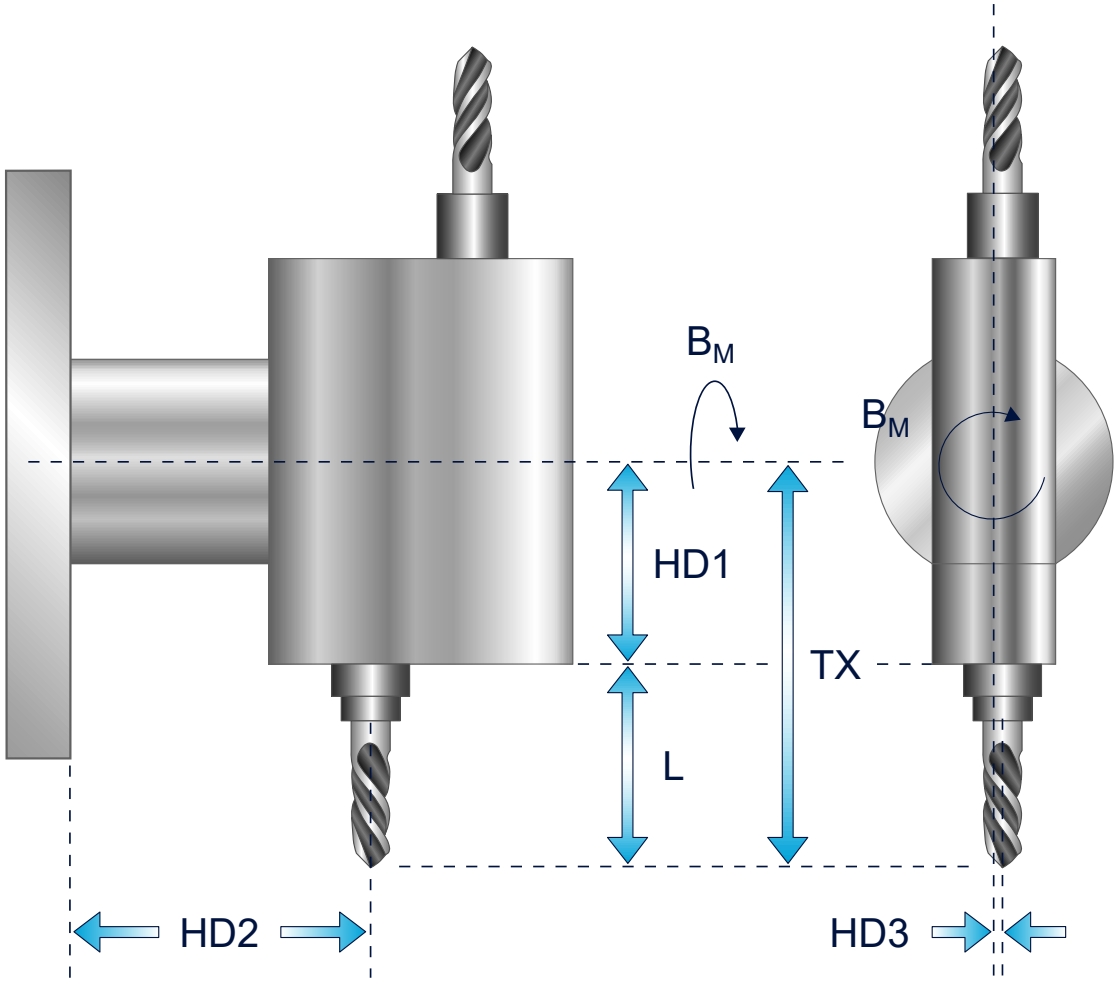


Fig. 13: Side view and front view of the double spindle head (bottom spindle)

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Offset tool holding device to rotation point B axis	1.0 E-4 mm
HD2	1	Y offset tool head	1.0 E-4 mm
HD3	2	X offset from tool holding device to B axis	1.0 E-4 mm

2.5 KIN_TYP_5 – 4-axis kinematics with crosshead for 4 tools

Kinematic structure

The kinematic structure consists of 3 translatory axes and 1 rotary axis in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C	-

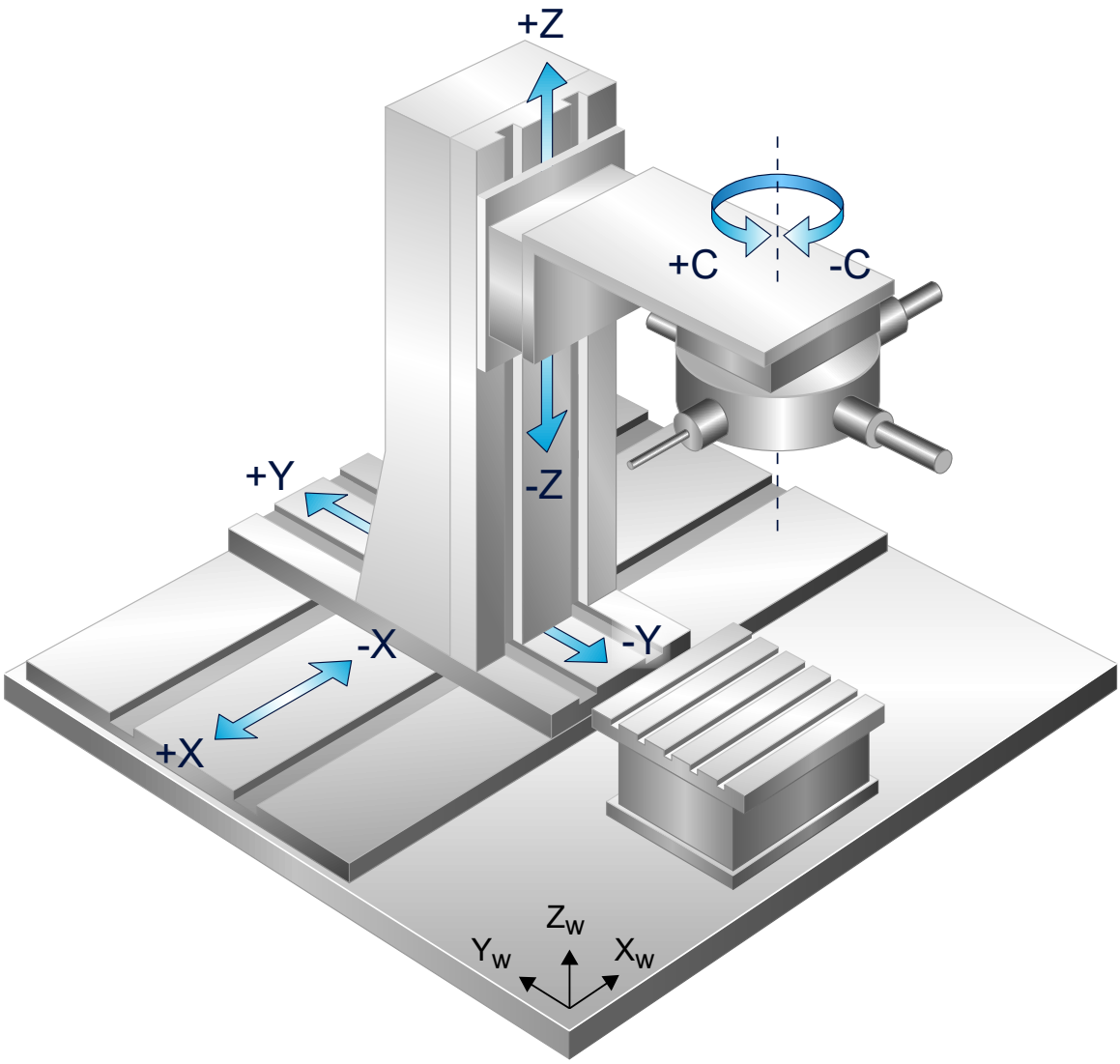


Fig. 14: 4-axis kinematics with crosshead for 4 tools

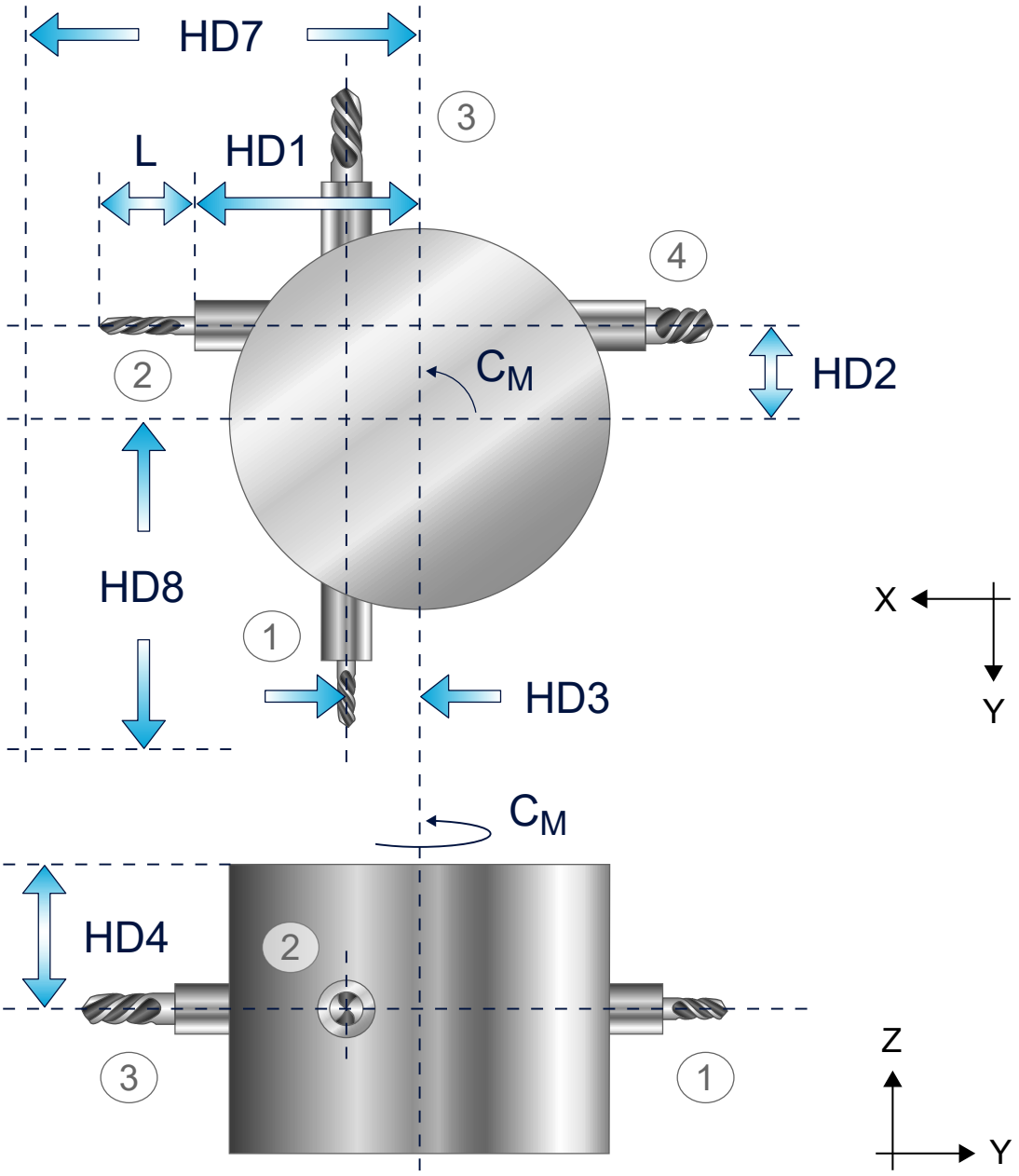


Fig. 15: Tool crosshead

The tool that is currently active is specified by assigning tool offset HD5 to the C axis. HD5 is calculated positively from the zero position of the C axis (Y axis) in the direction of the tool position.

If the 4 tools are arranged at right angles to each other as shown in the figure above, changing spindles results in a rotation of the C axis through 90° or 180° and translatory shifts of the X axis and Y axis. This is due to the geometry constants when RTCP is active.

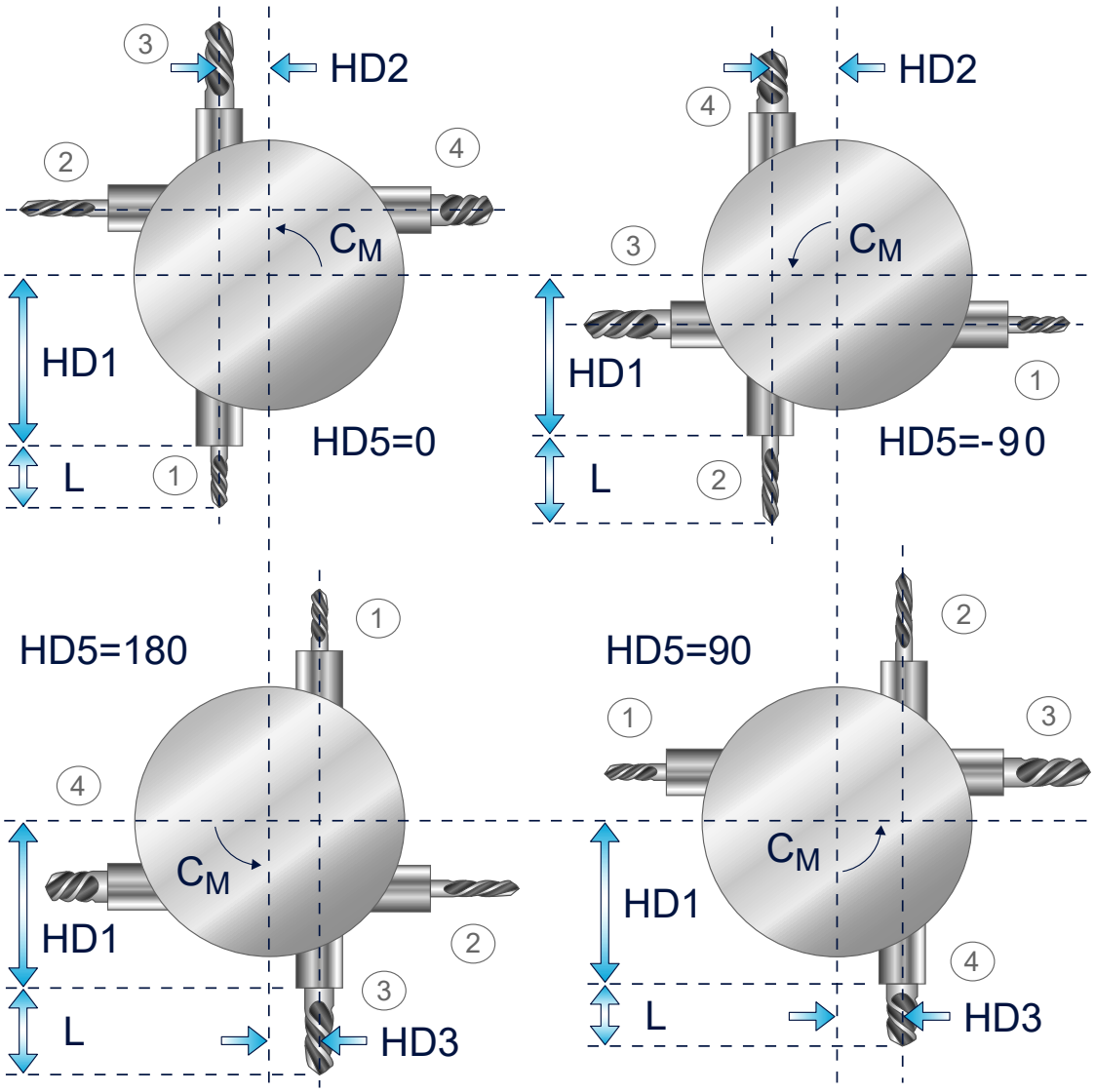


Fig. 16: Tool crosshead with zero positions of the tools 1 to 4

Notice

A data record containing head parameters must be kept for each head tool. The related tool head data record is used to select one of the tools 1 to 4.

To measure the head offsets of the individual tools, the related tool is rotated and brought to zero position of tool 1 (positive Y direction).

Besides the uniform head parameters HD1, HD4, HD5, head parameter HD2 is used for tools 1 and 2 and head parameter HD3 for tools 3 and 4.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Offset tool holding device to reference point	1.0 E-4 mm
HD2	1	Offset reference point rotation centre point C axis tool 1 and 2	1.0 E-4 mm
HD3	2	Offset reference point rotation centre point C axis tool 3 and 4	1.0 E-4 mm
HD4	3	Z axis offset tool holding device	1.0 E-4 mm
HD5	4	Rotary angular offset C axis zero position	1.0 E-4°
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm

2.6 KIN_TYP_6 – 4-axis kinematics with underfloor milling tool

Kinematic structure

The kinematic structure consists of 3 translatory axes and 1 rotary axis in the tool. A special feature of this kinematic structure is that the tool points in the positive Z direction.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C	-

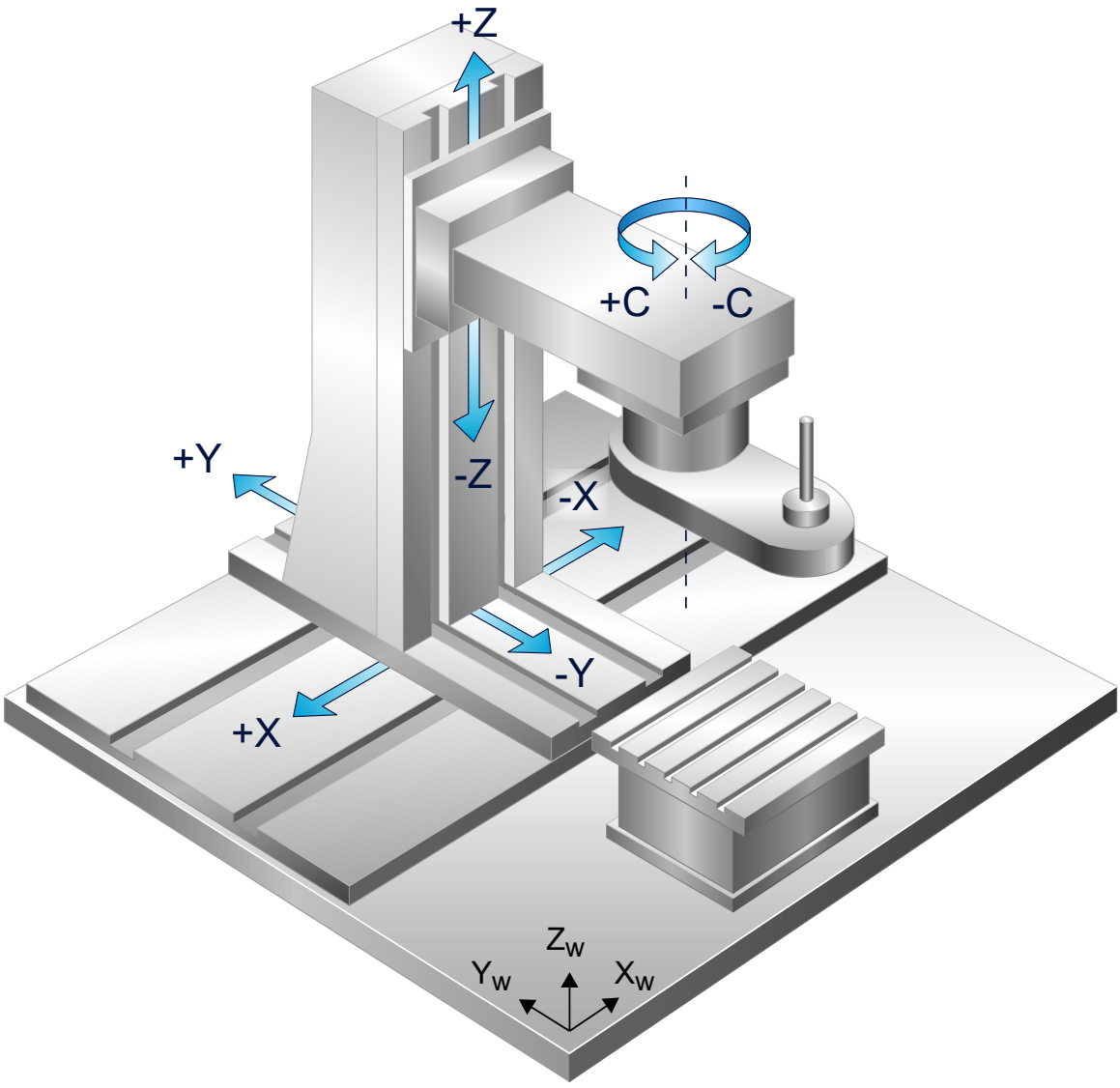


Fig. 17: 4-axis kinematics with underfloor milling tool

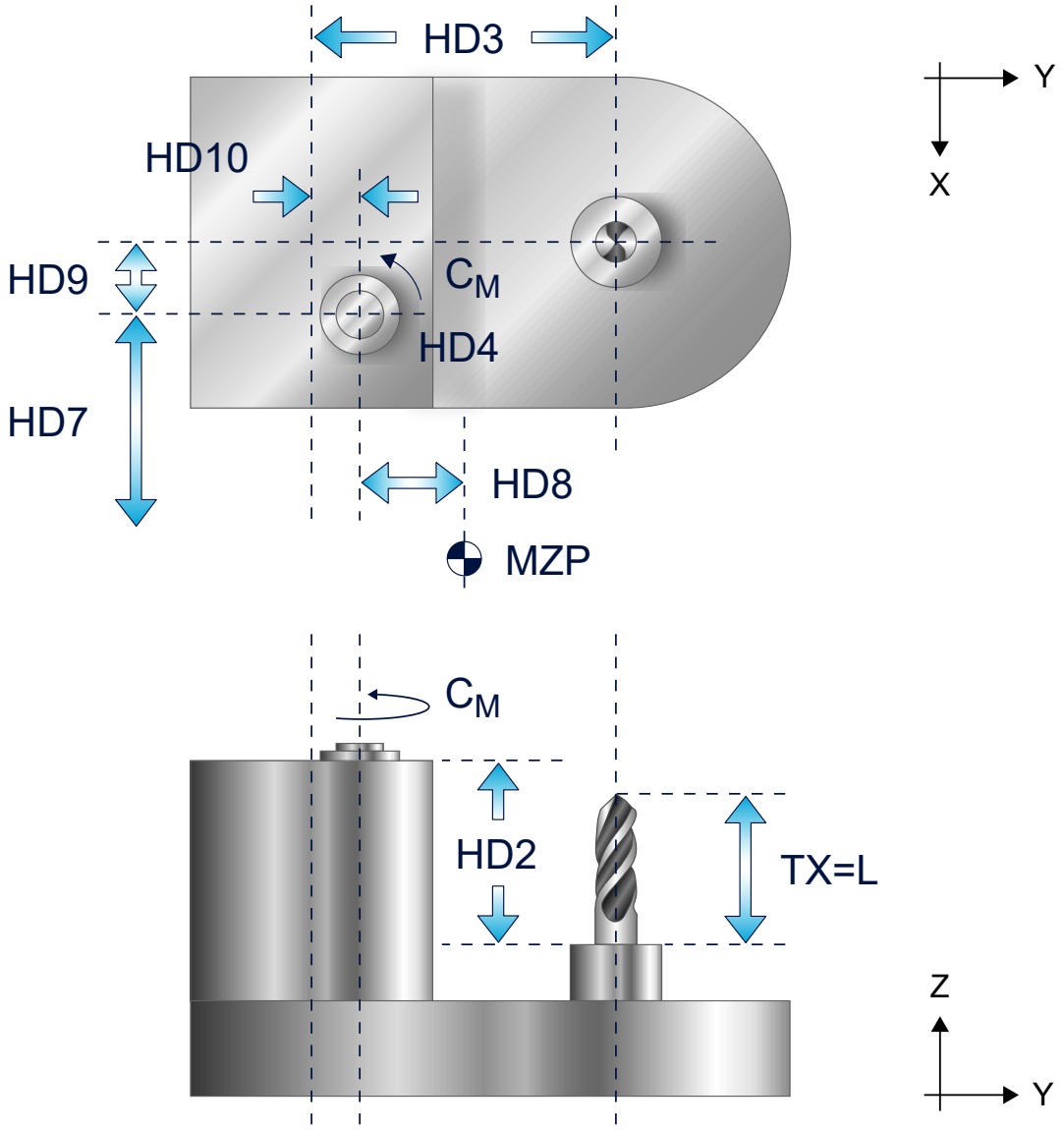


Fig. 18: Tool head for underfloor milling (zero position where HD4 = 0)

The axes are arranged as for a right-handed system. The zero position of the C axis is in the positive direction of the Y axis.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD2	1	Z axis offset tool holding device	1.0 E-4 mm
HD3	2	Y axis offset rotary axis C axis to tool rotary axis	1.0 E-4 mm
HD4	3	Rotary angular offset C axis zero position	1.0 E-4°
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm
HD9	8	X axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm
HD10	9	Y axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm

2.7 KIN_TYP_7 – 5-axis kinematics with man. auxiliary axis (drilling)

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 1 rotary NC axis in the tool. In addition, a manually adjustable rotary 5th axis is available. This fifth axis cannot be addressed from the NC program.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, C	-
Auxiliary axes	A	-

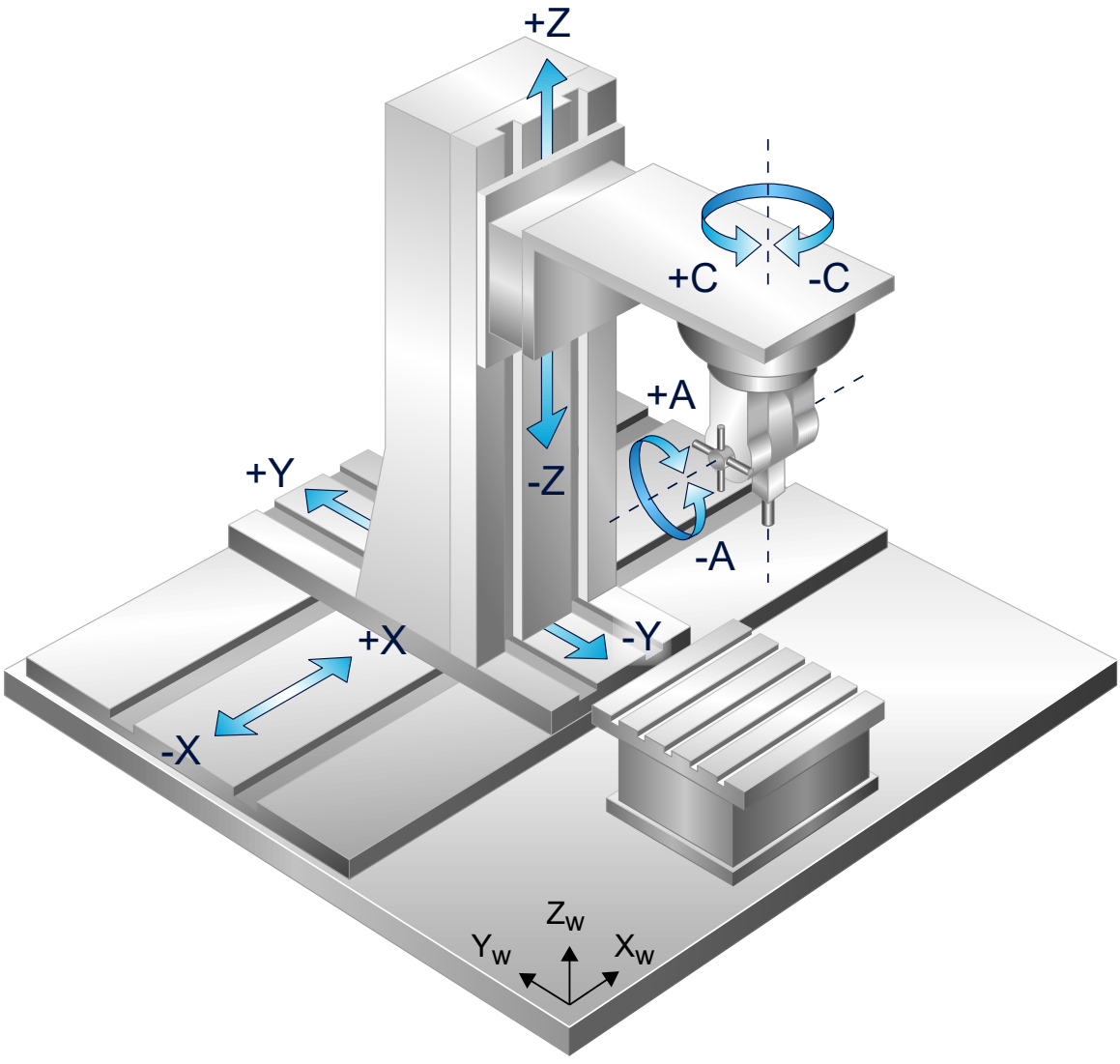


Fig. 19: 5-axis kinematics (boring and milling tool with manual auxiliary axis A)

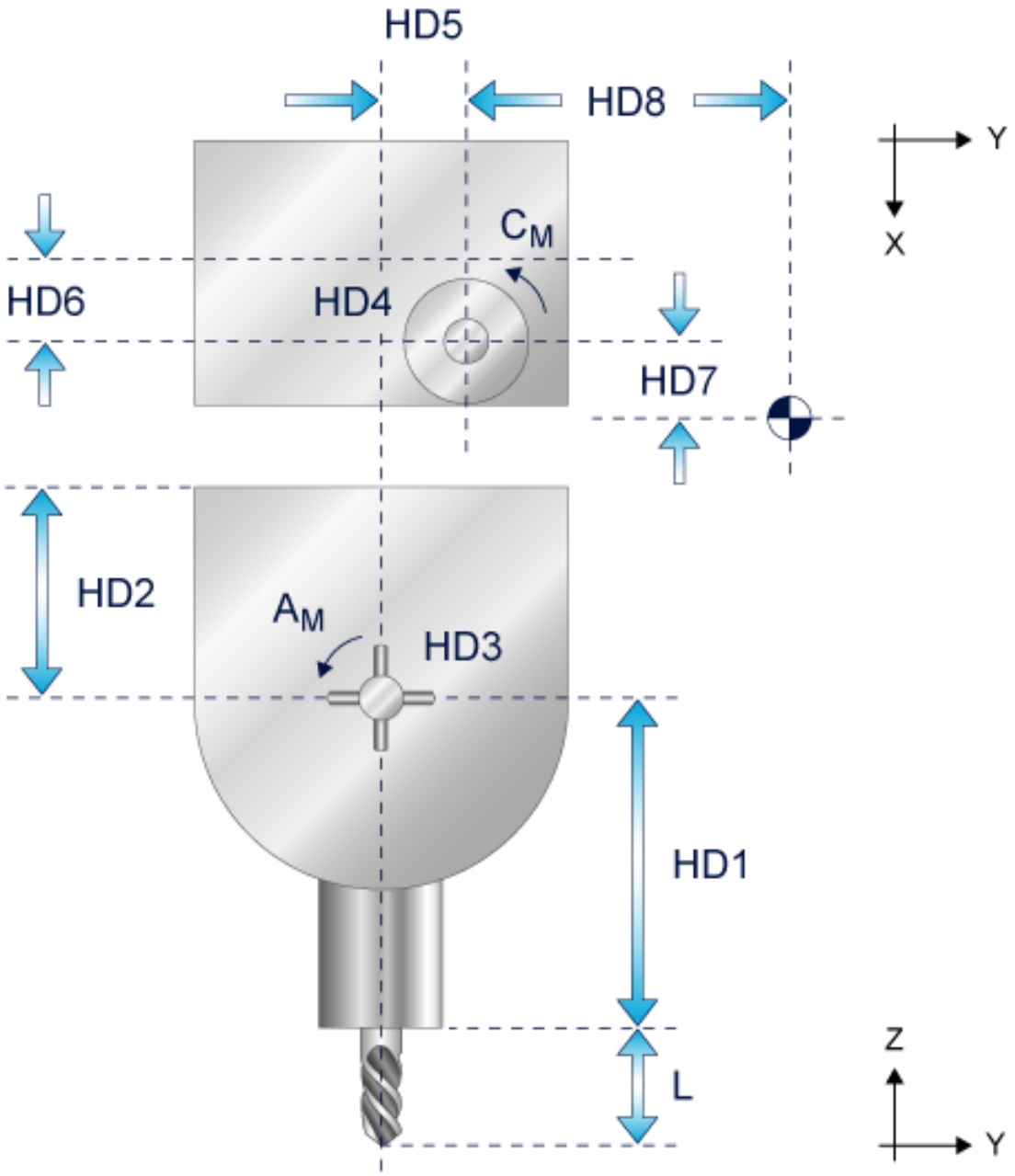


Fig. 20: 5-axis boring and milling tool (zero position where HD3=0, HD4=0, CM=0)

The axes are arranged as for a right-handed system. The zero position of the A axis is in the negative direction of the Z axis.

The automatic orientation setting of the 5-axis tool head with manually adjustable A axis depends on the position of the A axis. If the physical machine axis position and the value in the HD parameter of the A axis do not match, no correct automatic alignment is possible.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset tool holding device to rotation point of A axis (swivel axis)	1.0 E-4 mm
HD2	1	Z axis offset rotation point A axis to tool head reference point	1.0 E-4 mm
HD3	2	Fixed angle setting of rotary A axis (swivel axis)	1.0 E-4°
HD4	3	Angular offset tool to C axis zero position	1.0 E-4°
HD5	4	Y axis offset rotation point A axis to rotation point C axis (offset)	1.0 E-4 mm
HD6	5	X axis offset tool head reference point to rotation point C axis (offset)	1.0 E-4 mm
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm

2.8 KIN_TYP_8 – 5-axis kinematics with man. auxiliary axis (sawing)

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 1 rotary NC axis in the tool. A manually adjustable rotary 5th axis continues to be available. This axis cannot be addressed from the NC program.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, C	-
Auxiliary axes	A	-

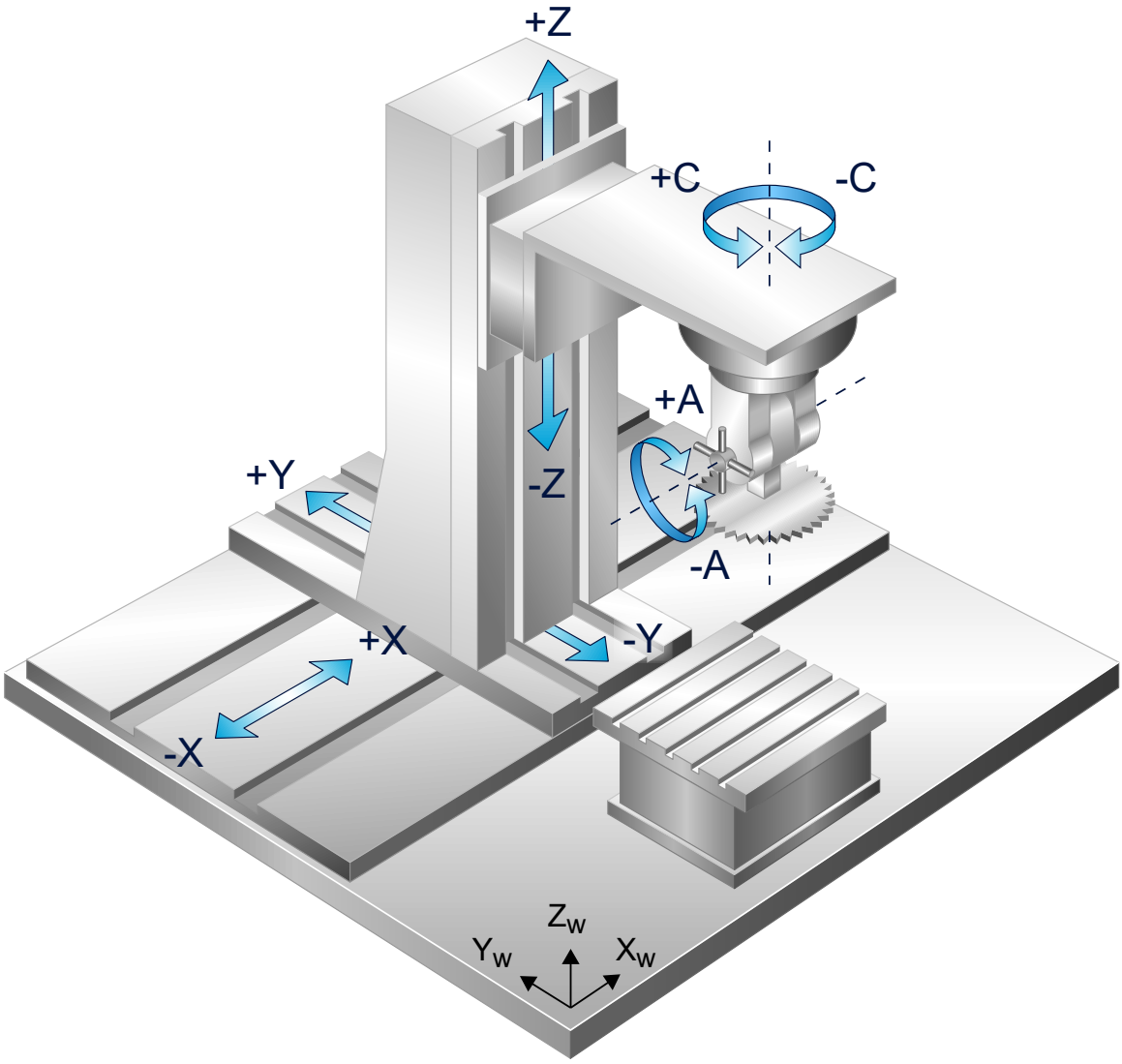


Fig. 21: 5-axis kinematics (sawing tool with manual auxiliary axis A)

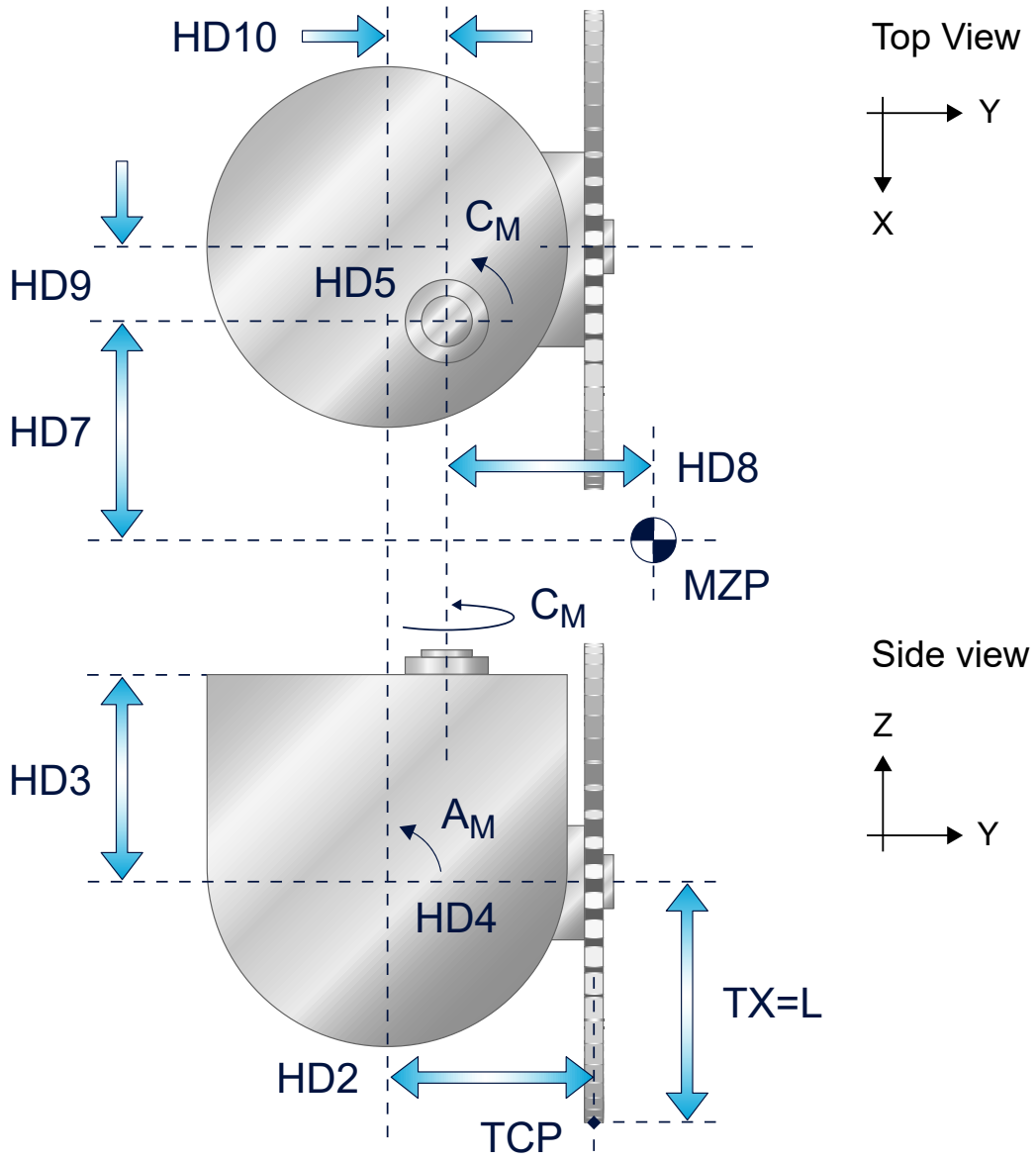


Fig. 22: 5-axis sawing tool (zero position where HD5 = 0, HD4 = +90,CM=0)

The automatic orientation setting of the 5-axis tool head with manually adjustable A axis depends on the position of the A axis.

If the physical machine axis position and the value in the HD parameter of the A axis do not match, no correct automatic alignment is possible.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD2	1	Y axis offset from tool holding device to rotation point A axis (swivel axis)	1.0 E-4 mm
HD3	2	Z axis offset from rotation point A axis to tool reference point	1.0 E-4 mm
HD4	3	Fixed angle setting of rotary A axis (swivel axis)	1.0 E-4°
HD5	4	Rotary angular offset C axis	1.0 E-4°
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm
HD9	8	X axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm
HD10	9	Y axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm

2.9 KIN_TYP_9 – 5-axis kinematics (boring and milling unit)

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 2 rotary NC axes in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C, A	-

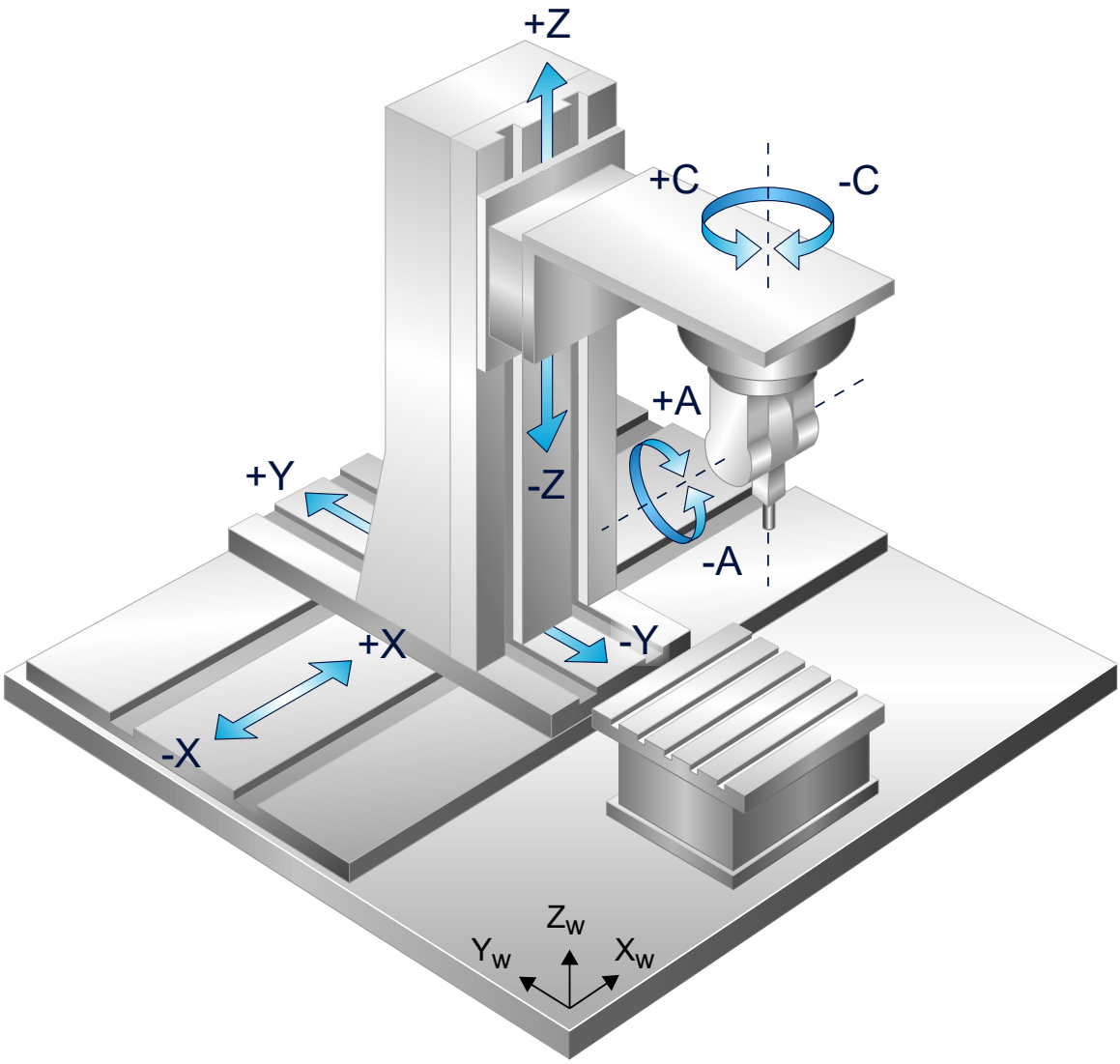


Fig. 23: 5-axis kinematics (boring and milling unit)

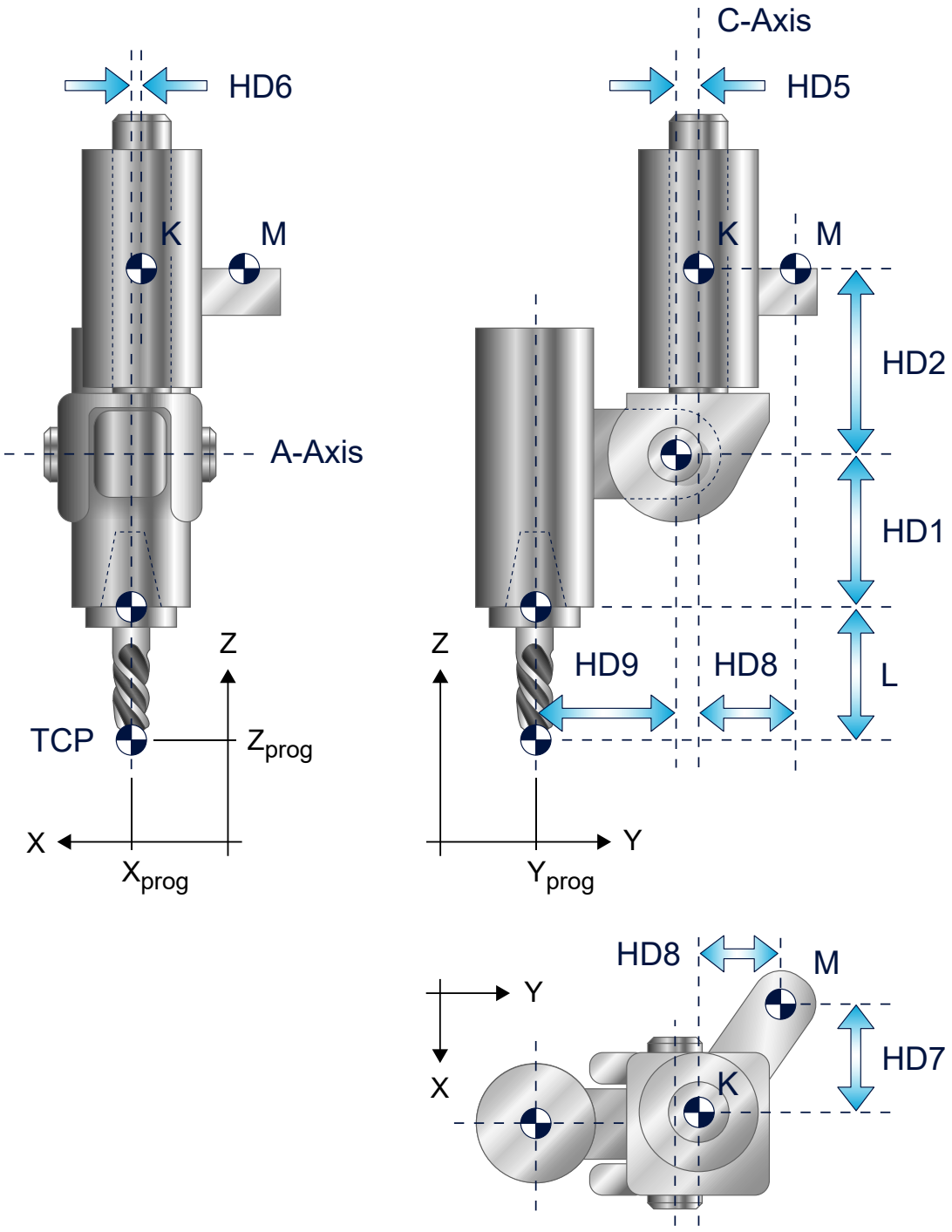


Fig. 24: 5-axis boring and milling tool (zero position where HD3 = 0, AM=0, HD4=0, CM=0)

The M and K points in the figure above are two reference points

(**M**)achine reference point and (**K**)inematic reference point

The ACS offset between the points M and K is a static offset, i.e. it is independent of the angular position of the rotary axes C, A.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset from tool holding device to rotation point A axis (swivel axis)	1.0 E-4 mm
HD2	1	Z axis offset rotary axis A to tool head reference point	1.0 E-4 mm
HD3	2	Rotary angular offset A axis (default 0)	1.0 E-4°
HD4	3	Rotary angular offset C axis (default 0)	1.0 E-4°
HD5	4	Y axis offset rotation point C axis	1.0 E-4 mm
HD6	5	X axis offset rotation point C axis	1.0 E-4 mm
HD7	6	Static head offset in X (default 0)	1.0 E-4 mm
HD8	7	Static head offset in Y (default 0)	1.0 E-4 mm
HD9	8	Y axis offset milling tool axis to rotation point A axis	1.0 E-4 mm

2.10 KIN_TYP_10 – 5-axis kinematics (sawing)

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 2 rotary NC axes in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C, A	-

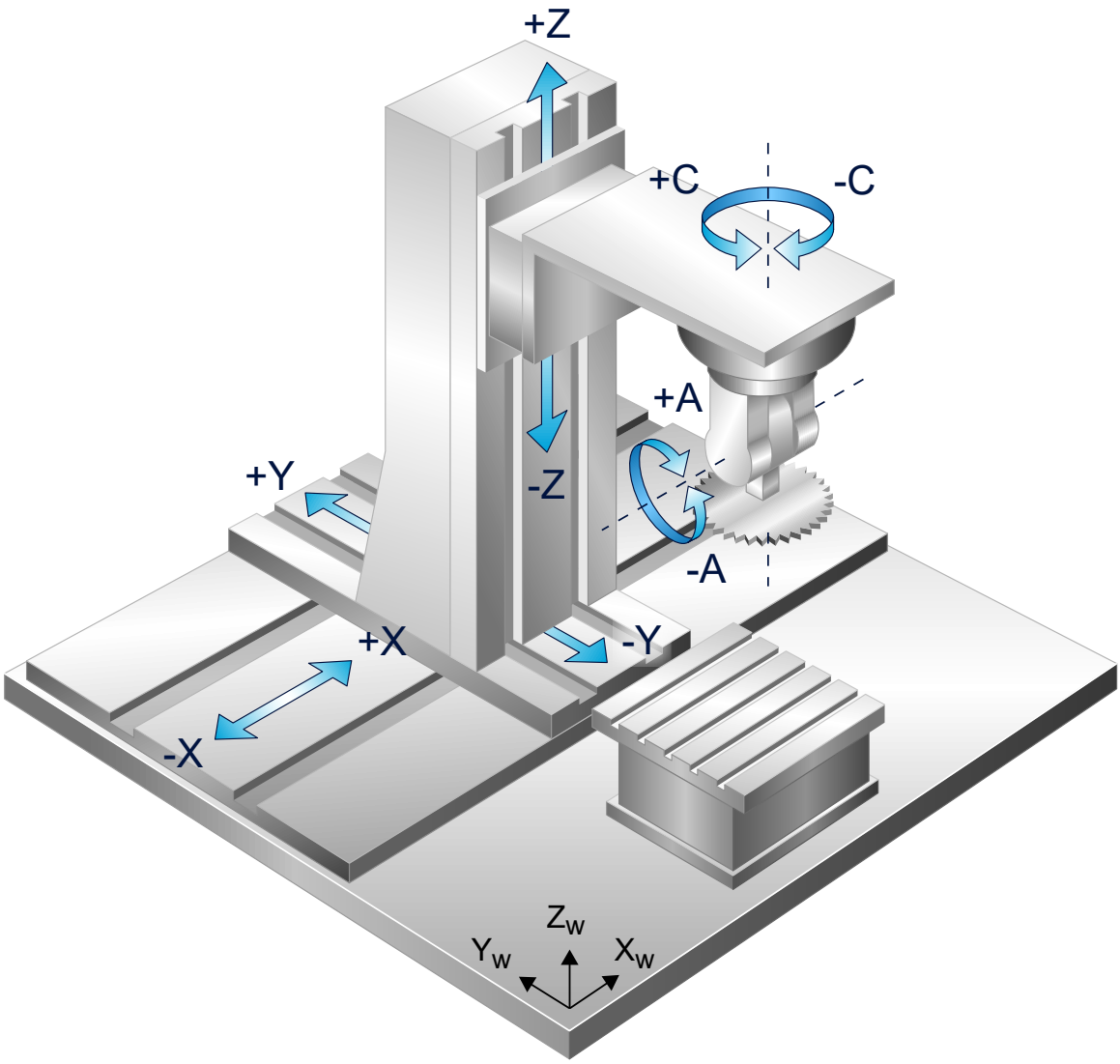


Fig. 25: 5-axis kinematics (sawing tool)

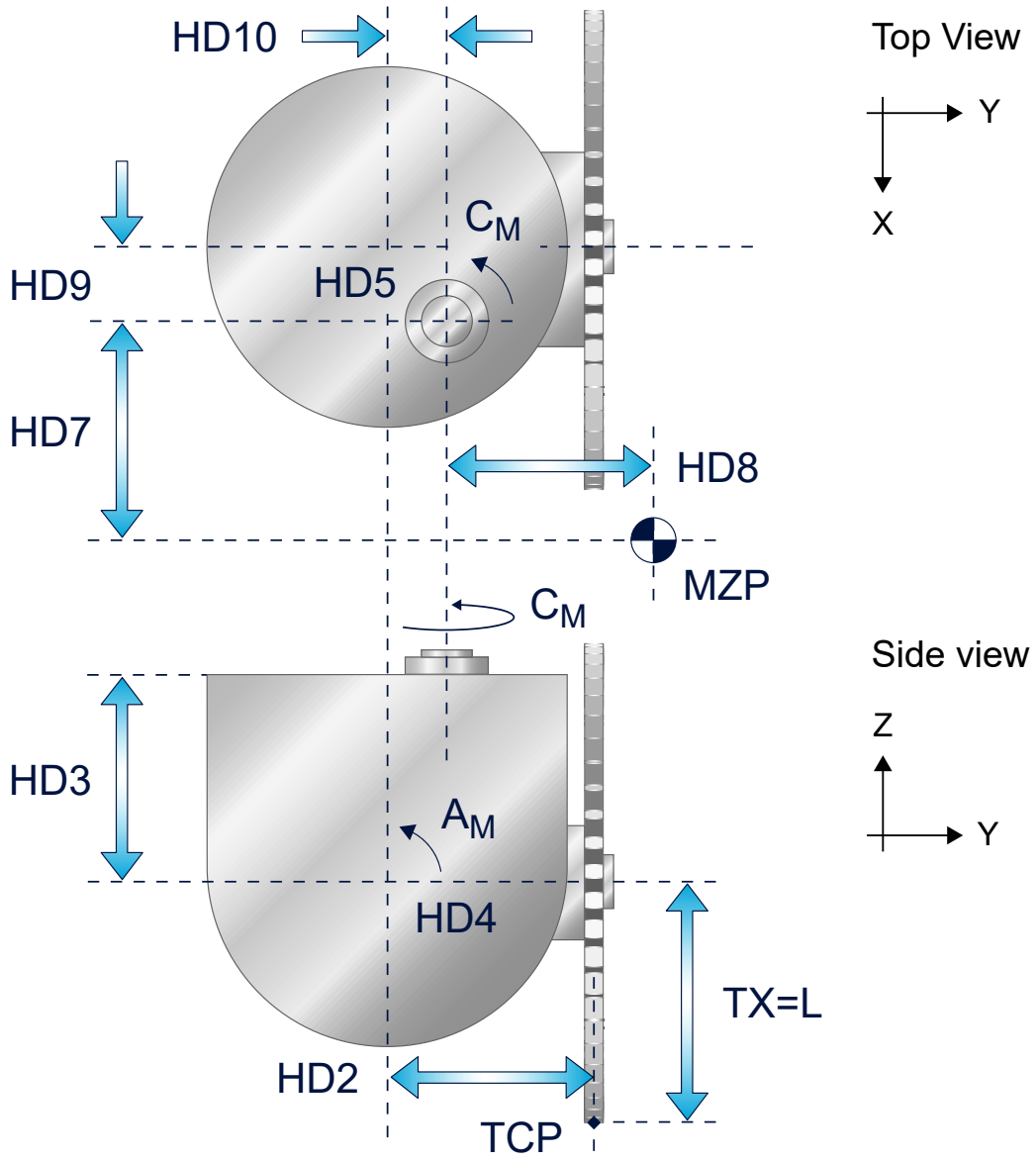


Fig. 26: 5-axis sawing tool (zero position where HD5 =0, CM=0, HD4 =0, AM =90)

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD2	1	Y axis offset from tool holding device to rotation point A axis (swivel axis)	1.0 E-4 mm
HD3	2	Z axis offset from rotation point A axis (swivel axis) to tool reference point	1.0 E-4 mm
HD4	3	Rotary angular offset A axis	1.0 E-4°
HD5	4	Rotary angular offset C axis	1.0 E-4°
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm
HD9	8	X axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm
HD10	9	Y axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm

2.11 KIN_TYP_11 – 5-axis kinematics with oblique tool head

Kinematic structure

The kinematic structure consists of 3 translatory Cartesian axes and 2 rotary axes. As a special feature the machine has an oblique B axis.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, B	Z, A

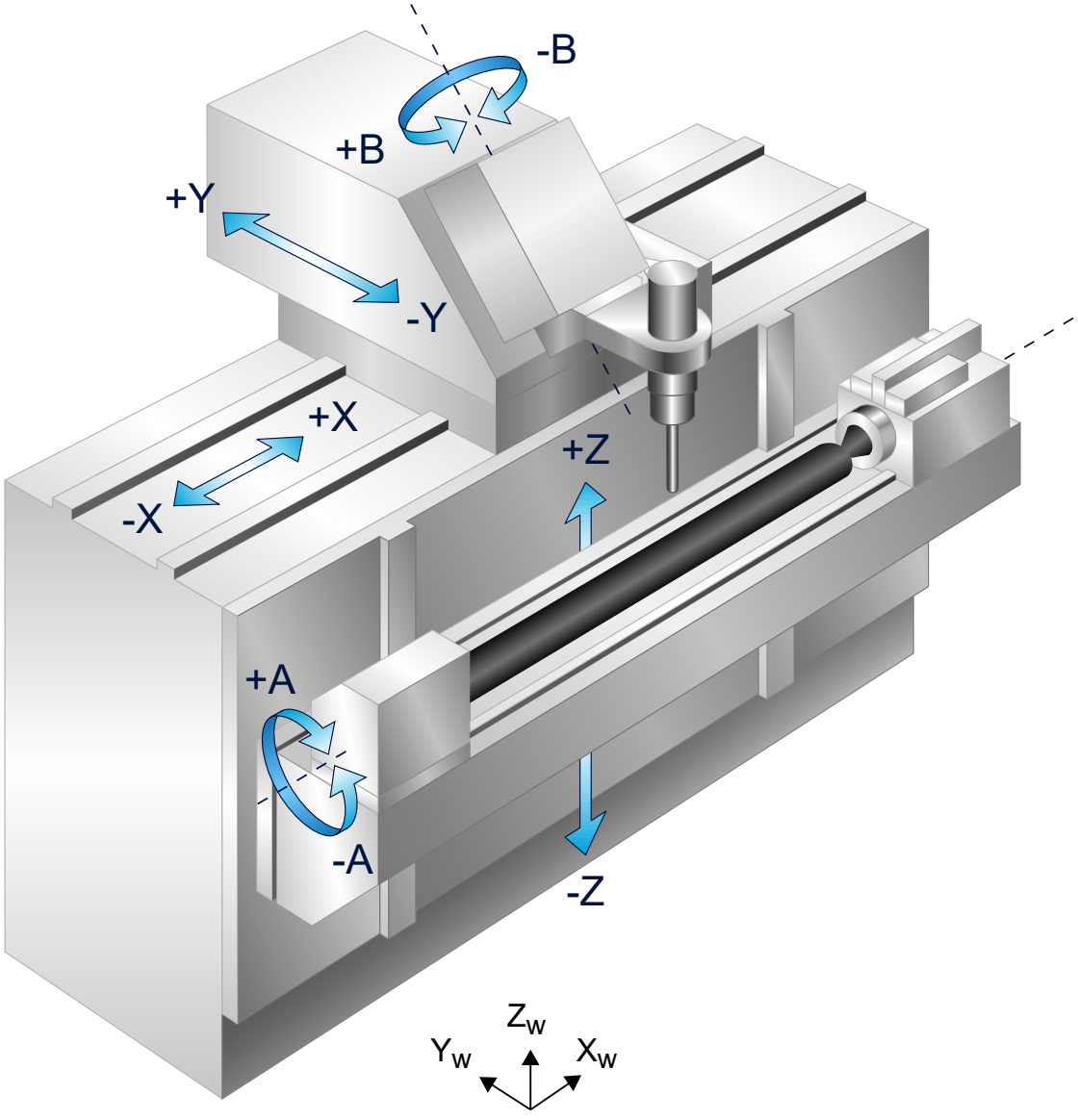


Fig. 27: Axis configuration of the 5-axis machine with oblique angle head

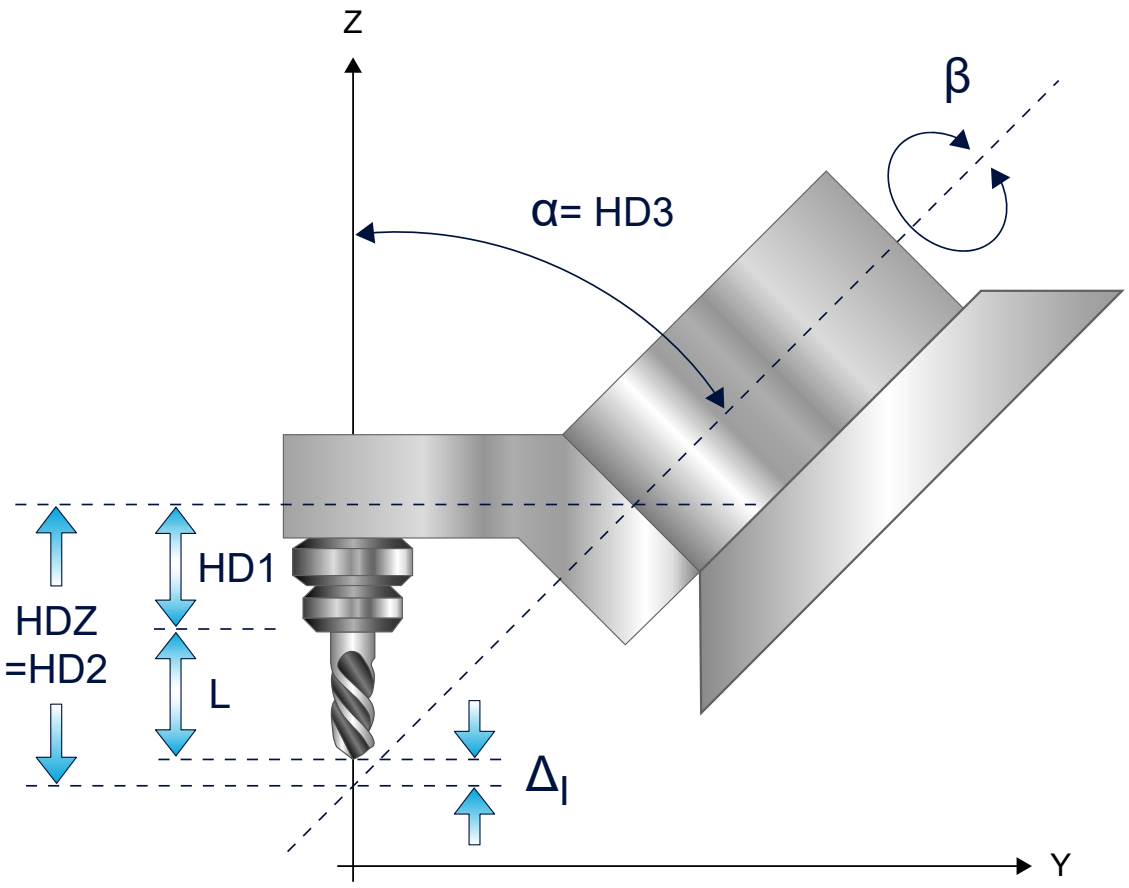


Fig. 28: Angles and lengths at the oblique angle head

The design of the oblique B axis is the most striking feature of the kinematic structure. If the tool length is selected such that the TCP (tool centre point) lies exactly on the extension of the B axis (tool offset HDZ), no compensation motions are required in the translatory axes when the tool orientation via the B axis changes (compensation motions due to changes in A axis orientation are always present). If the selected tool length is not ideal (i.e. if the TCP is not exactly on the extension of the B axis), there are minor additional compensation motions on the linear axes depending on the deviation from the ideal length.

Due to the particular design of the B axis, there can be no singular points in the backward transformation of the orientation axes. On the other hand, not all tool orientations can be selected (see below).

The zero positions of machine axes XM, YM, ZM are selected such that the fictitious extensions of AM and BM intersect. The zero position of BM is selected such that the tool is in a vertical position and, consequently, parallel to Z0 if BM=0 (The figure “Axis configuration of the 5-axis machine with oblique angle head” shows the zero position of BM). Expediently, the zero position of AM should be selected such that the Y0, Z0 workpiece axes run parallel to the directions of the machine axes.

HDZ represents the ideal tool length as geometry parameter of the machine kinematics; HD1 represents the first tool head parameter; L is the actual tool length (milling cutter length).

Please note that l is a signed value and may also be negative.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset tool holding device to tool head reference point	1.0 E-4 mm
HD2	1	Ideal tool length	1.0 E-4 mm
HD3	2	Angle between B axis and Z axis (oblique angle)	1.0 E-4°

2.12 KIN_TYP_12 – Tripod kinematics

Kinematic structure

The strut kinematic structure (referred to as “tripod”) consists of 3 translatory axes in a non-Cartesian arrangement. Strut pairs parallel to each other carry the tool holder platform. Tool orientation is constant.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z (Z1, Z2, Z3)	
Axis index	0, 1, 2	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	-

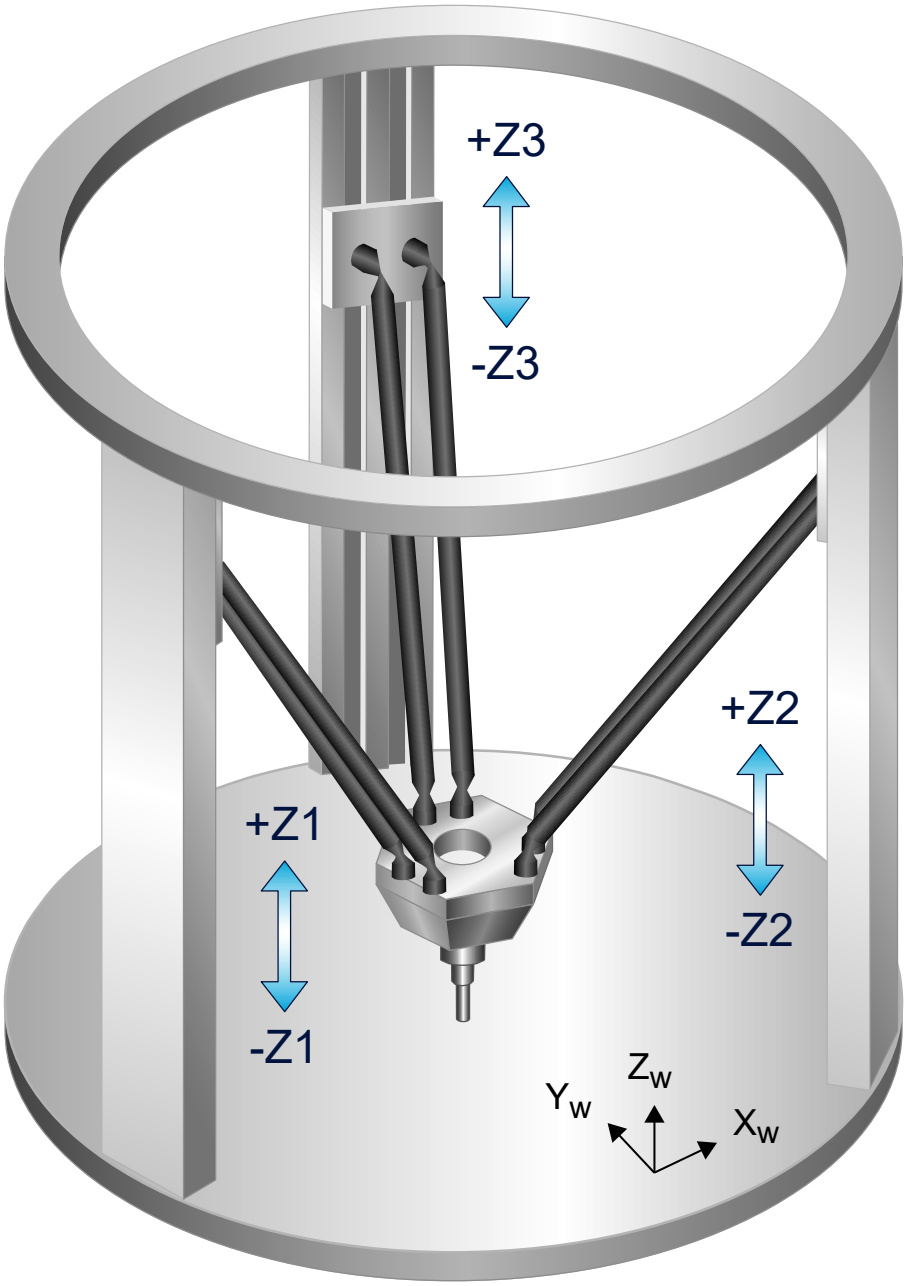


Fig. 29: Tripod kinematics

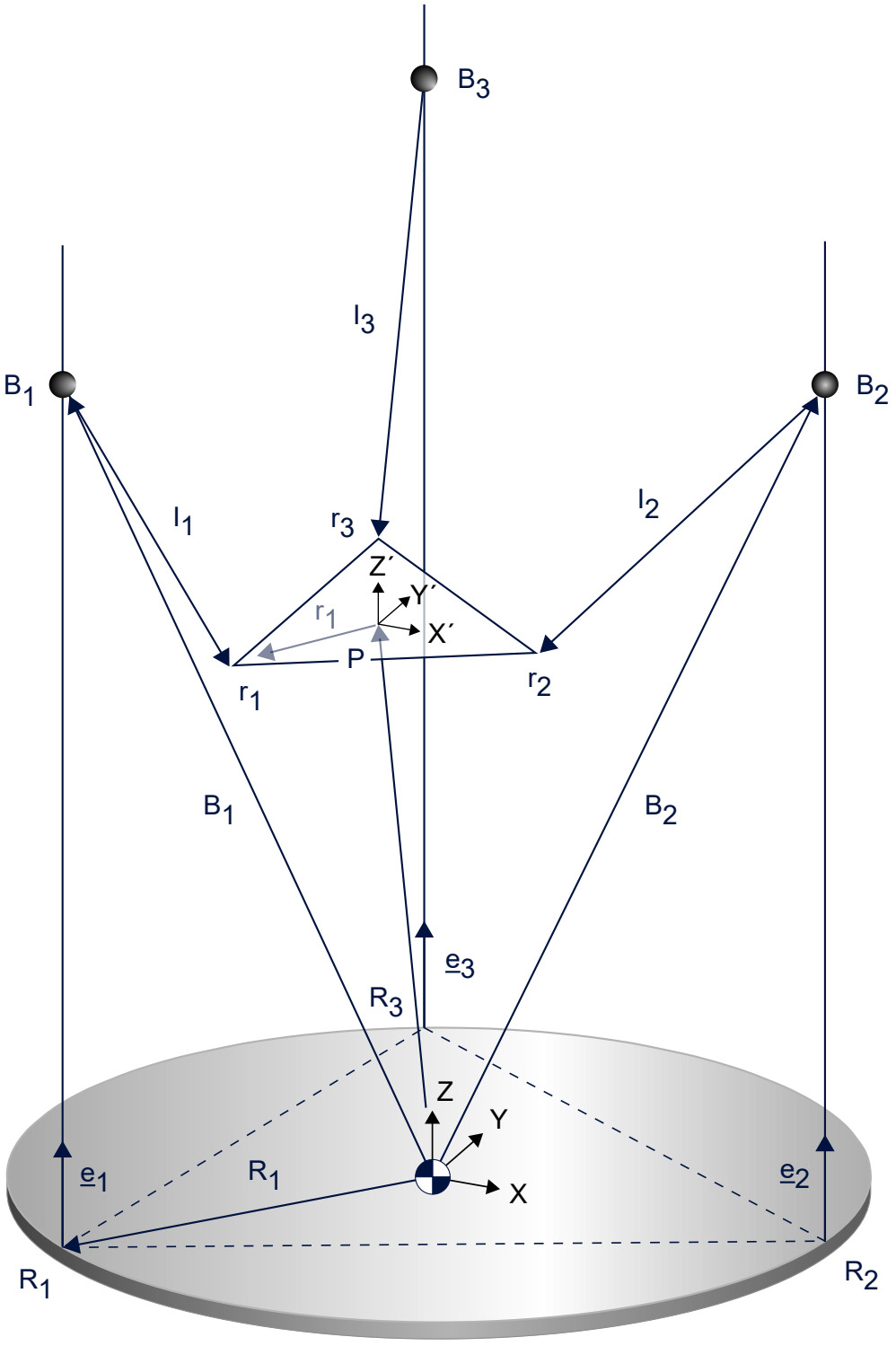


Fig. 30: Vector representation of strut kinematics

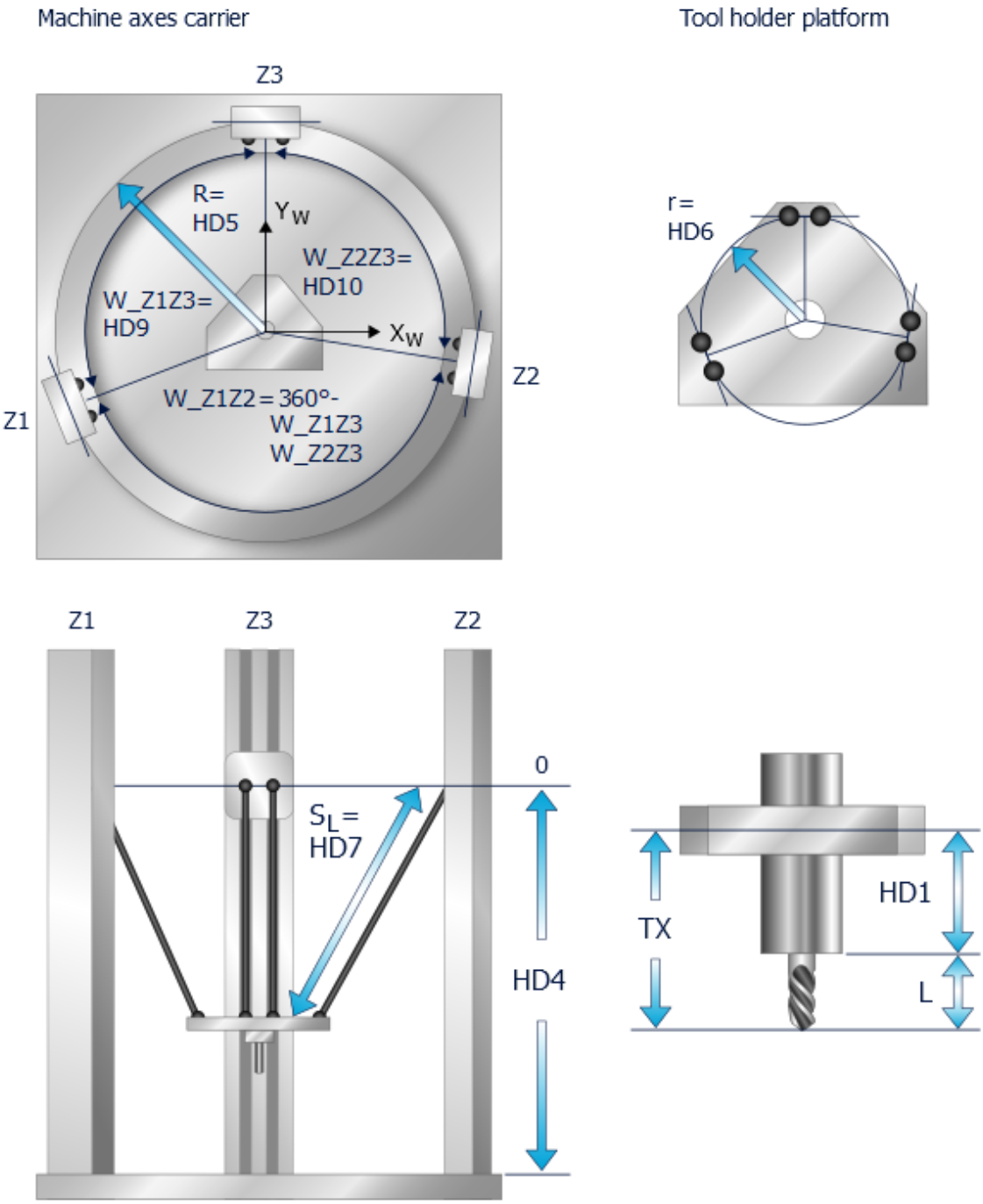


Fig. 31: Offset dimensions of strut kinematics

The parameter HD8 is used to toggle between an ideal (1) and non-ideal (0) tripod. An ideal tripod has an angle of 120° between all columns. A non-ideal tripod must be defined by the angles HD9 and HD10.
The third angle between columns is calculated as follows:

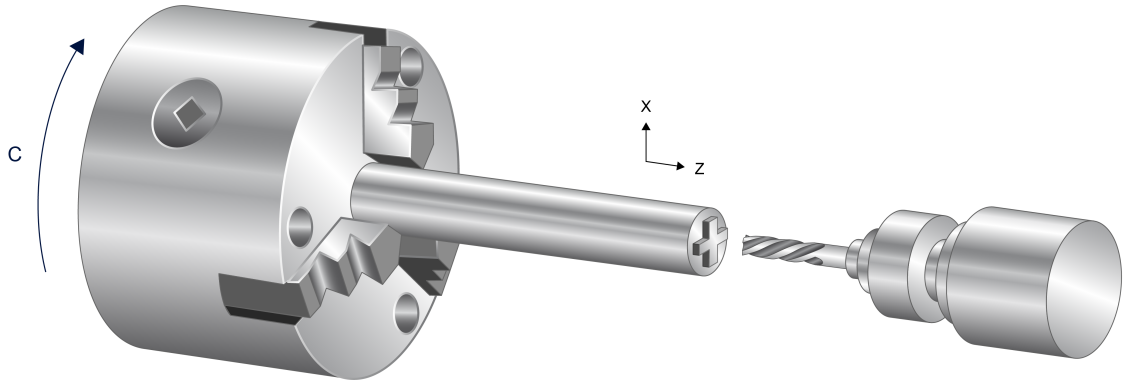
W_Z1Z2 = 360° - HD9 – HD10 = 360° - W_Z2Z3 – W_Z1Z3

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool offset Z	1.0 E-4 mm
HD2	1	Tool offset Y	1.0 E-4 mm
HD3	2	Tool offset X	1.0 E-4 mm
HD4	3	Z axis offset machine origin	1.0 E-4 mm
HD5	4	Radius to connecting line of the joint centre points on the drive columns (large circle)	1.0 E-4 mm
HD6	5	Radius to connecting line of the joint centre points on the holder platform (small circle)	1.0 E-4 mm
HD7	6	Strut length to each joint centre point	1.0 E-4 mm
HD8	7	Switch to switch over to non-ideal tripod 0 : ideal tripod 1 : non-ideal tripod and enable HD9 / HD 10	[-]
HD9	8	Angle column / joint 3 to column / joint 1	1.0 E-4°
HD10	9	Angle column / joint 3 to column / joint 2	1.0 E-4°

2.13 KIN_TYP_13/14 - Face transformation

An ideal machine structure is assumed for face machining (#FACE) with kinematic IDs 13 or 14.



Mechanical offset corrections in Y direction

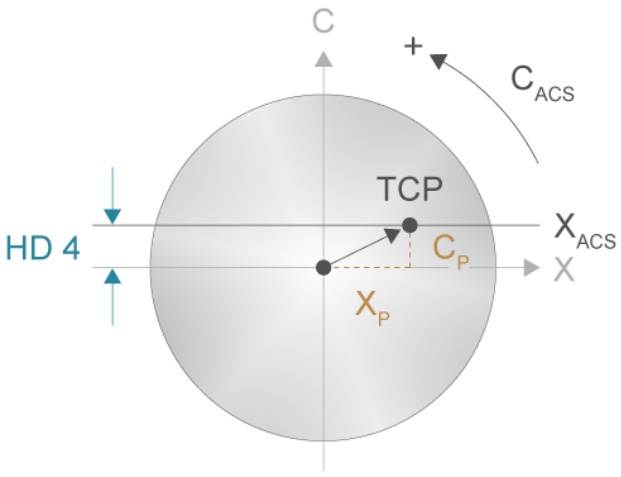
The effect of mechanical offset corrections depends on the machine ID for C axis face machining (P-CHAN-00008).

Characteristics of a Y offset

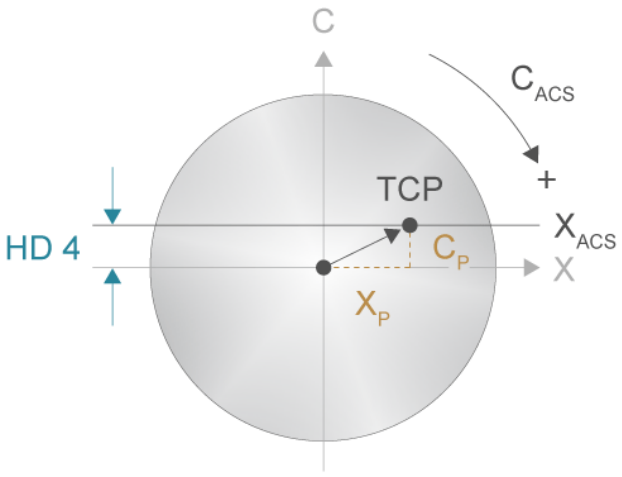
- With face transformation 2, i.e. P-CHAN-00008=2 - ID 14, it is impossible to pass through the rotation centre.
- The Y offset results in an enlargement of the critical zone about the rotation centre. With an ideal kinematic, however, this is only one point.
- The Y offset results in a critical zone (circle in the rotation centre) that cannot be approached.
- The dynamics in the vicinity of the critical zone are asymmetrical due to the Y offset.

The direction of rotation can be set using the HD parameter HD5.

HD5 = 0 (default)



HD5 = 1



Offset data of the kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset up to tool fixing point	1.0 E-4 mm
HD2	1	Not assigned	
HD3	2	Not assigned	
HD4	3	Y offset	1.0 E-4 mm
HD5	4	Direction of rotation	[-]

Programing Example

Change in direction of rotation in face machining

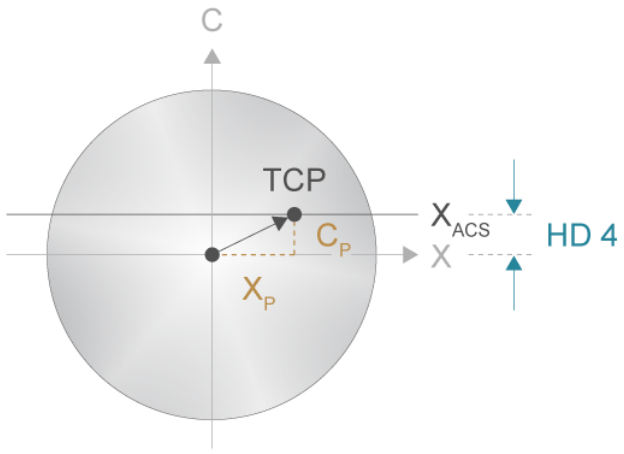
```
%L sub_face_mach
N10 #FACE[X, C]
N20 X1 C0
N30 $FOR P1=1, 2, 1
N40 P2 = P1*0.1
N50  G01 XP2 F2000
N[60+P1] G02 I-P2
N70 $ENDFOR
N80 #FACE OFF
M29

%main
V.G.KIN[13].PARAM[0]=1000000
V.G.KIN[13].PARAM[1]=0
V.G.KIN[13].PARAM[2]=0
V.G.KIN[13].PARAM[3]=P10*10000
V.G.KIN[13].PARAM[4]=1

N100 #SET AX[X,1,0][Y,2,1][Z,3,2][C,5,3]
N200 G00 X10 Y0 Z100 C0
N300 V.G.KIN[13].PARAM[4] = 0.0
N400 LL SUB_FACE_MACH
N500 V.G.KIN[13].PARAM[4] = 1.0 (Switch over direction of rotation)
N600 LL SUB_FACE_MACH
N700 V.G.KIN[13].PARAM[4] = 0.0
N800 LL SUB_FACE_MACH
M30
```

TCP position left of rotation centre

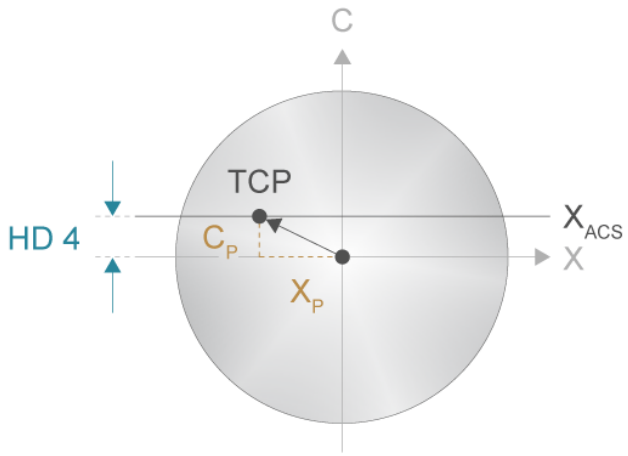
The X_{TCP} position and hence also the X_{ACS} position have no offsets on the right of the rotation centre of the workpiece rotation axis (for face_id 1 and face_id 2). Machining takes place on the right-hand side.

The TCP can also machine on the left-hand side if P-CHAN-00008=2 (face_id 2) is used. The switch-over from left to right can occur when the kinematic is inactive. Before selecting the kinematic, the X axis must be positioned at the negative position on the left of the rotation centre.

TCP machining on the right of rotation centre



TCP machining on the left of rotation centre



2.14 KIN_TYP_16 – 5-axis kinematics

Kinematic structure

The kinematic structure consists of 3 translatory and 3 rotary NC axes in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, B, A	-

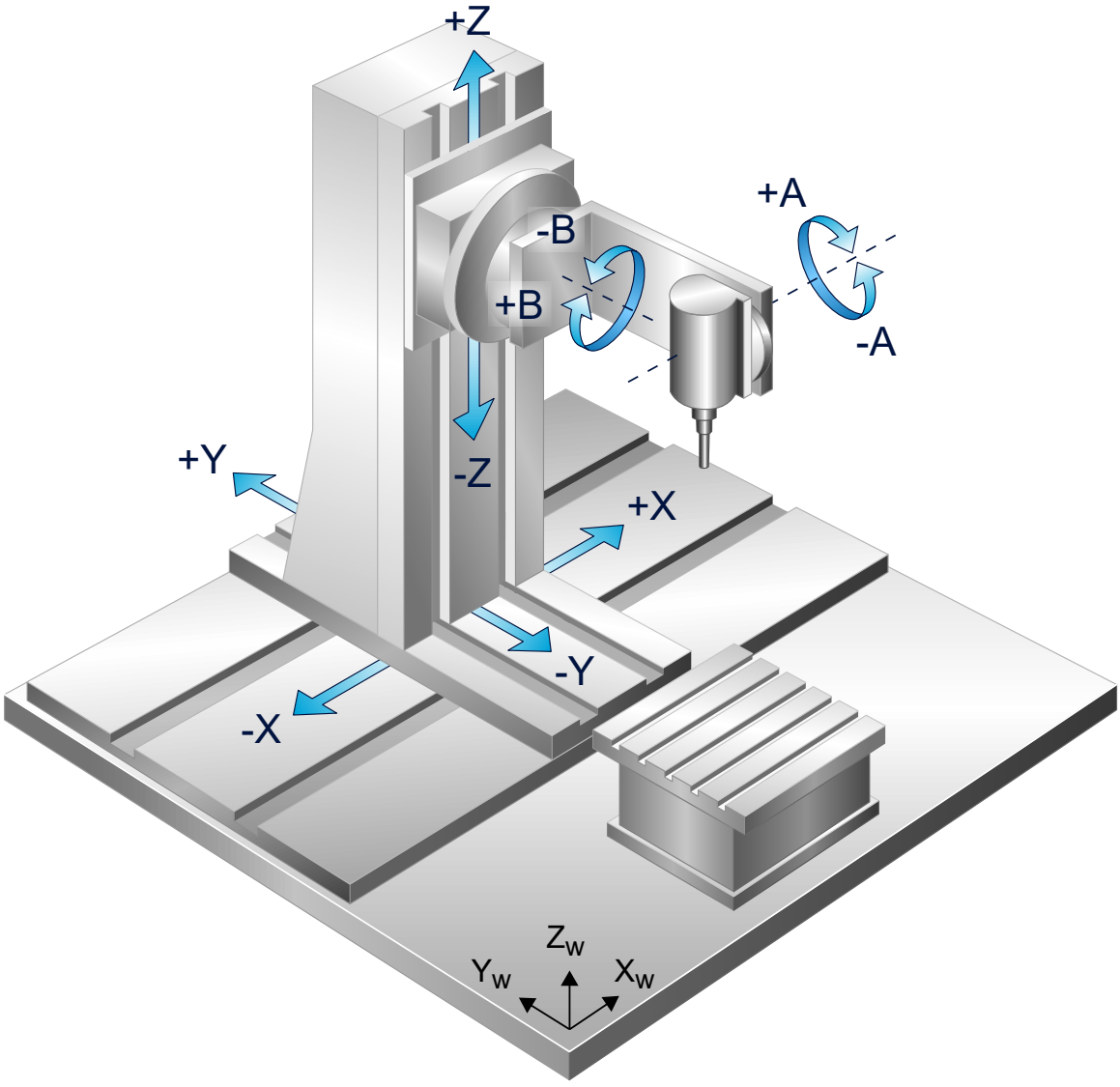


Fig. 32: Axis configuration of 5-axis machine

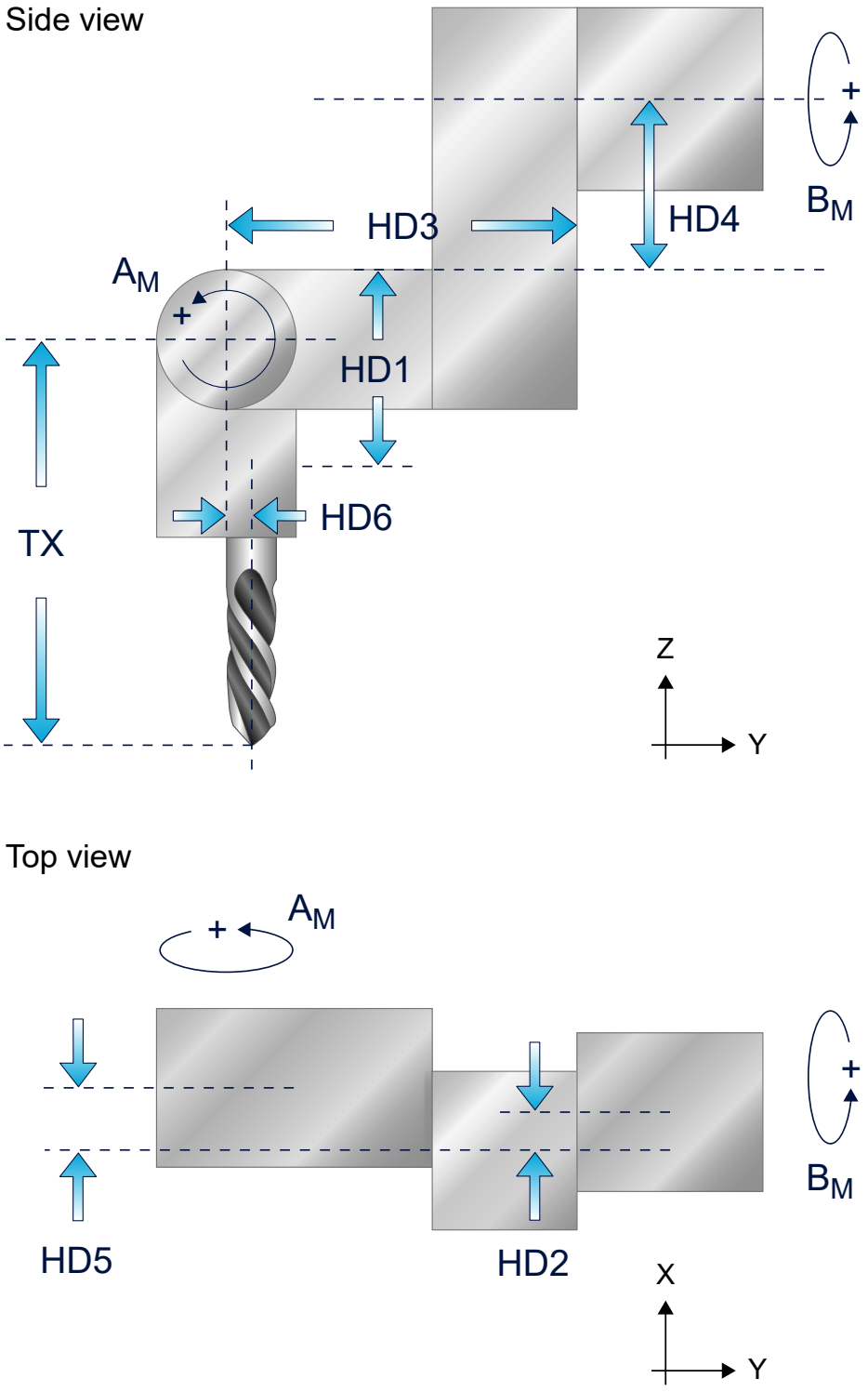


Fig. 33: Parameters of rotary/swivel head

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset to tool holding device	1.0 E-4°
HD2	1	X offset	1.0 E-4°
HD3	2	Y offset	1.0 E-4°
HD4	3	Z offset	1.0 E-4°
HD5	4	X offset	1.0 E-4°
HD6	5	Y axis offset to tool	1.0 E-4°
HD7	6	Rotary offset A axis	1.0 E-4°
HD8	7	Rotary offset B axis	1.0 E-4°
HD9	8	Sign for direction of rotation A axis	[-]
HD10	9	Sign for direction of rotation B axis	[-]

2.15 KIN_TYP_17 – five-axis kinematics with 2 manual auxiliary axes

Kinematic structure

The kinematic structure consists of 3 translatory NC axes. In addition, 2 manually adjustable rotary axes are available. These axes cannot be addressed from the NC program.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z	
Axis index	0, 1, 2	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	-
Auxiliary axes	C, A	-

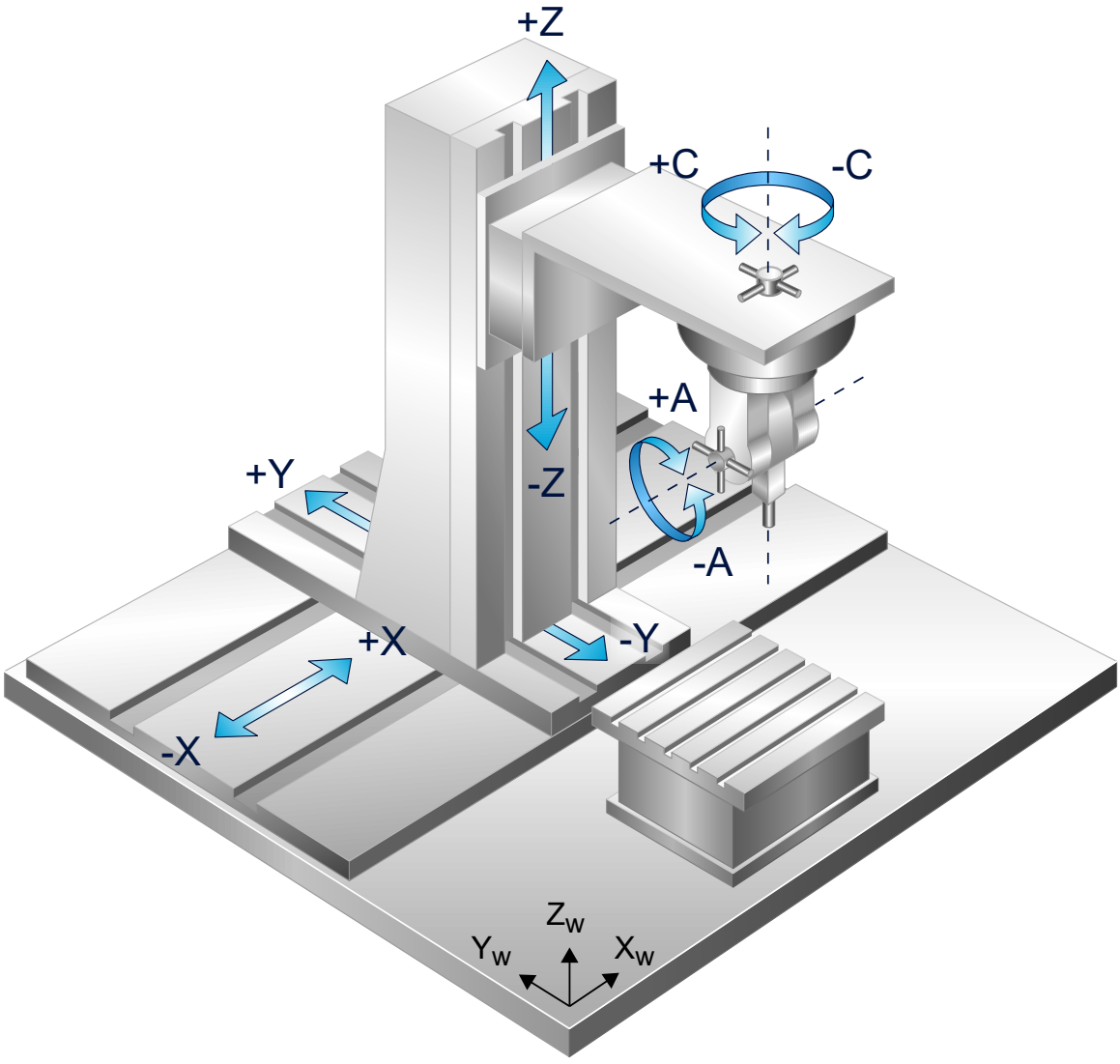


Fig. 34: 5-axis kinematics (boring and milling tool with manual auxiliary axes C and A)

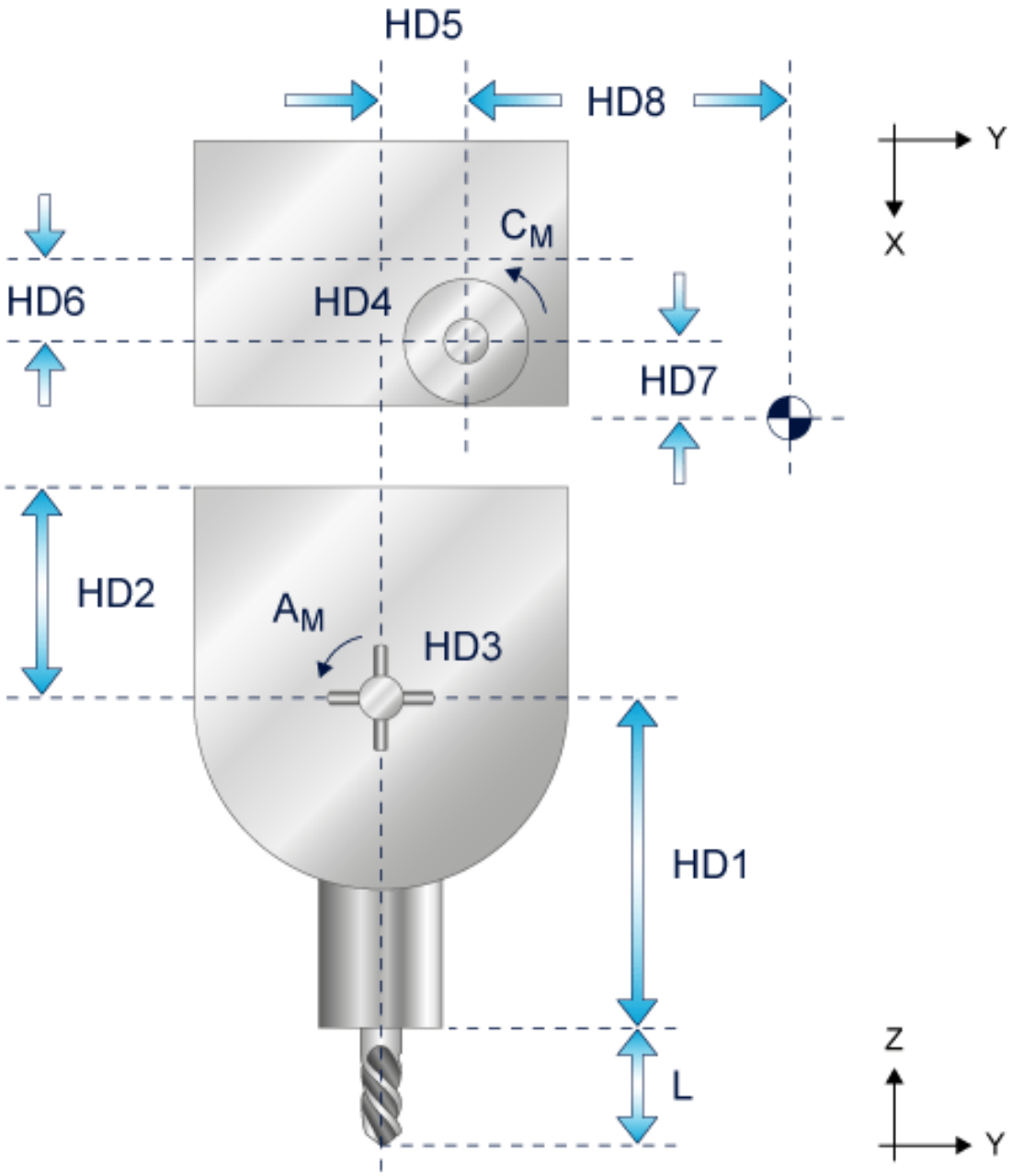


Fig. 35: Boring and milling tool (zero position where HD3 = 0, HD4 = 0)

The axes are arranged as for a right-handed system. The zero position of the A axis is in the negative direction of the Z axis. No automatic orientation setting is possible for the 2-axis tool head with manually adjustable C and A axes.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset tool holding device to rotation point of A axis (swivel axis)	1.0 E-4 mm
HD2	1	Z axis offset rotation point A axis to tool head reference point	1.0 E-4 mm
HD3	2	Fixed angle setting of rotary A axis (swivel axis)	1.0 E-4°
HD4	3	Fixed angle setting of rotary C axis	1.0 E-4°
HD5	4	Y axis offset rotation point A axis to rotation point C axis (offset)	1.0 E-4 mm
HD6	5	X axis offset tool head reference point to rotation point C axis (offset)	1.0 E-4 mm
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm

2.16 KIN_TYP_18 – five-axis kinematics with 2 manual auxiliary axes (sawing)

Kinematic structure

The kinematic structure consists of 3 translatory NC axes. In addition, 2 manually adjustable rotary axes are available. These axes cannot be addressed from the NC program.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z	
Axis index	0, 1, 2	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	-
Auxiliary axes	C, A	-

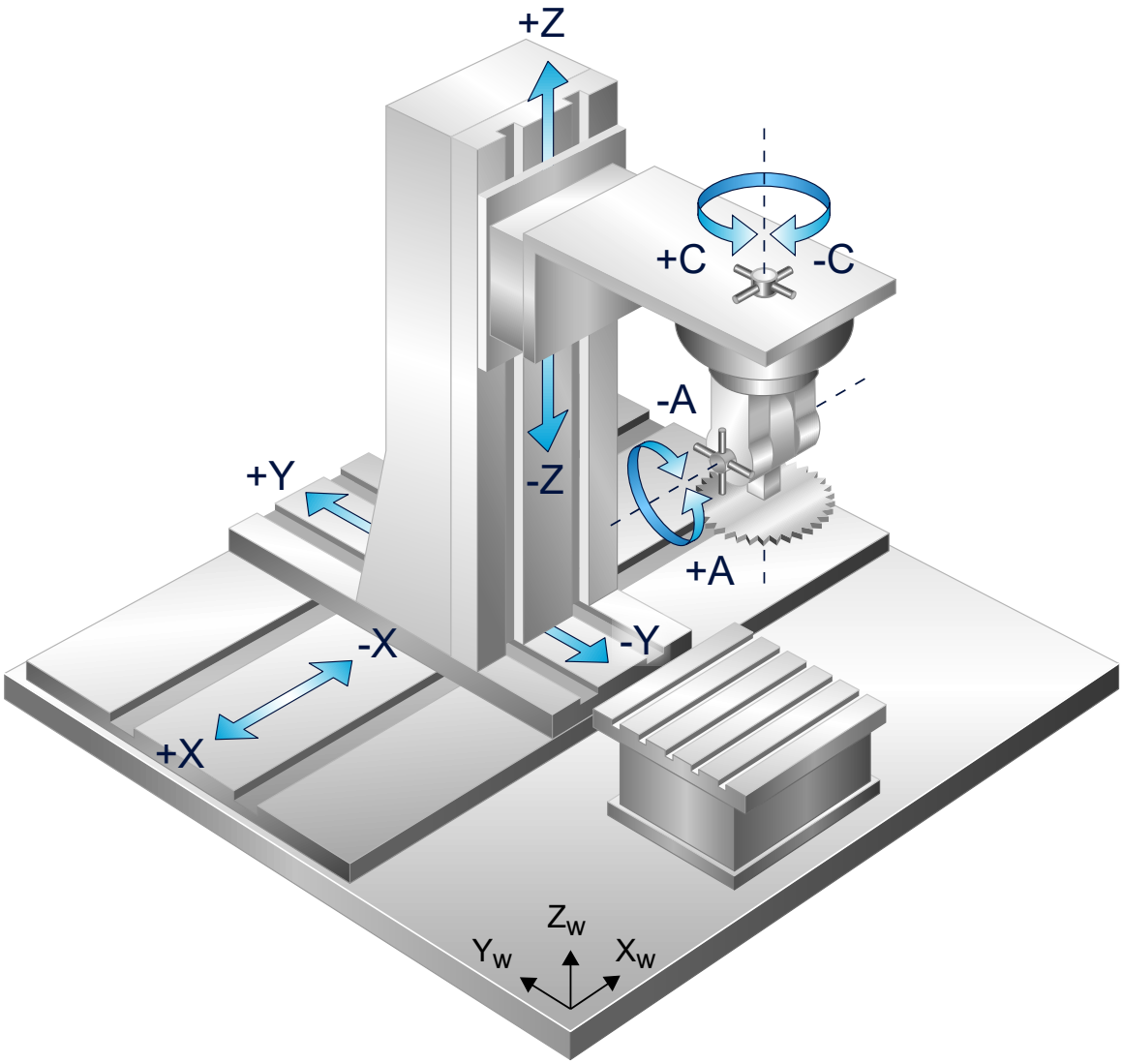


Fig. 36: 5-axis kinematics (sawing tool with manual auxiliary axes C and A)

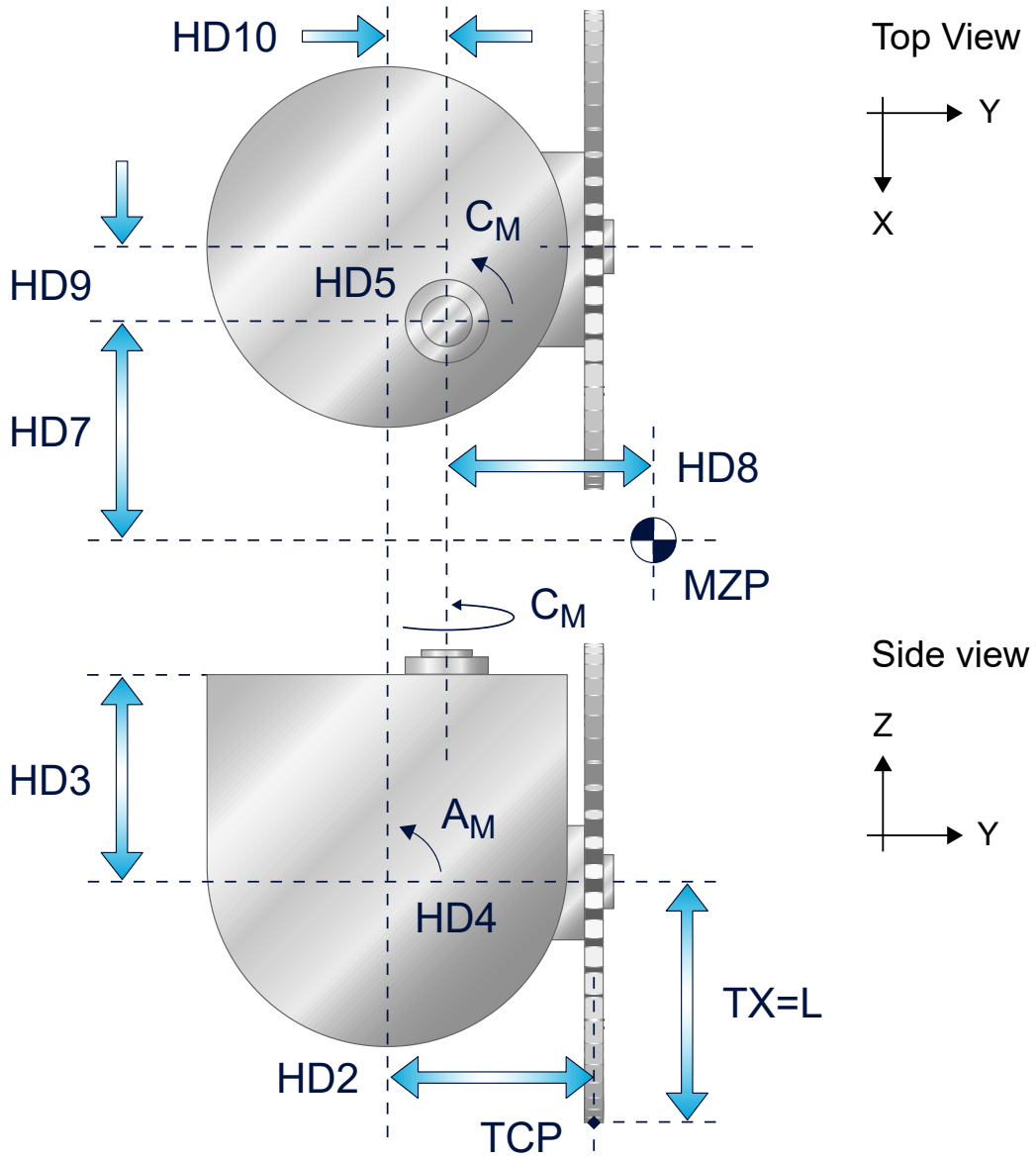


Fig. 37: Sawing tool (zero position where HD5 = 0, HD4 = +90)

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD2	1	Y axis offset from tool holding device to rotation point A axis (swivel axis)	1.0 E-4 mm
HD3	2	Z axis offset from rotation point A axis to tool reference point	1.0 E-4 mm
HD4	3	Fixed angle setting of rotary A axis (swivel axis)	1.0 E-4°
HD5	4	Fixed angle setting of rotary C axis	1.0 E-4°
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm
HD9	8	X axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm
HD10	9	Y axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm

2.17 KIN_TYP_19 – Tripod kinematics

Kinematic structure

The strut kinematics consists of 3 translatory axes in a non-Cartesian arrangement and 2 Cartesian axes. 3 struts with ball joints support the workpiece platform. This may affect the Z height and orientation of the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, U, V, W (X, Y, Z1, Z2, Z3, W)	
Axis index	0, 1, 2, 3, 4, 5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y	Z1, Z2, Z3

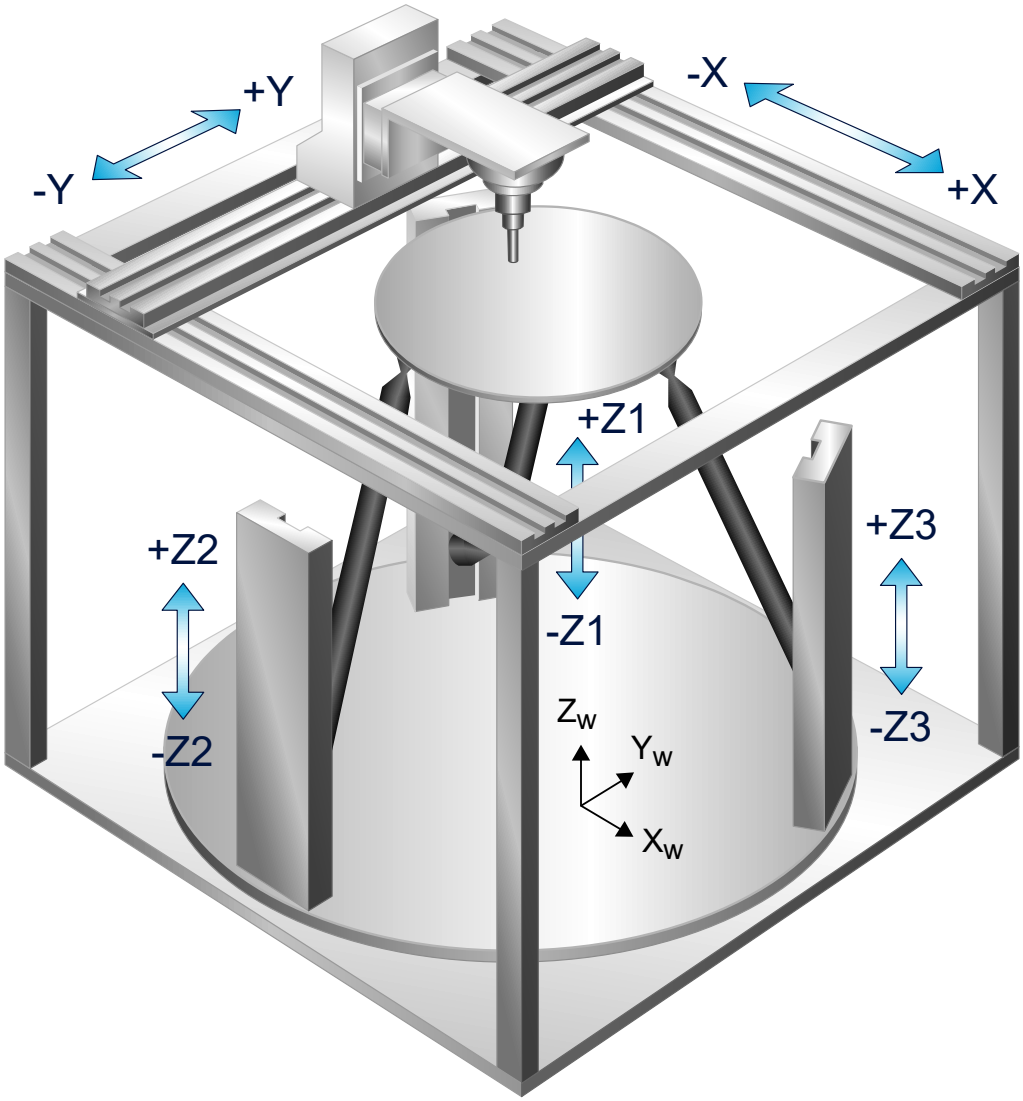


Fig. 38: Tripod kinematics

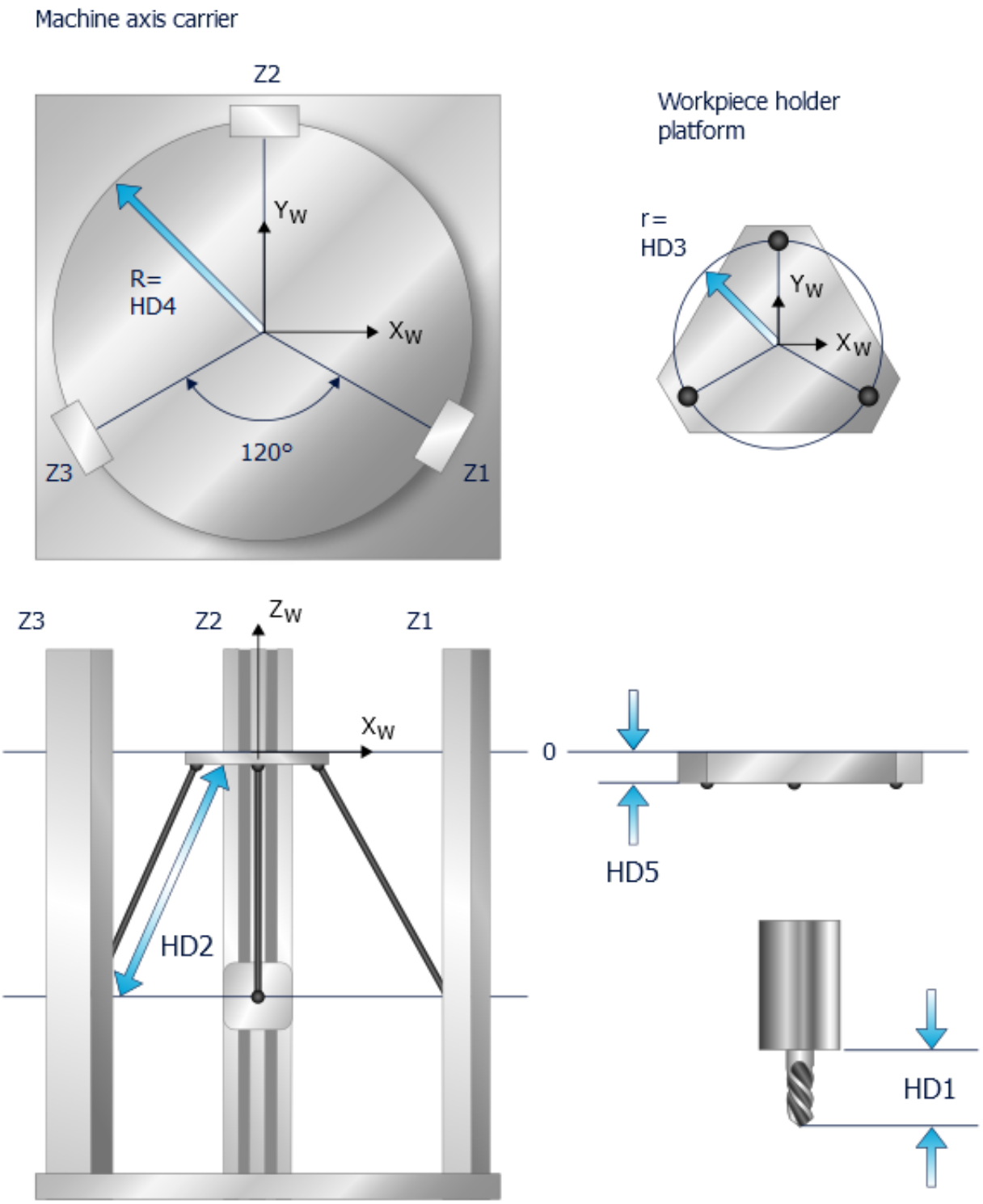


Fig. 39: Kinematic offsets

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool offset in Z	1.0 E-4 mm
HD2	1	Strut length to joint centre point	1.0 E-4 mm
HD3	2	Radius to connecting line of joint centre points of holder platform (small circle)	1.0 E-4 mm
HD4	3	Radius to connecting line joint centre points of drive columns (large circle)	1.0 E-4 mm
HD5	4	Distance between workpiece holder platform and joint centre points on the holder platform	1.0 E-4 mm

2.18 KIN_TYP_21 – Lambda kinematics

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 1 rotary NC axis in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C (X1, X2, Z, C)	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X,Y, Z, C	-

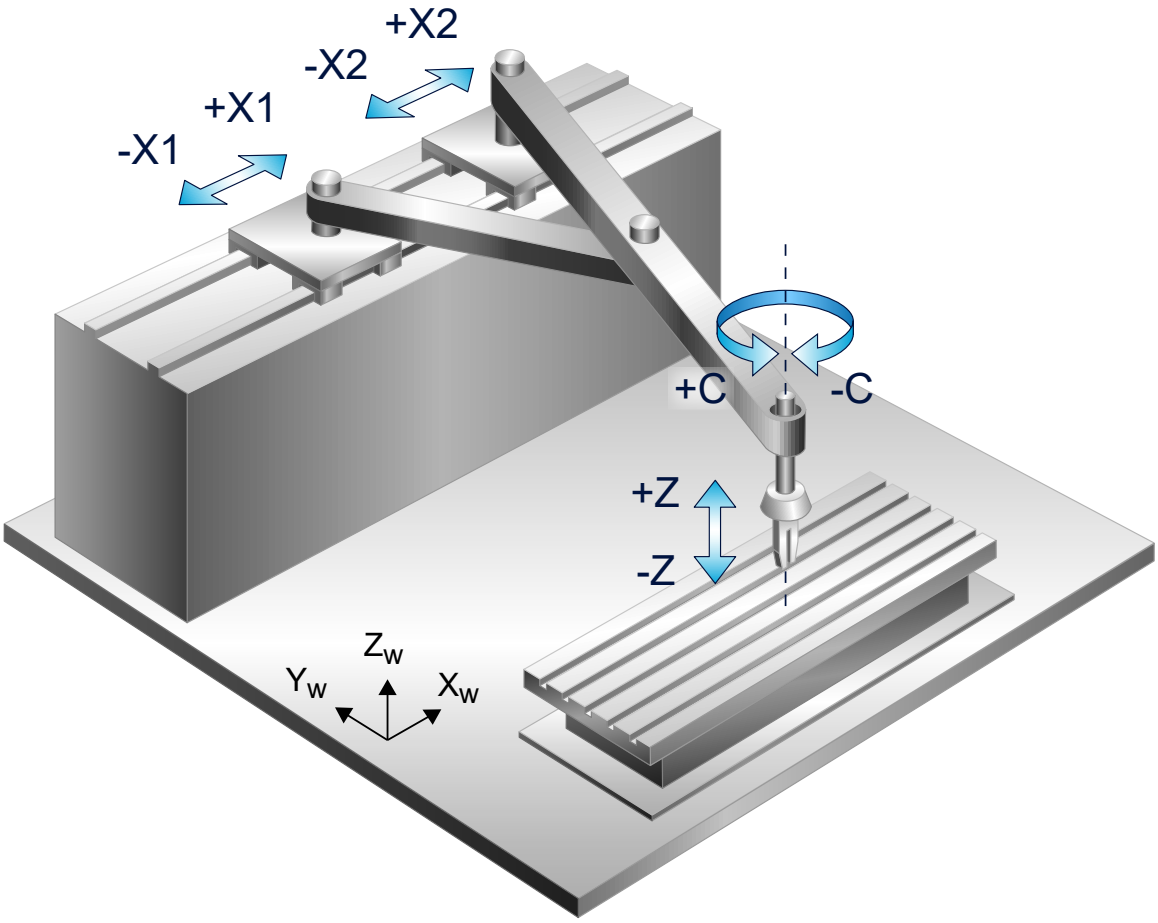


Fig. 40: Lambda kinematics

The XY plane kinematics are known as a variant of shear kinematics. The struts (lengths l2, l1) that are connected to each other at point D and are also rotatable are located on 2 linear slides XM1 and XM2 at rotary joints C and B.

Strut CA (length l3) is attached to strut CD via the fixed angle ß. The C axis is located at the top of this strut. The actual tool holding strut (length l4) starts at the rotation point of the C axis and ends in the TCP.

Related to the Cartesian axes the C axis is not mechanically guided, i.e. it must be compensated depending on the joint position.

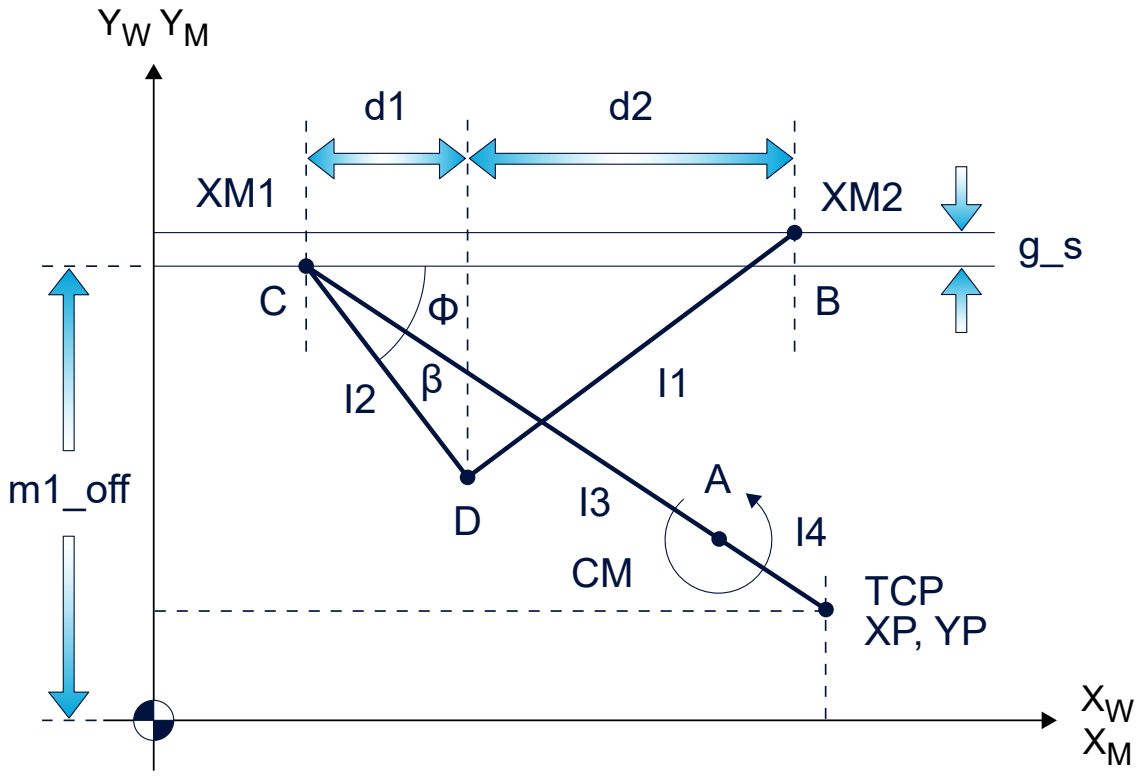


Fig. 41: Lambda kinematics, variant 1

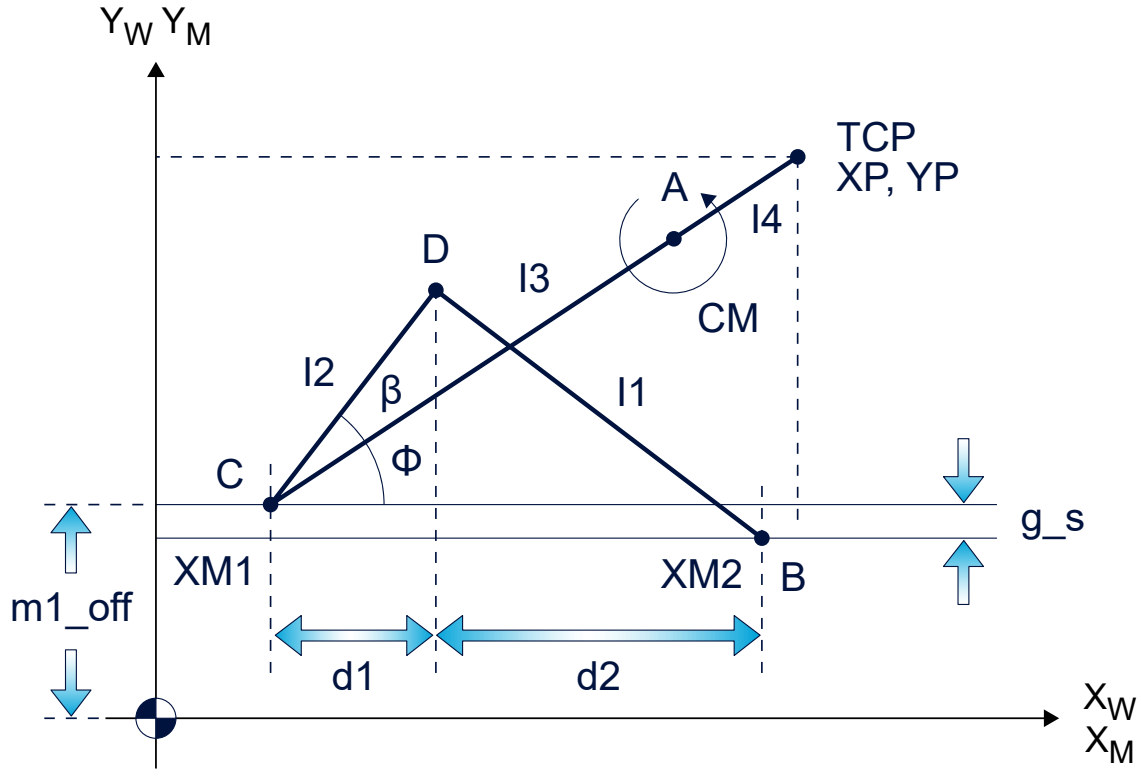


Fig. 42: Lambda kinematics, variant 2

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset to tool holding point	1.0 E-4 mm
HD2	1	l1: Strut length 1	1.0 E-4 mm
HD3	2	l2: Strut length 2	1.0 E-4 mm
HD4	3	l3: Strut length 3	1.0 E-4 mm
HD5	4	g_s : Offset joint points C to B	1.0 E-4 mm
HD6	5	ß= fixed angle between strut CD and strut CA	1.0 E-4°
HD7	6	m1_off: Y position of drive 1 referred to Y origin WCS	1.0 E-4 mm
HD8	7	phi_min: Minimum value for angle j (0°)	1.0 E-4°
HD9	8	phi_max: Maximum value for angle j (90°)	1.0 E-4°
HD10	9	X-Offset	1.0 E-4 mm
HD11	10	L4= gripper offset	1.0 E-4 mm
HD12	11	Kinematic variant	[-]

2.19 KIN_TYP_22 – 5-axis kinematics with X/Y workpiece table

Kinematic structure

The kinematic structure consists of 2 translatory NC axes in the workpiece, 2 rotary NC axes and 1 translatory axis in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	Z, A, B	X, Y

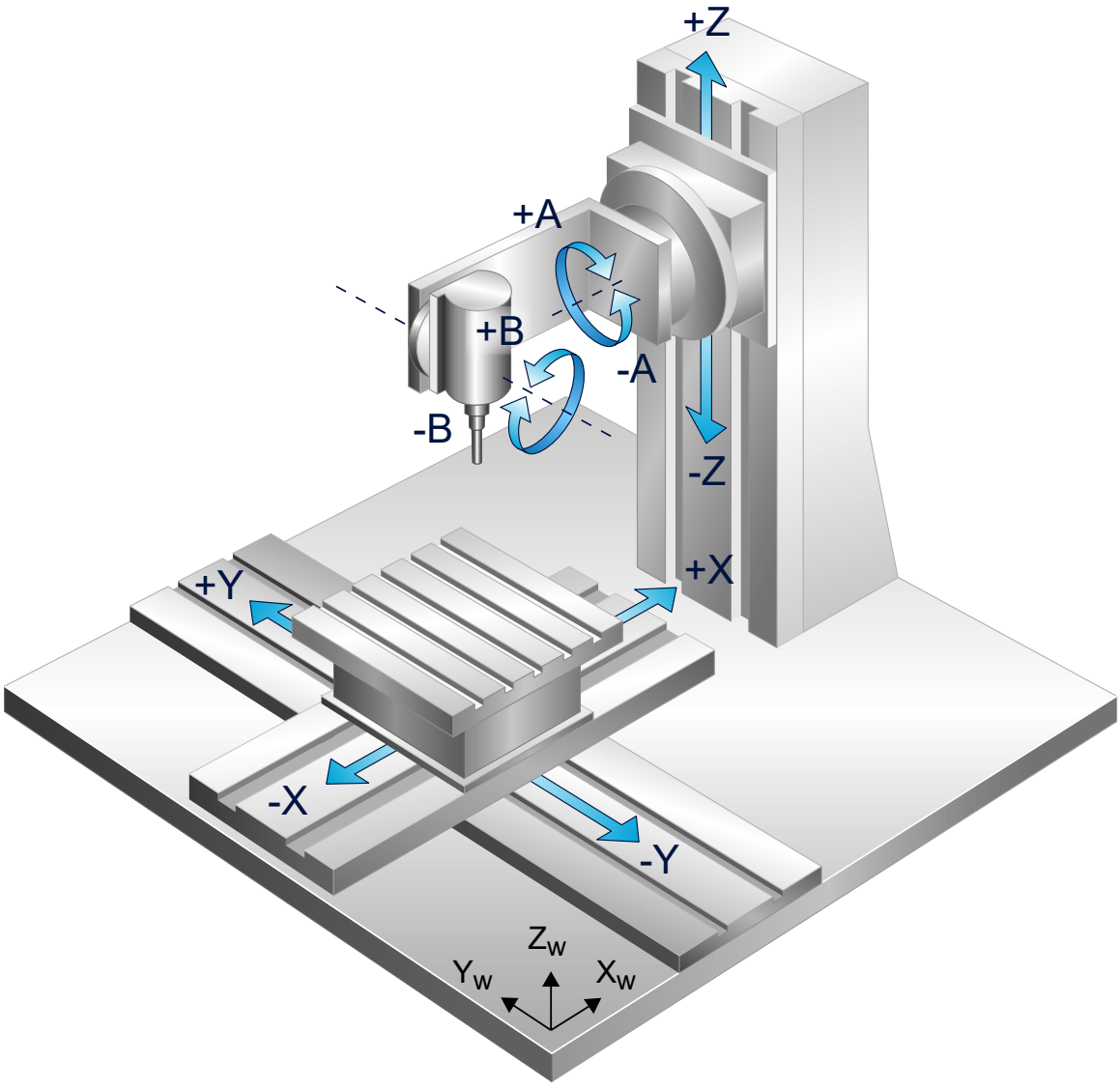


Fig. 43: Axis configuration of 5-axis machine

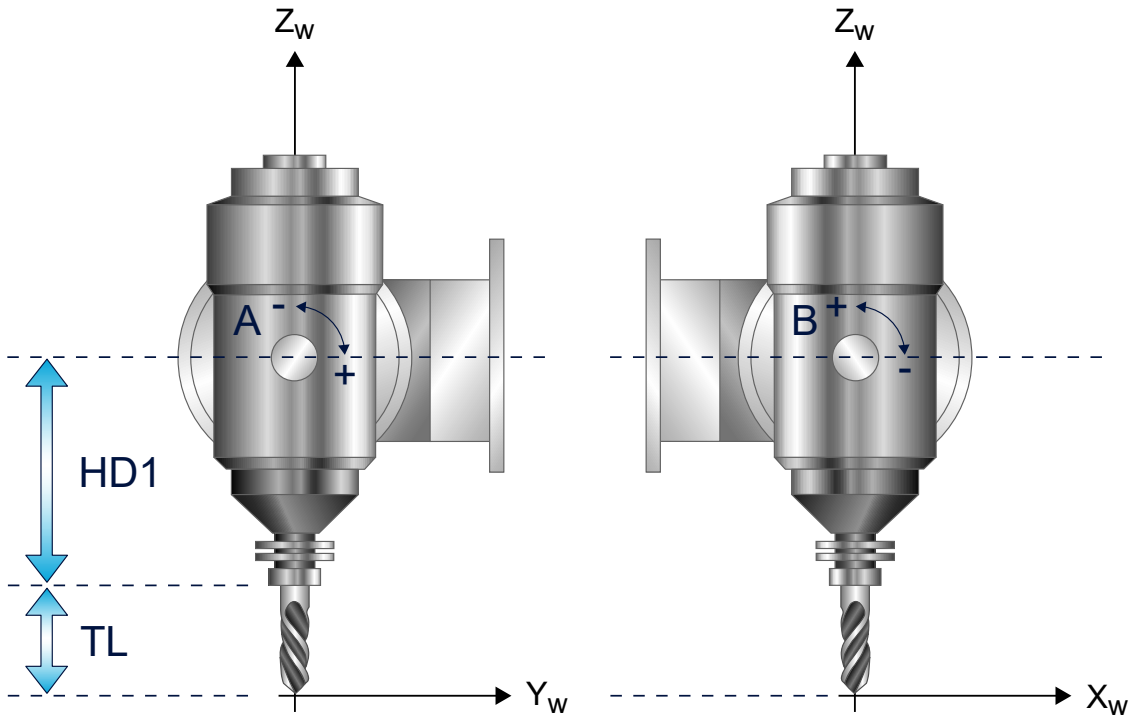


Fig. 44: Kinematic offsets

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset tool holding device to rotation point A / B axis	1.0 E-4 mm
HD4	3	Motion direction rotary axis A	[-]
HD5	4	Motion direction rotary axis B	[-]

2.20 KIN_TYP_23 – 5-axis kinematics with X/Y/B workpiece table

Kinematic structure

The kinematic structure consists of 2 translatory NC axes in the workpiece, 1 translatory axis in the tool and 1 rotary NC axis in both the workpiece and the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	Z, A	X, Y, B

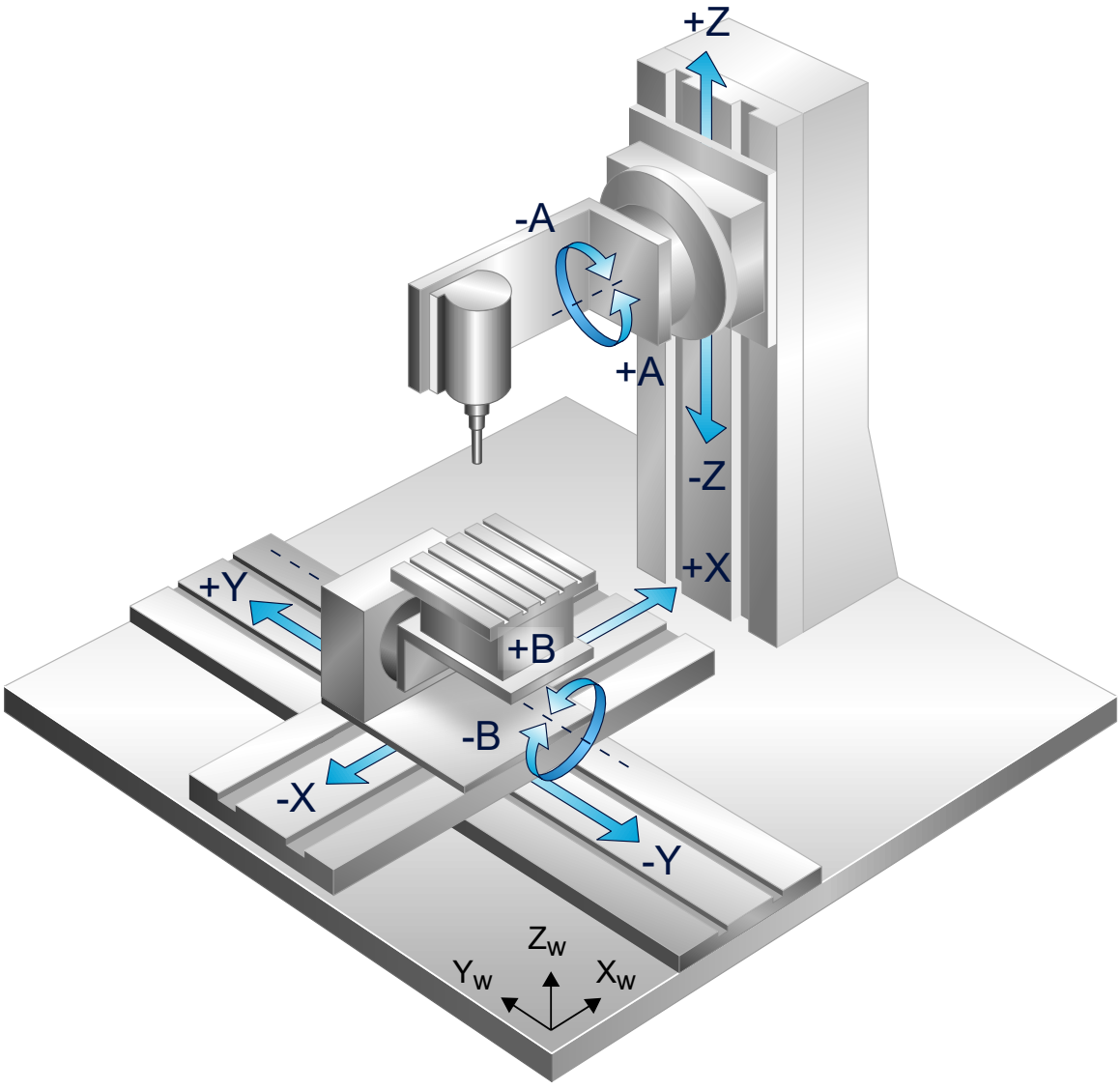


Fig. 45: Axis configuration of 5-axis machine

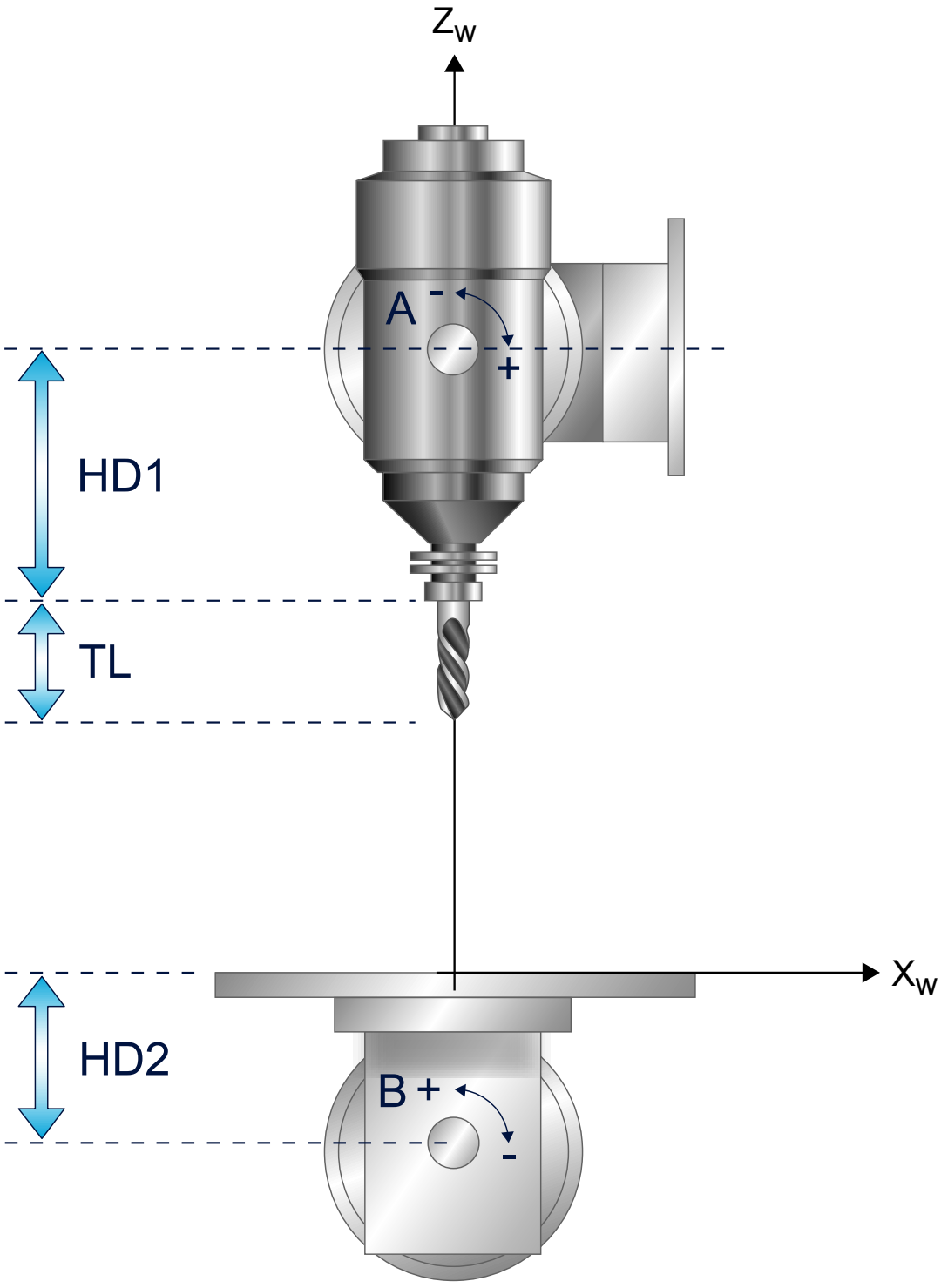


Fig. 46: Kinematic offsets

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset tool holding device to rotation point A axis	1.0 E-4 mm
HD2	1	Distance rotation point B axis to workpiece platform	1.0 E-4 mm
HD4	3	Motion direction rotary axis A	[-]
HD5	4	Motion direction rotary axis B	[-]

2.21 KIN_TYP_25 – 5-axis kinematics with plasma/laser head

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 2 rotary NC axes in the tool. As a special feature, the effective tool length with these kinematics changes depending on the A angle.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C, A	-

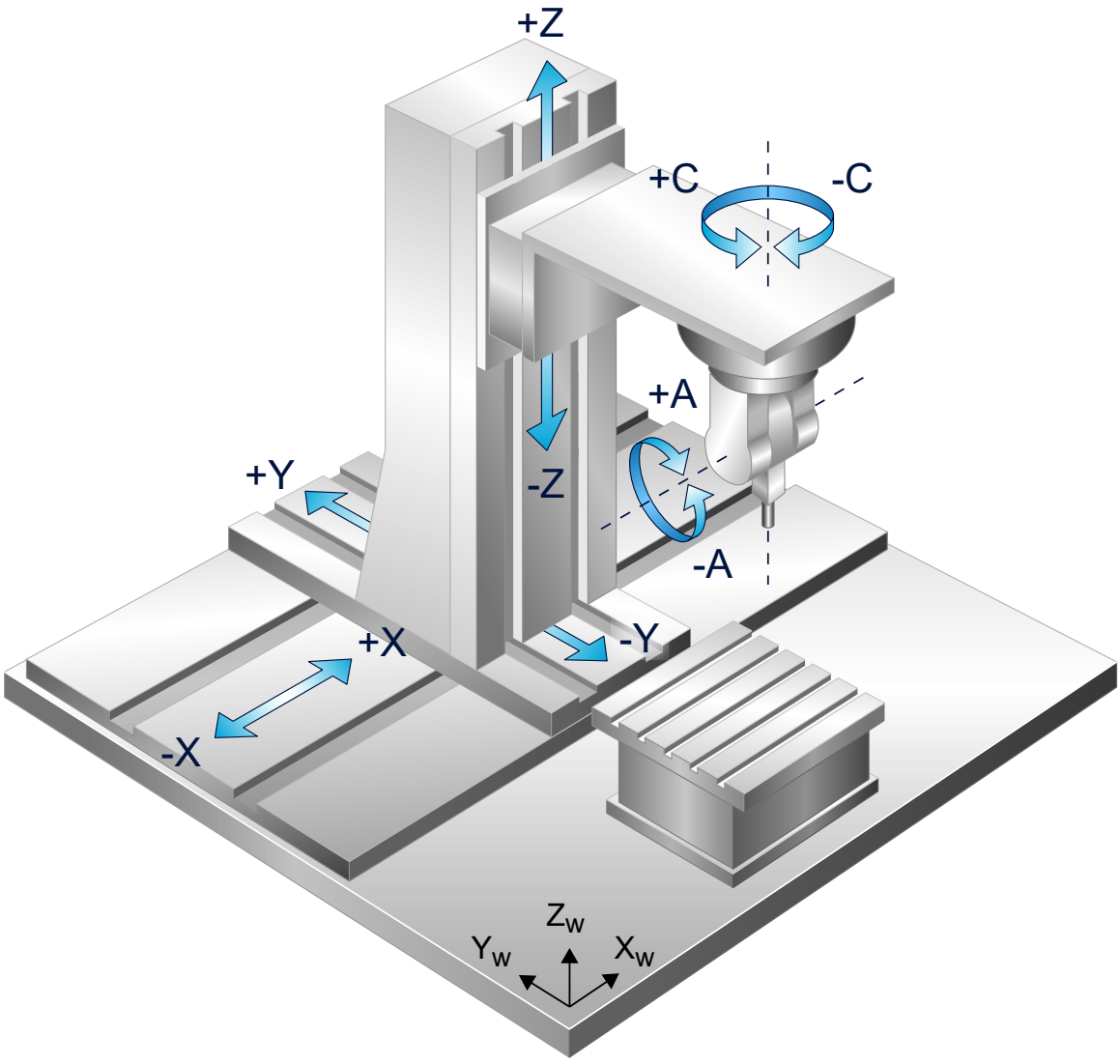


Fig. 47: 5-axis kinematics (plasma/laser head)

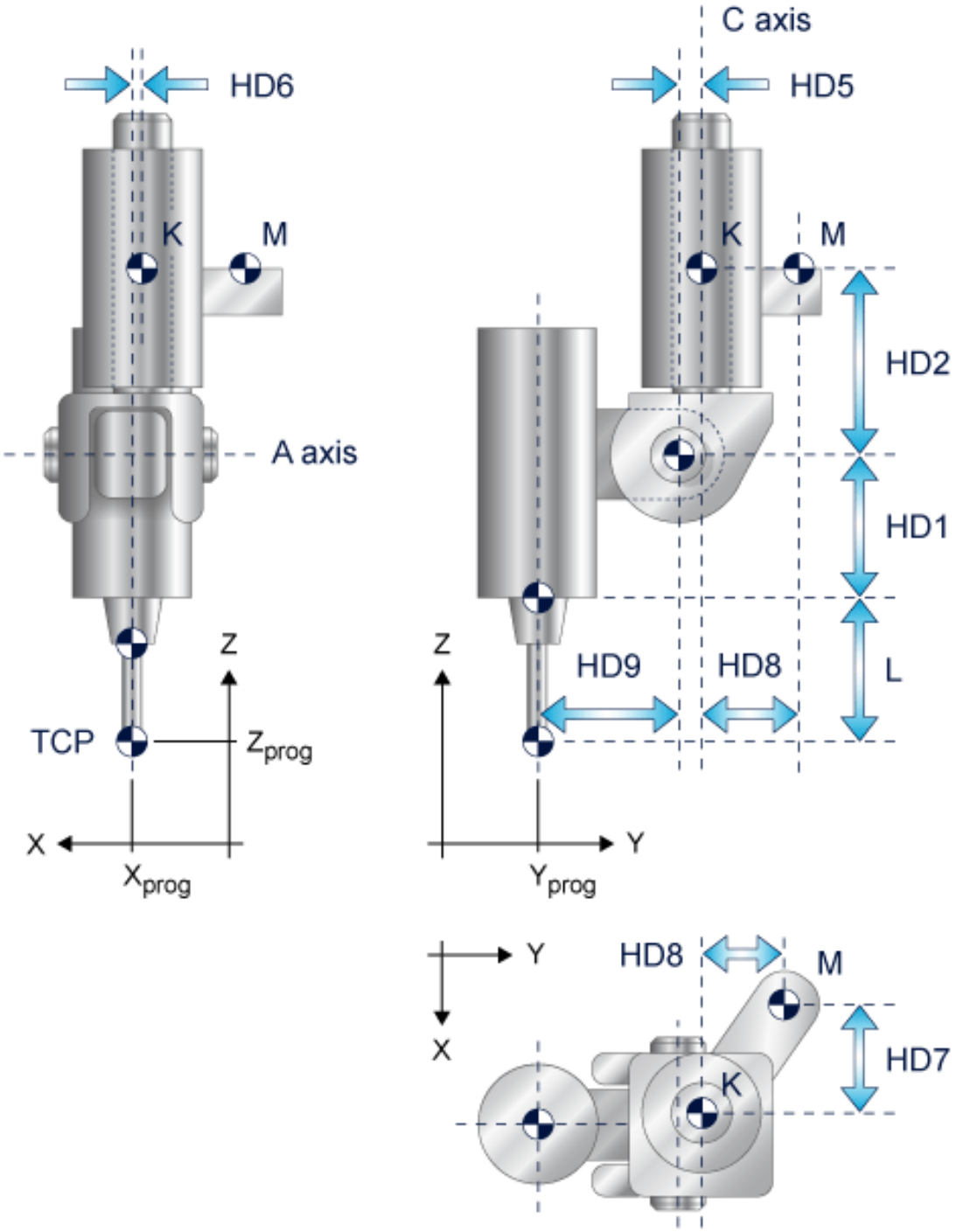


Fig. 48: 5-axis plasma/laser head (zero position where HD3 = 0, AM=0, HD4=0, CM=0)

The M and K points in the figure above are two reference points

(**M**)achine reference point and (**K**)inematic reference point

The ACS offset between the points M and K is a static offset, i.e. it is independent of the angular position of the rotary axes C, A.

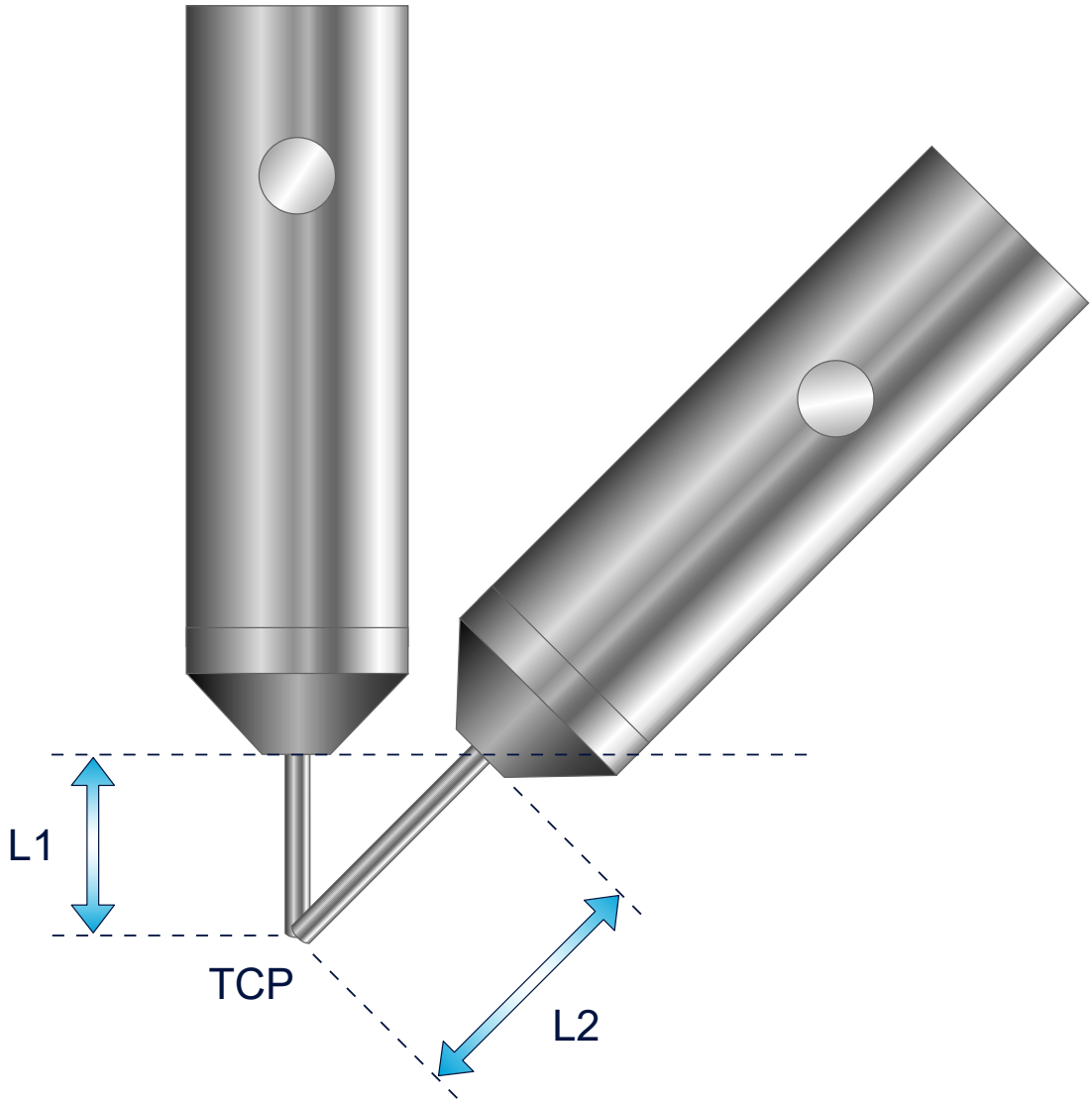


Fig. 49: When the head is in oblique position, the torch tip is at a constant height above the workpiece, i.e. where A!= 0 is the effective length L2 > L1.

To limit the active length L2 and therefore keep the required machine compensation movements as small as possible, select a small head inclination. (Maximum recommended: +/-45 degrees)

The inclined position is limited by configuring the software limit switches (P-AXIS-00177/ P-AXIS-00178) of the A axis.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset from torch tip to rotation point A axis (swivel axis)	1.0 E-4 mm
HD2	1	Z axis offset rotary axis A to tool head reference point	1.0 E-4 mm
HD3	2	Rotary angular offset A axis (default 0)	1.0 E-4°
HD4	3	Rotary angular offset C axis (default 0)	1.0 E-4°
HD5	4	Y axis offset rotation point C axis	1.0 E-4 mm
HD6	5	X axis offset rotation point C axis	
HD7	6	Static head offset in X (default 0)	1.0 E-4 mm
HD8	7	Static head offset in Y (default 0)	1.0 E-4 mm
HD9	8	Y axis offset torch axis to rotation point A axis	1.0 E-4 mm

2.22 KIN_TYP_28 – 5-axis kinematics

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 2 rotary NC axes in the tool. The physical angle position of the head C, A is adjusted by 2 gear-linked axes.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A (X, Y, Z, C1, C2)	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C(C1), A(C2)	-

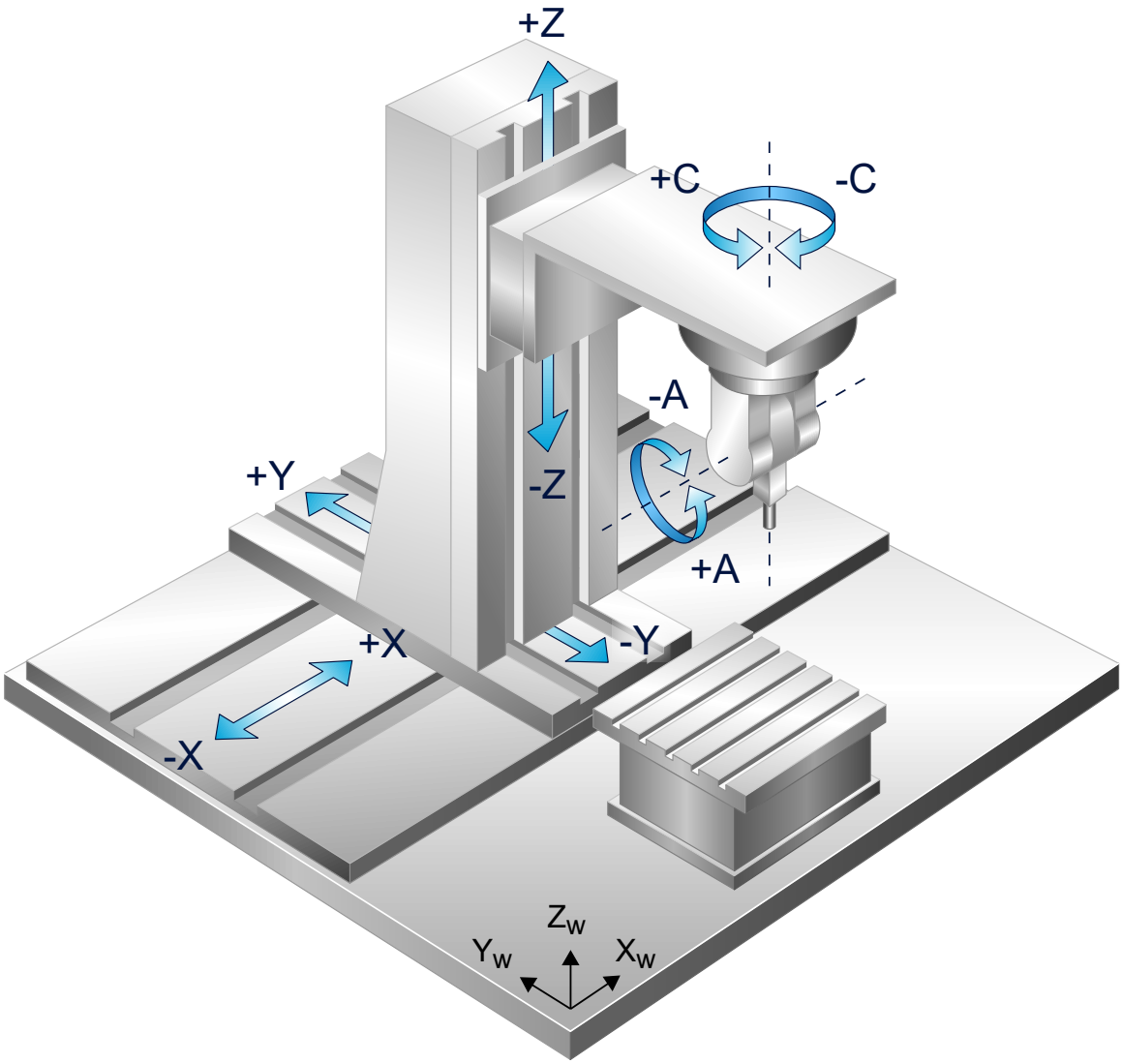


Fig. 50: 5-axis kinematics

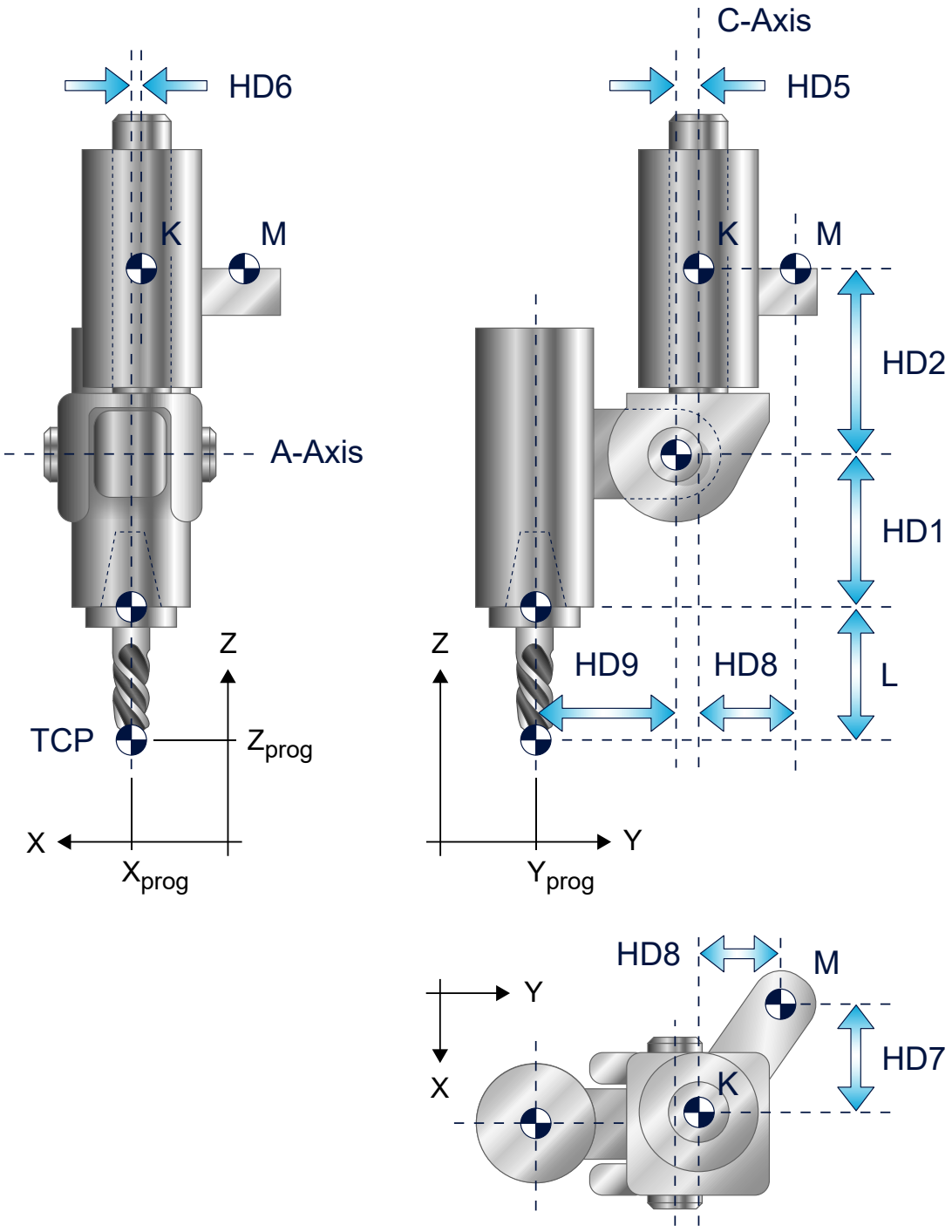


Fig. 51: Tool head (zero position where HD3 = 0, A=0, HD4=0, C=0)

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset from tool holding device to rotation point A axis (swivel axis)	1.0 E-4 mm
HD2	1	Z axis offset rotary axis A to tool head reference point	1.0 E-4 mm
HD3	2	Rotary angular offset A axis (default 0)	
HD4	3	Rotary angular offset C axis (default 0)	
HD5	4	Y axis offset rotation point C axis	1.0 E-4 mm
HD6	5	X axis offset rotation point C axis	1.0 E-4 mm
HD7	6	Static head offset in X (default 0)	1.0 E-4 mm
HD8	7	Static head offset in Y (default 0)	1.0 E-4 mm
HD9	8	Y axis offset milling tool axis to rotation point A axis	1.0 E-4 mm
HD10	9	n.a.	[-]
HD11	10	Origin offset CA gear link	1.0 E-4°
HD12	11	Gear link factor numerator	[-]
HD13	12	Gear link factor denominator	[-]
HD14	13	Sign rotary axis C	[-]
HD15	14	Sign rotary axis A	[-]
HD16	15	A factor numerator	[-]
HD17	16	A factor denominator	[-]

The gear link between C and A is absolute and is executed as shown in the following equations:

CM = CW

AM = AW*k_a + NP0 + k_{ca}*CW

where

$$kca = \frac{HD12}{HD13}$$: C -> A gear link factor

$$ka = \frac{HD16}{HD17}$$: A resolution factor

NP0 = HD11 : Origin offset gear link

The head rotary axes must be adjusted either as linear axes or as rotary axes with a sufficiently large modulo range. The SLS monitor in the channel acts on the drive positions depending on the limits in set in the MDS.

2.23 KIN_TYP_30 – 4-axis kinematics

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 1 rotary NC axis in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A	-

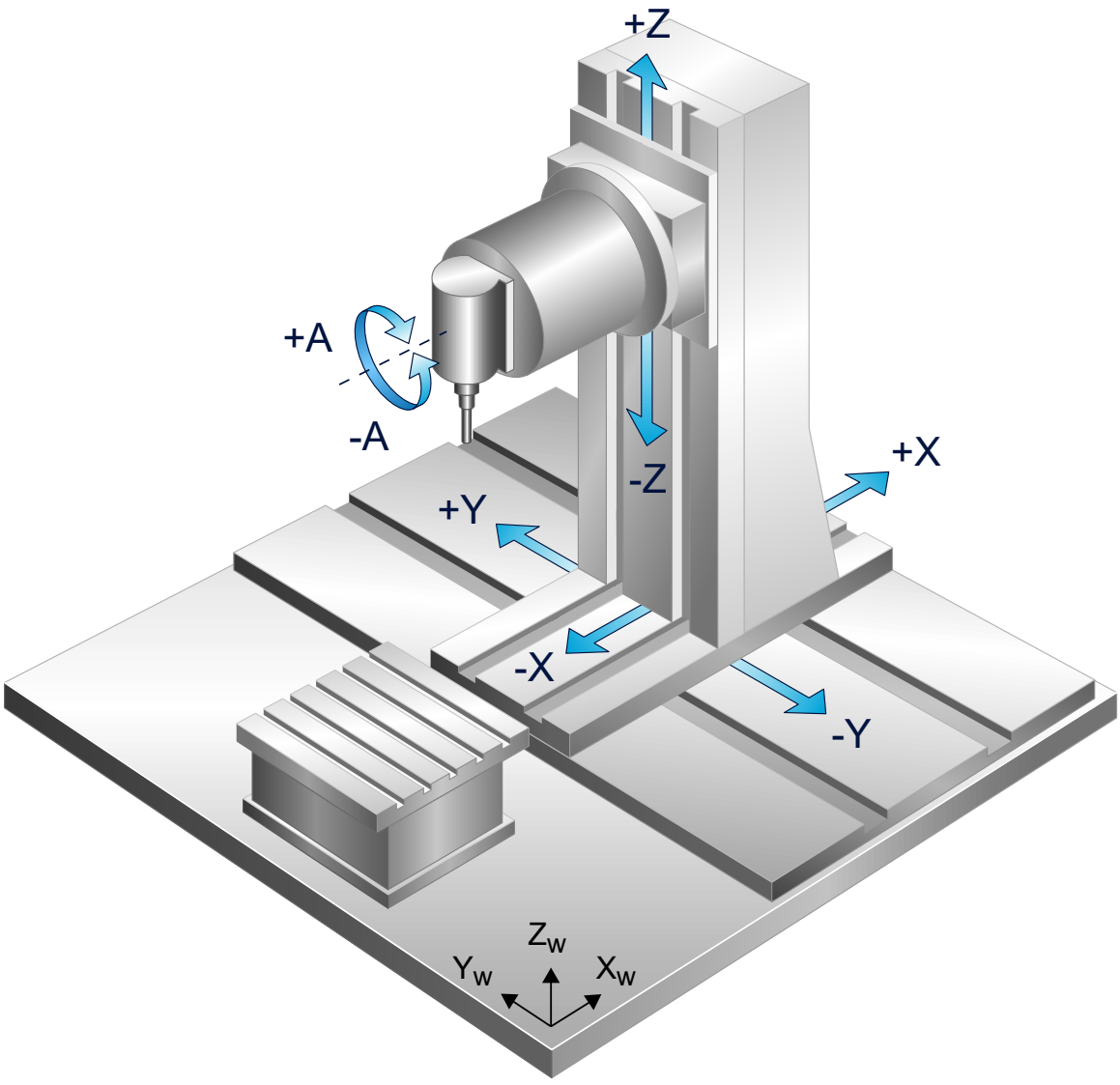


Fig. 52: 4-axis kinematics (drilling and milling unit)

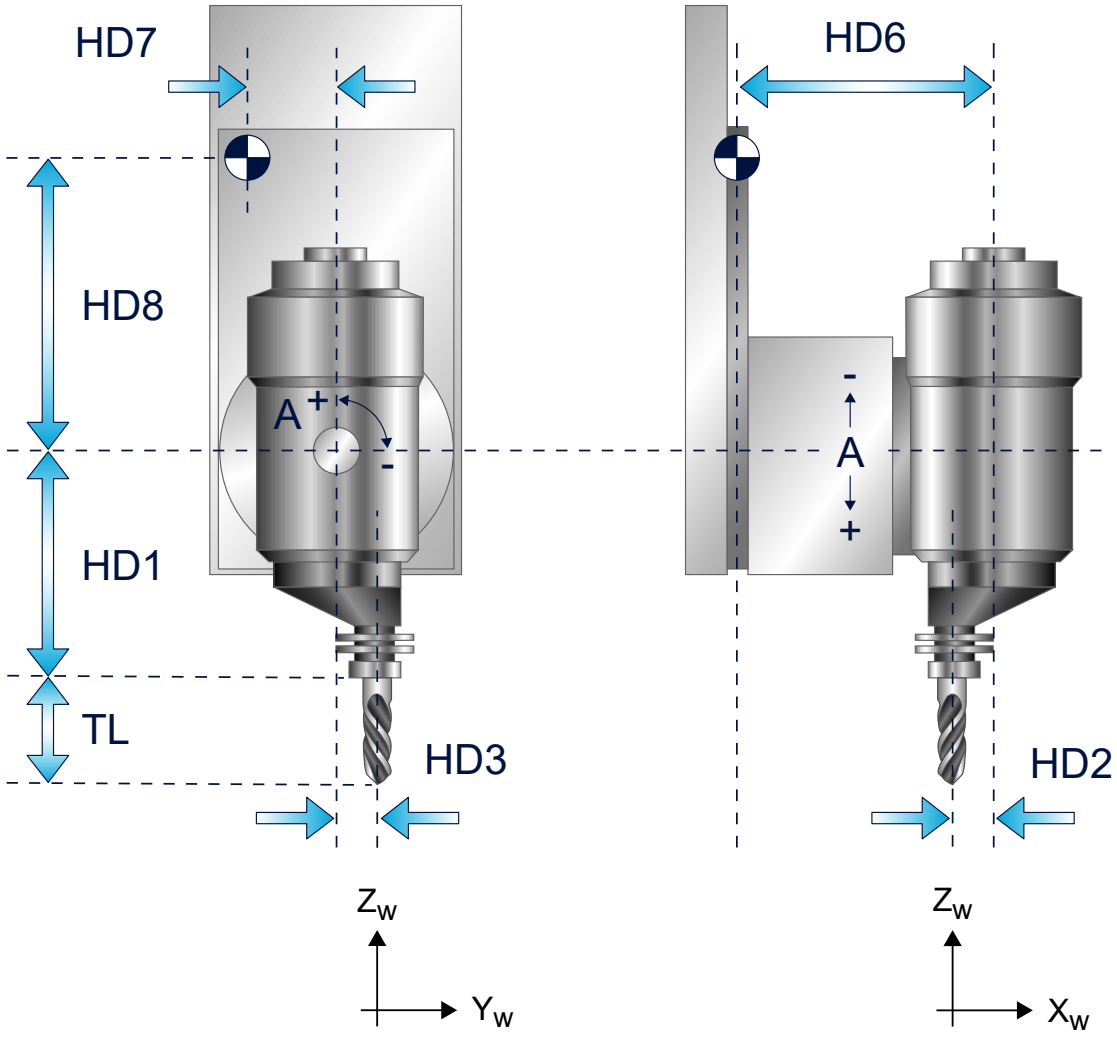


Fig. 53: Offsets of 4-axis kinematics

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset tool holding device to rotation point A axis	1.0 E-4 mm
HD2	1	X axis offset tool holding device to rotation point A axis	1.0 E-4 mm
HD3	2	Y axis offset tool holding device to rotation point A axis	1.0 E-4 mm
HD4	3	Rotation direction sign A axis: 1 (default), -1	[-]
HD5	4	Rotary offset A axis	1.0 E-4°
HD6	5	X offset rotation point A axis to reference point tool slide	1.0 E-4 mm
HD7	6	Y offset rotation point A axis to reference point tool slide	1.0 E-4 mm
HD8	7	Z offset rotation point A axis to reference point tool slide	1.0 E-4 mm

2.24 KIN_TYP_33 – 5-axis kinematics with oblique tool head

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 2 rotary NC axes in the tool. As a special feature this kinematic structure requires no compensation motions of translatory axes due to the mechanical construction when the rotary axes rotate.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C, A	-

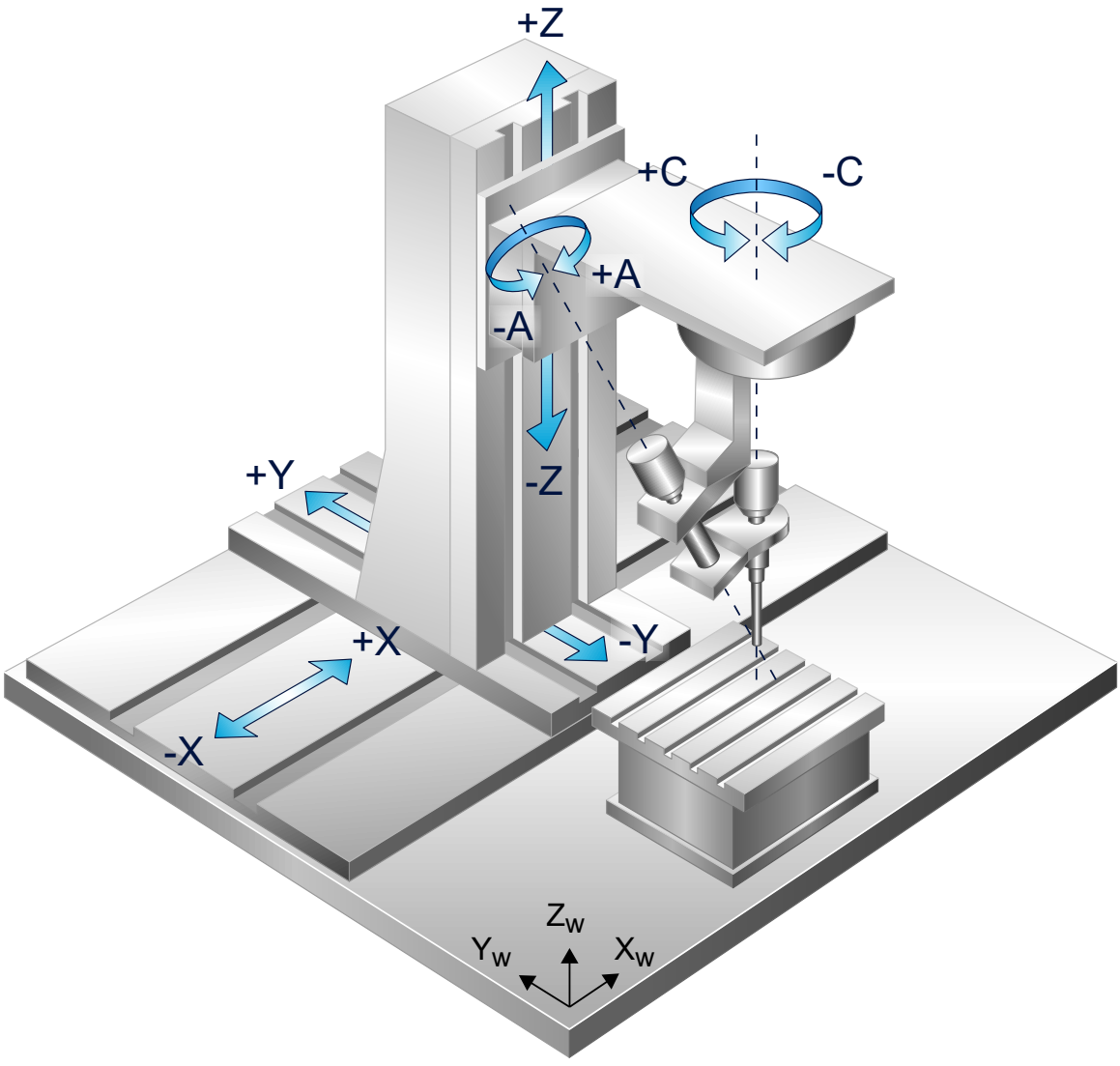


Fig. 54: 5-axis oblique tool head

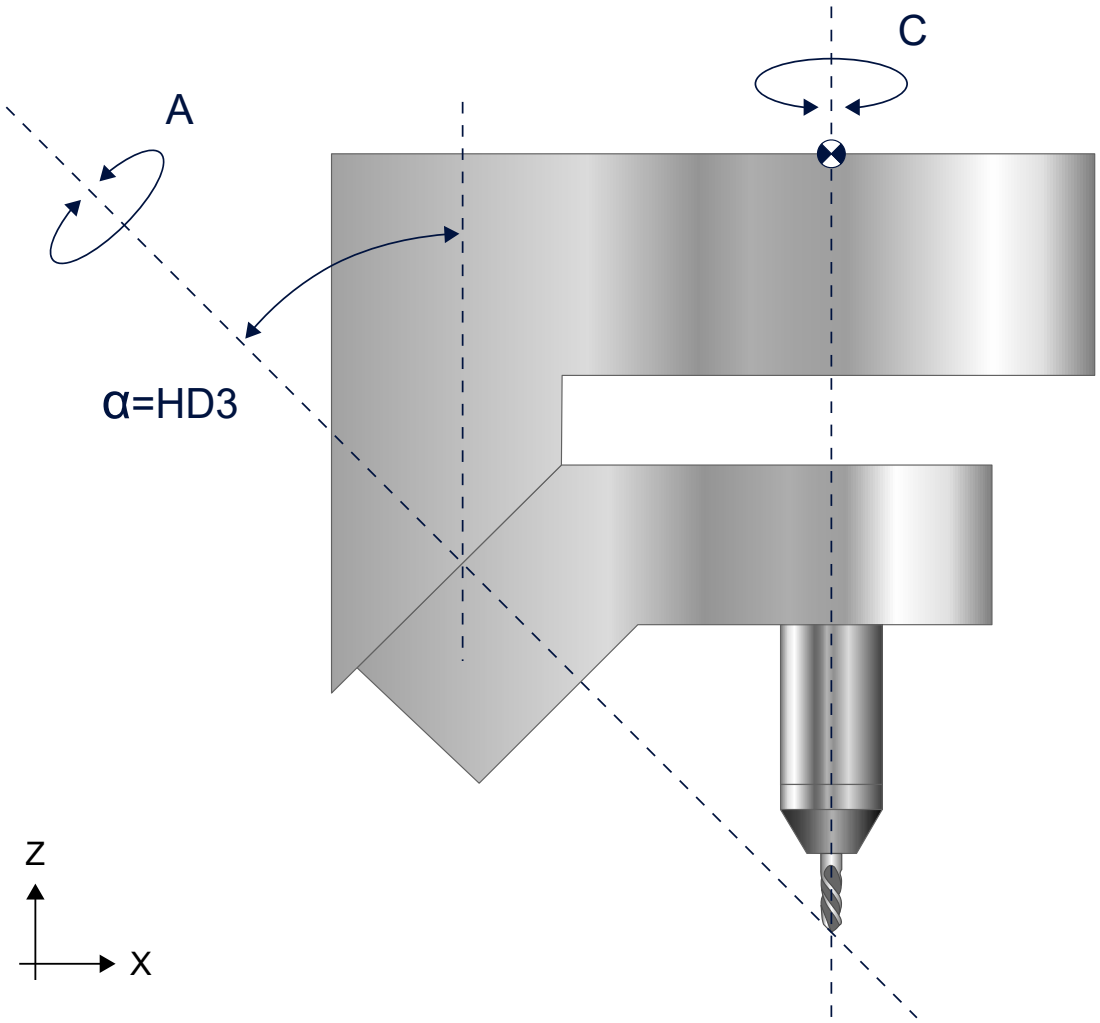


Fig. 55: Oblique tool head axis in zero position, HD7=0

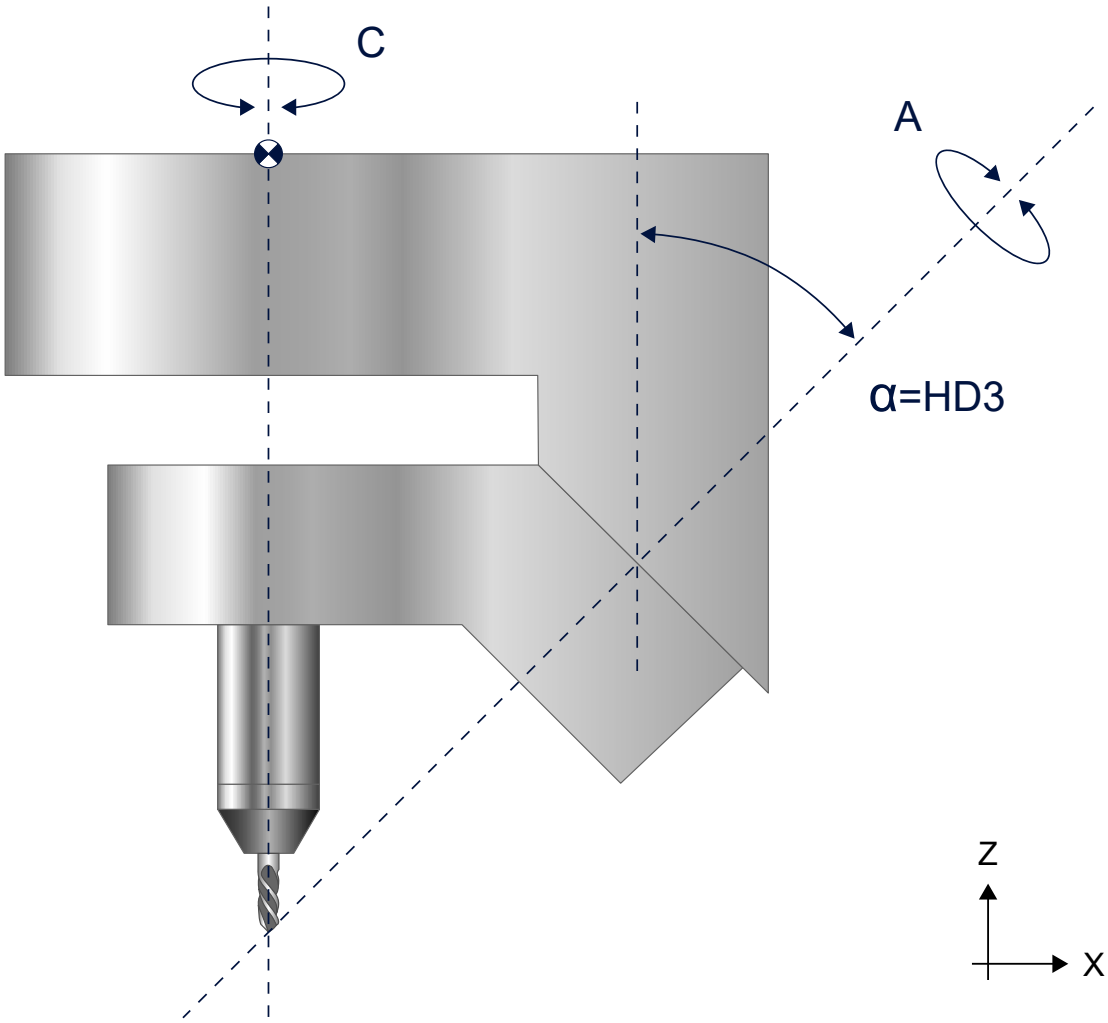


Fig. 56: Oblique tool head with 180 degree head offset in zero position, HD7=1

Offset data of kinematic structure

HD offset	param[i]	Description	Unit
HD3	2	Head angle	1.0 E-4°
HD4	3	Static X offset	1.0 E-4 mm
HD5	4	Static Y offset	1.0 E-4 mm
HD6	5	Static Z offset	1.0 E-4 mm
HD7	6	Orientation C axis head; required if head has a 180° offset in zero position	[-]

2.25 KIN_TYP_34 – 4-axis kinematics with X/C workpiece table

Kinematic structure

The kinematic structure consists of 2 translatory NC axes in the tool, 1 translatory and 1 rotary NC axis in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	Y, Z	X, C

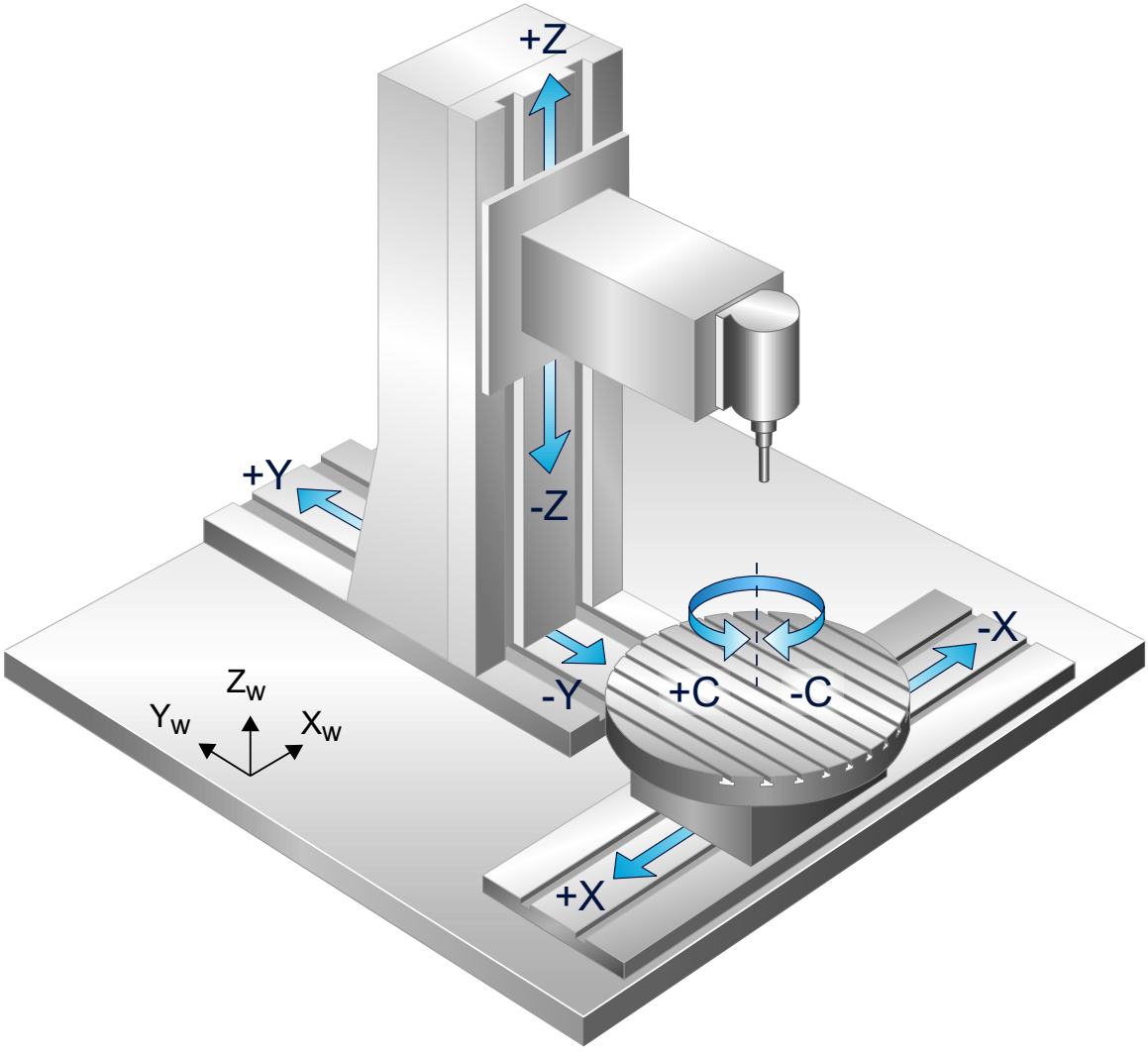


Fig. 57: 4-axis C axis kinematics

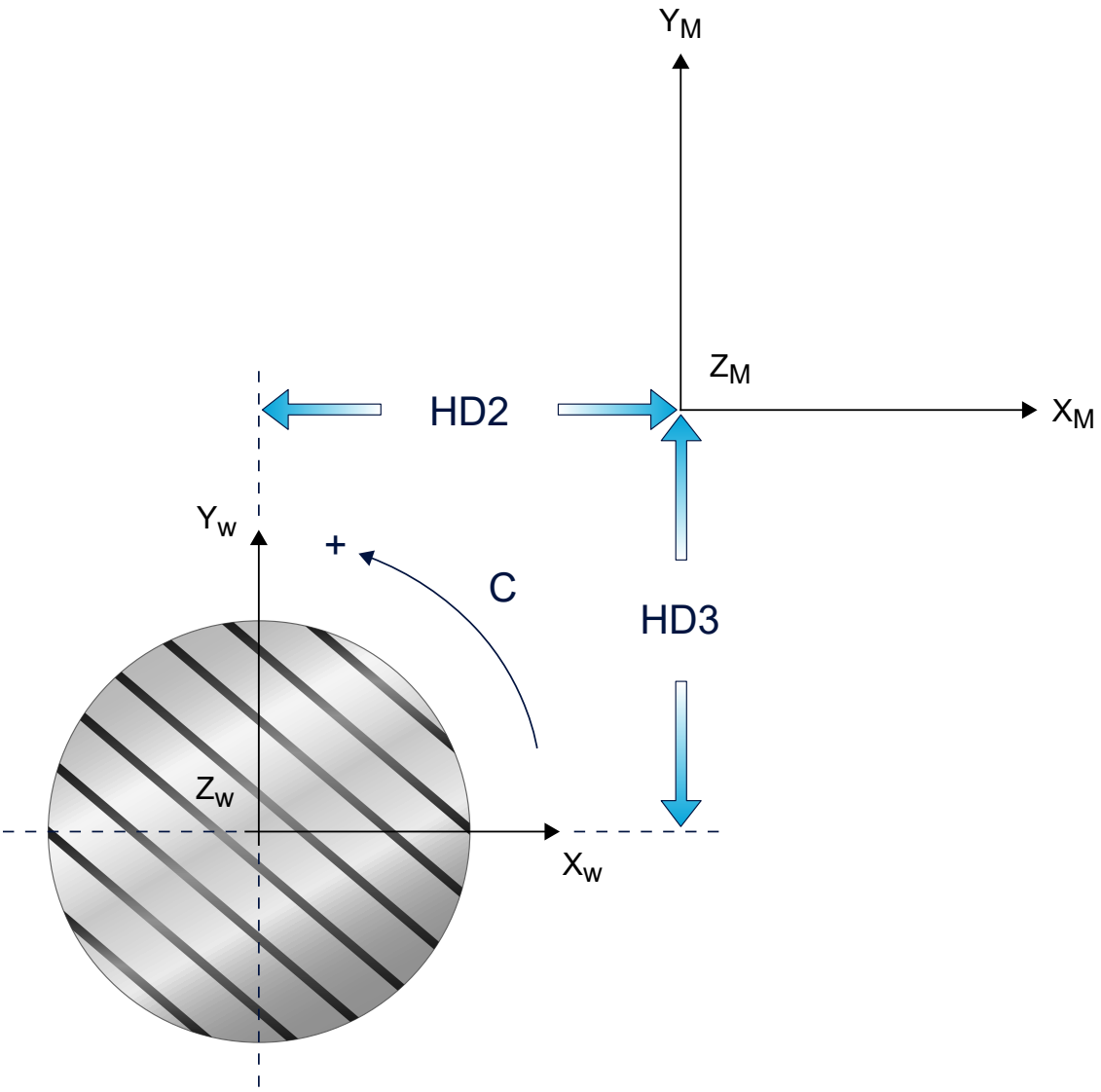


Fig. 58: Origin offsets in rotary C axis workpiece holder

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD2	1	MCS offset X	1.0 E-4 mm
HD3	2	MCS offset Y	1.0 E-4 mm

2.26 KIN_TYP_52 – 5-axis kinematics with A/B workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory axes and 2 rotary axis in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y	Z, A, B

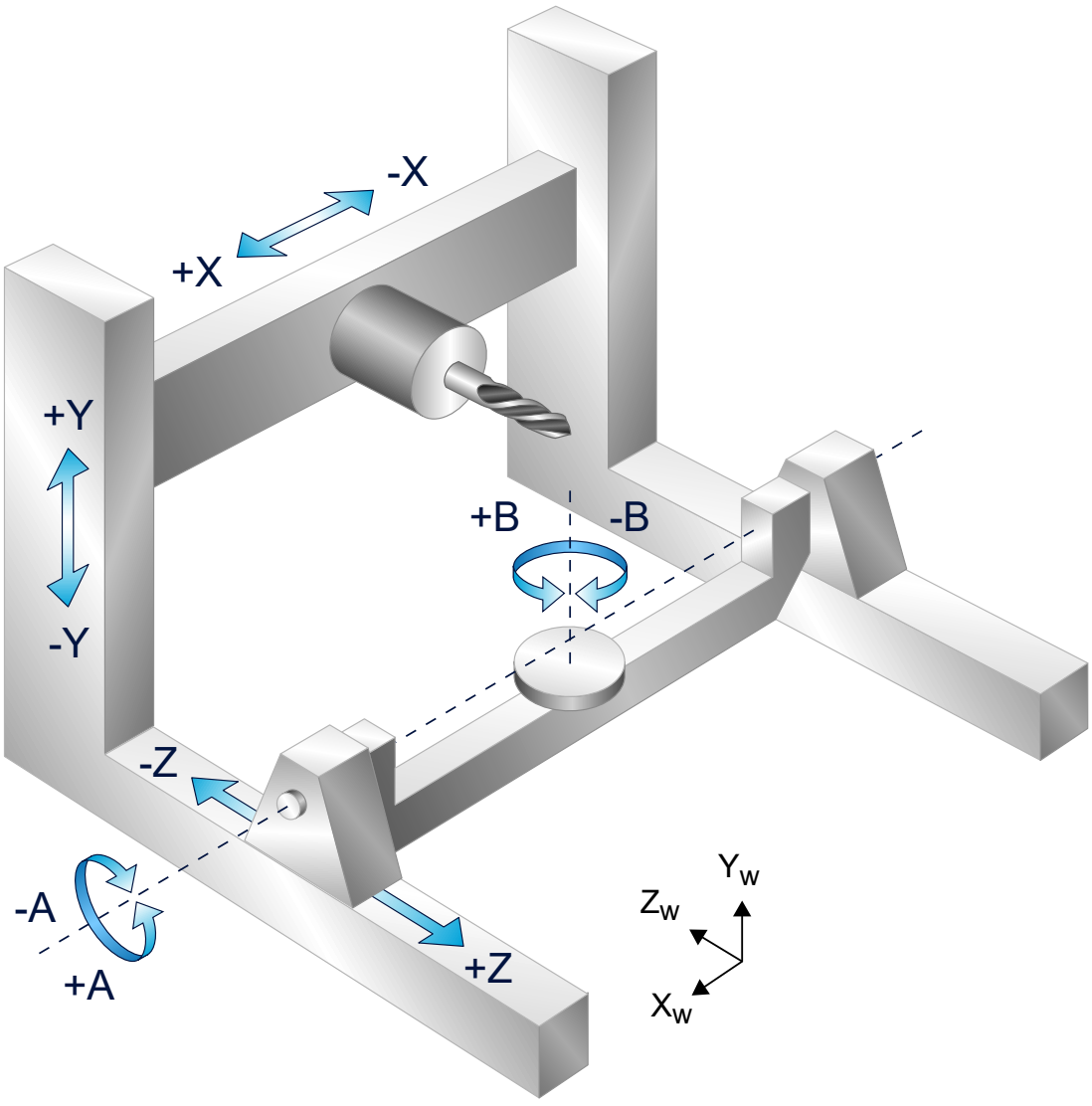


Fig. 59: Kinematics of 5-axis milling machine

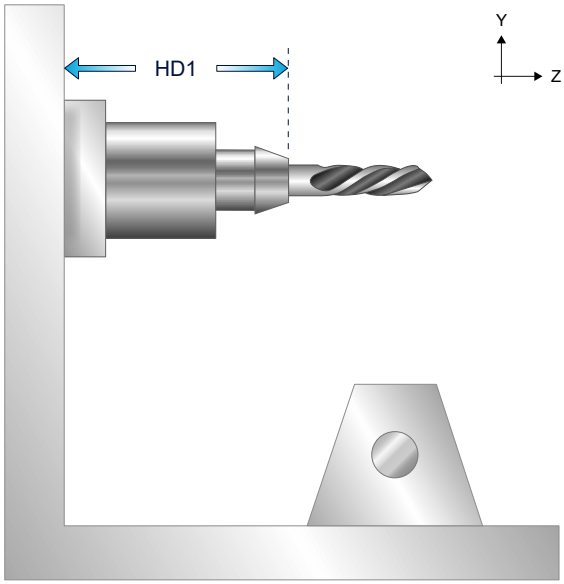


Fig. 60: Definition of offset parameters

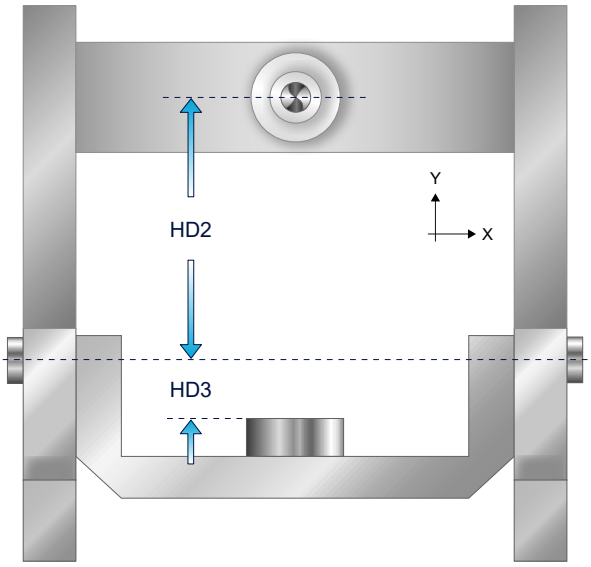


Fig. 61: Definition of offset parameters in front view

The figure above shows the kinematics for the machine axis positions Z = 0, Y = 0 and A = 0.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset up to tool clamping point.	1.0 E-4 mm
HD2	1	Y offset tool	1.0 E-4 mm
HD3	2	Y offset of workpiece coordinate system origin to rotary axis A axis	1.0 E-4 mm
HD4	3	Sign for direction of rotation A axis	[-]
HD5	4	Sign for direction of rotation B axis	[-]

2.27 KIN_TYP_57 – 5-axis kinematics with B/C workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory axes in the tool and 2 rotary axes in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B, C	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	B, C

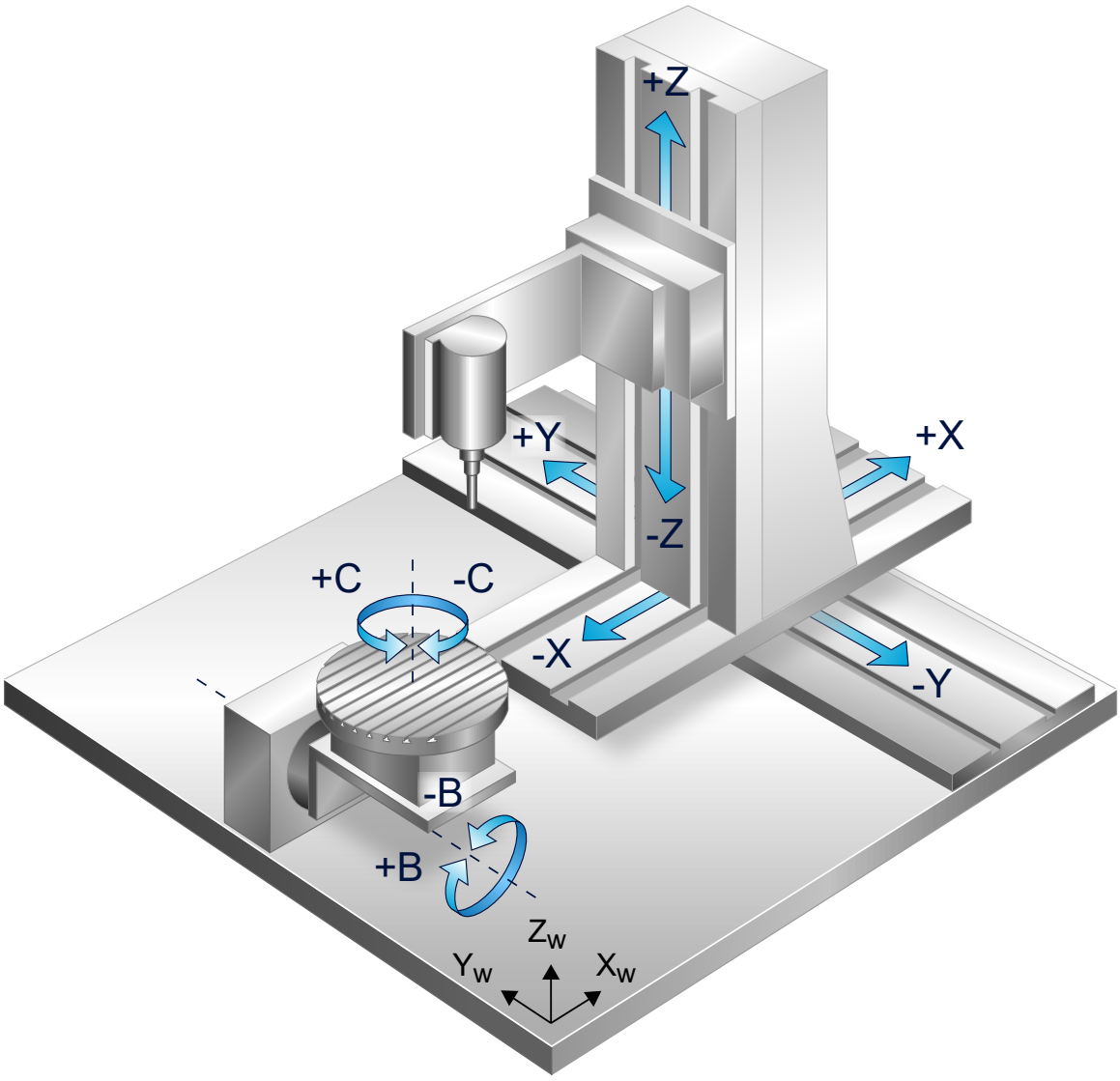


Fig. 62: Kinematics of 5-axis machine with BC workpiece table

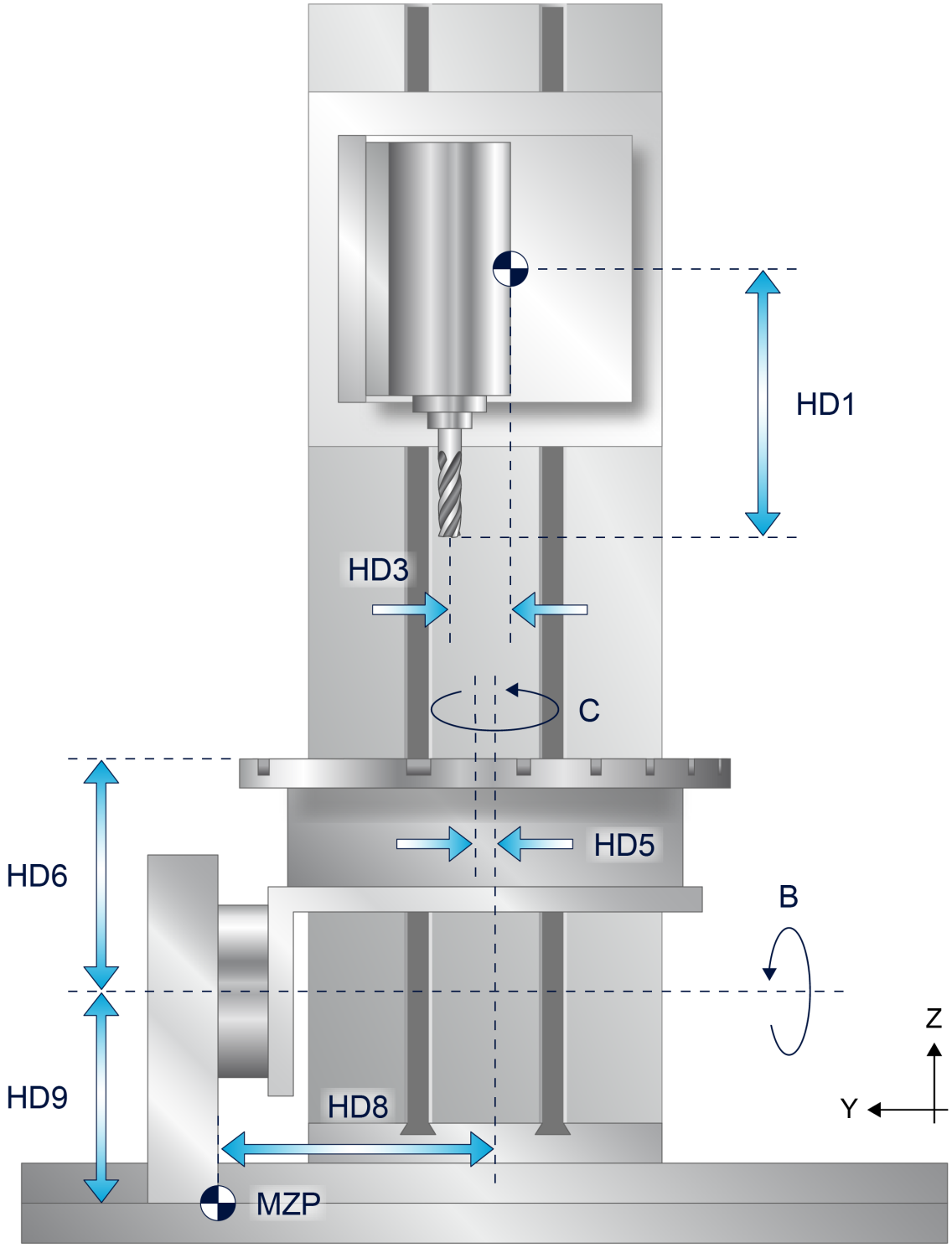


Fig. 63: Offsets in Y/Z view

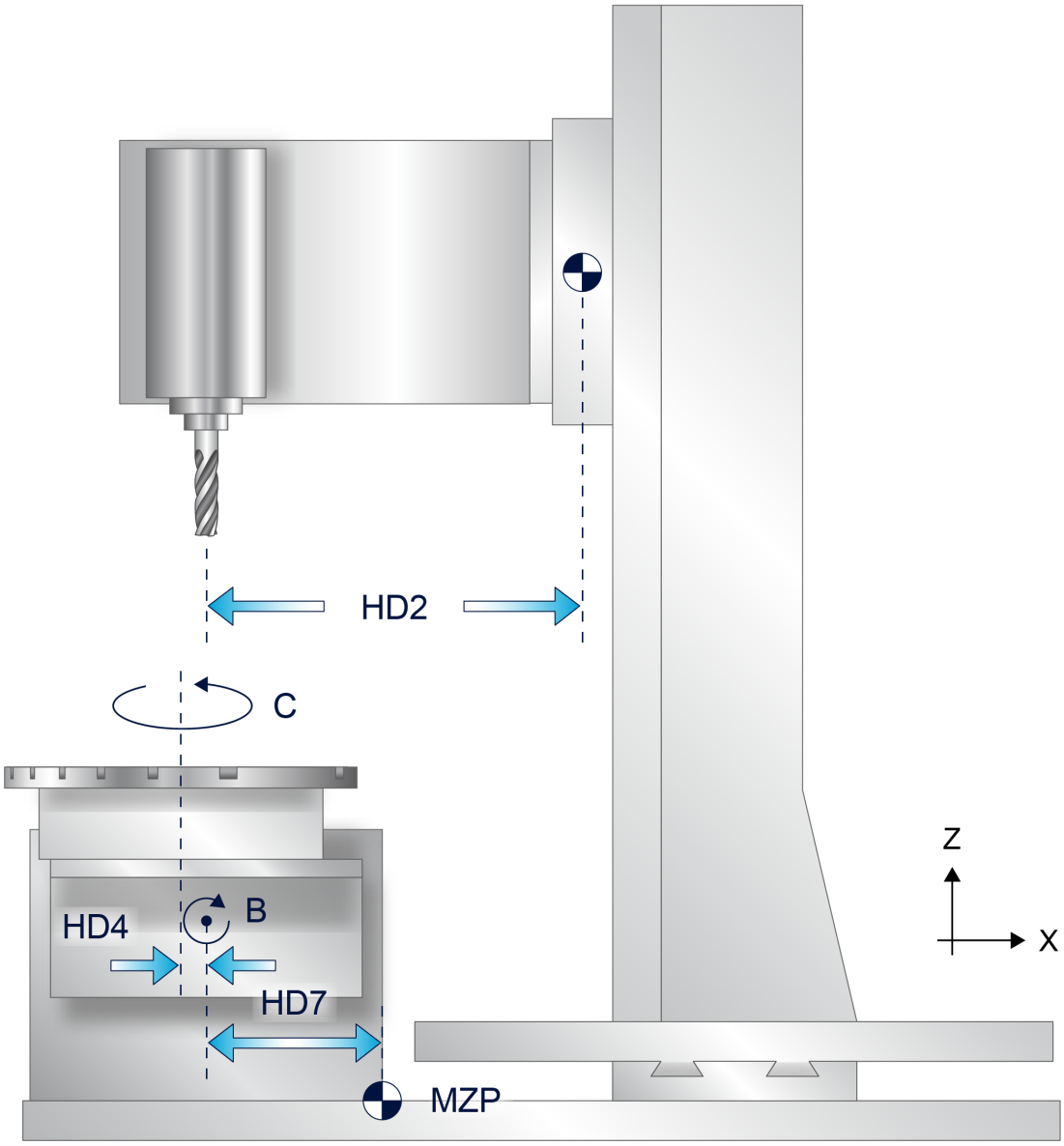


Fig. 64: Offsets in X/Z view

The machine origin can be shifted by the parameters HD7 to HD9. Differing zero positions of the rotary axes B and C can be set by the parameters HD10, HD11 so that the internal kinematic model matches the real machine kinematics. In the same way, differing rotation directions of the B and C axes can be set by the parameters HD12, HD13. In general, the signs of command and actual parameters must also be modified accordingly in the axis parameters.

The origin of the WCS on the turning table can be defined by the parameters HD14 to HD16.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z tool offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD2	1	X axis offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD3	2	Y axis offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD4	3	X axis offset rotary axis B to rotary axis C, origin WCS	1.0 E-4 mm
HD5	4	Y axis offset rotary axis B to rotary axis C, origin WCS	1.0 E-4 mm
HD6	5	Z axis offset rotary axis B to rotary axis C, origin WCS	1.0 E-4 mm
HD7	6	X offset machine origin MZP to rotary axis B	1.0 E-4 mm
HD8	7	Y offset machine origin MZP to rotary axis B	1.0 E-4 mm
HD9	8	Z offset machine origin MZP to rotary axis B	1.0 E-4 mm
HD10	9	Rotary offset B axis	1.0 E-4°
HD11	10	Rotary offset C axis	1.0 E-4°
HD12	11	Rotation direction flag B axis	[-]
HD13	12	Rotation direction flag C axis	[-]
HD14	13	X offset origin WCS	1.0 E-4 mm
HD15	14	Y offset origin WCS	1.0 E-4 mm
HD16	15	Z offset origin WCS	1.0 E-4 mm

2.28 KIN_TYP_58 – Five-axis kinematics with A/C workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory axes in the tool and 2 rotary axes in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, C	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	A, C

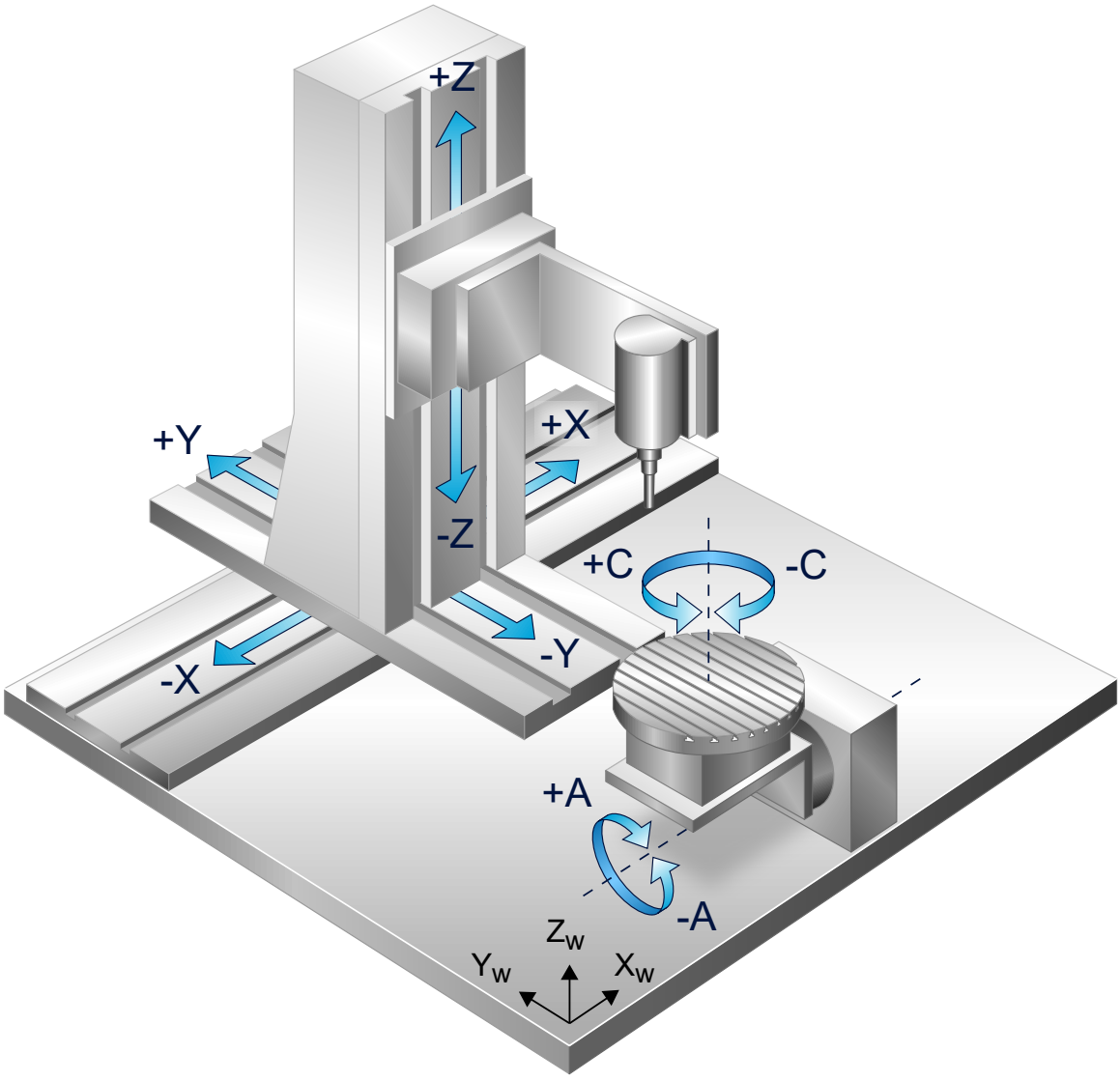


Fig. 65: Kinematics of 5-axis machine with AC workpiece table

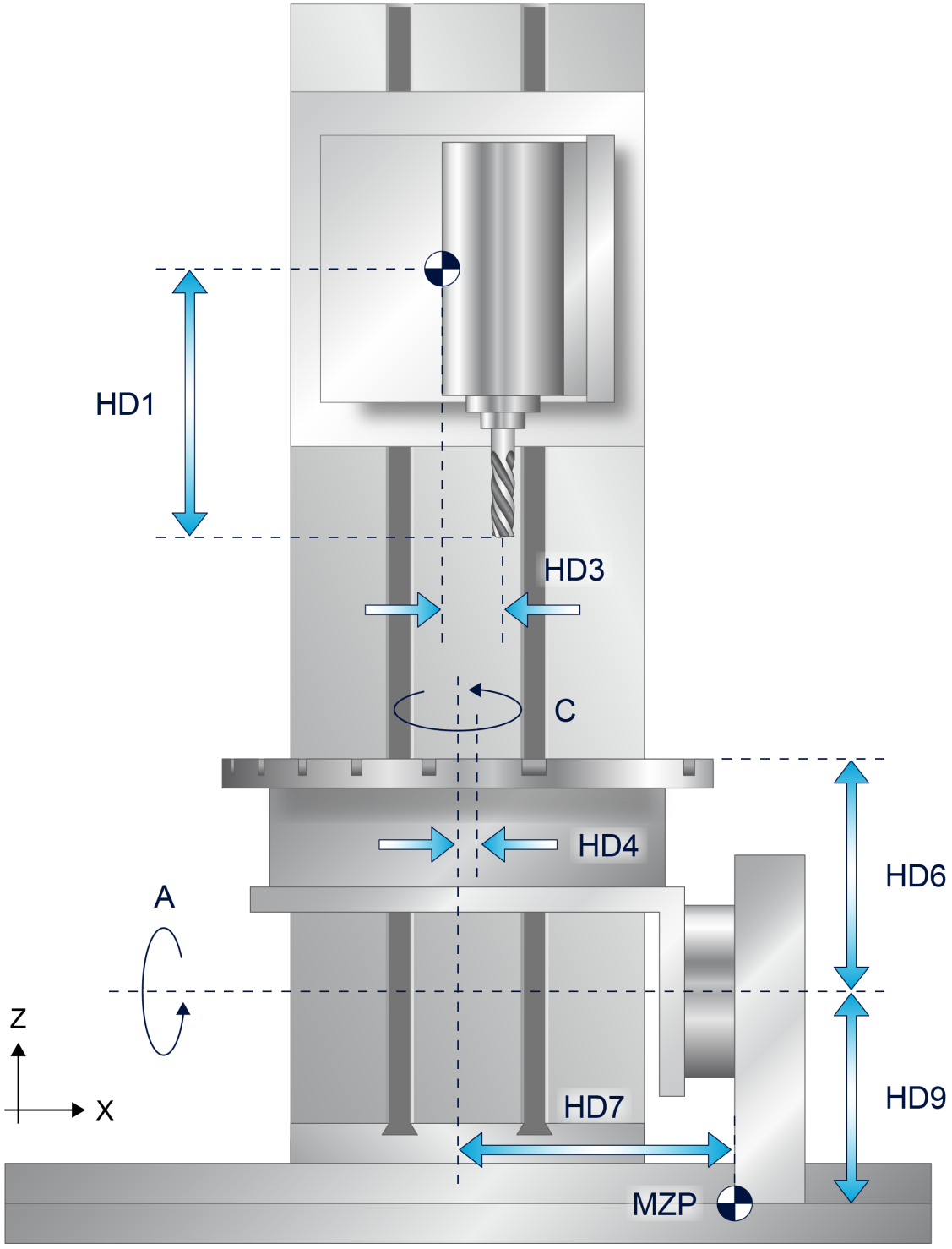


Fig. 66: Offsets in X/Z view

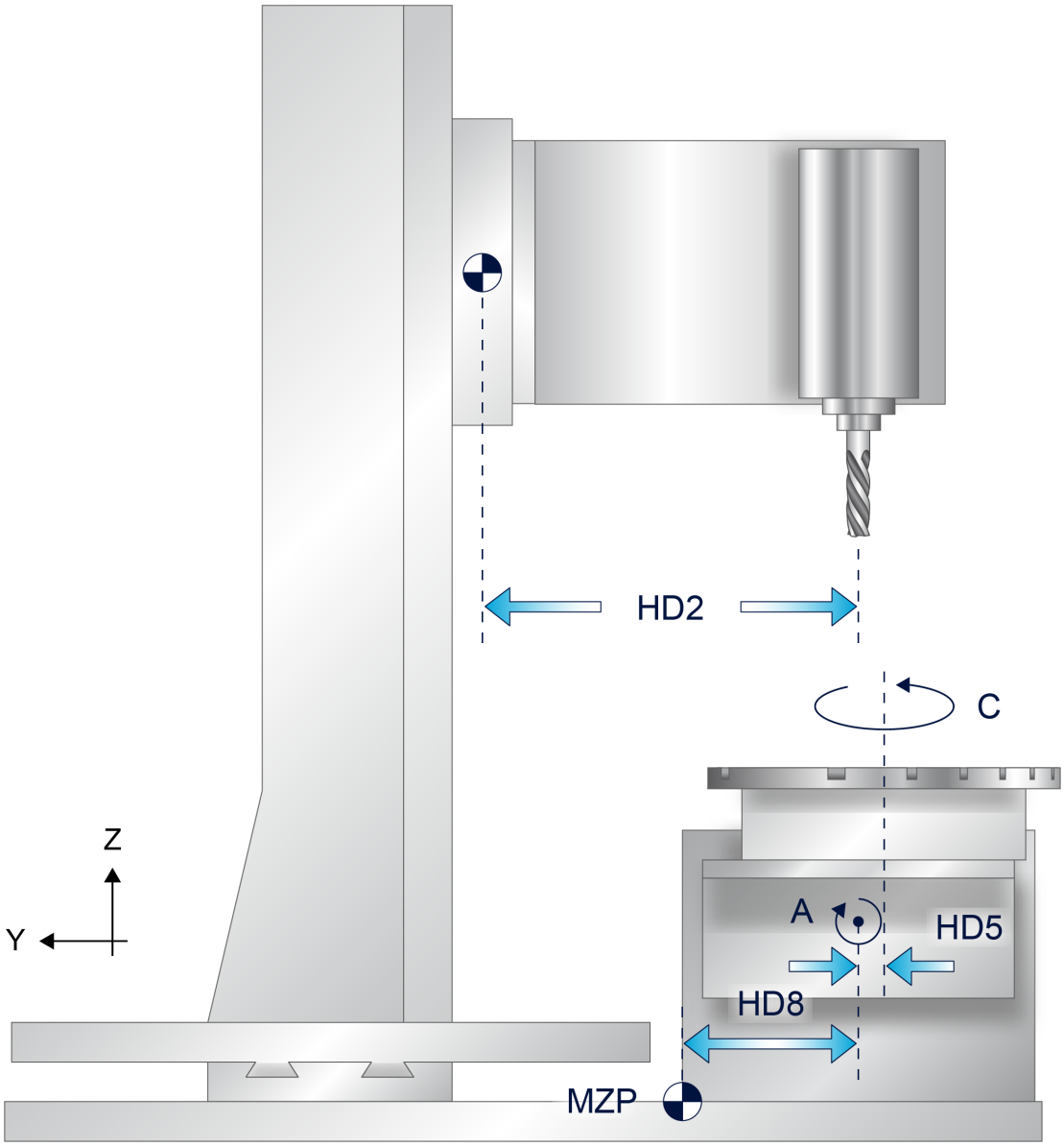


Fig. 67: Offsets in Y/Z view

Typically the machine origin is located in the rotary axis A. As required, it can be shifted using parameters HD7 to HD9. Differing zero positions of the rotary axes A and C can be set by the parameters HD10 and HD11 so that the internal kinematic model matches the real machine kinematics. In the same way differing rotation directions of the A and C axes can be set by the parameters HD12, HD13. In general, the signs of command and actual parameters must also be modified accordingly in the axis parameters.

The origin of the WCS on the turning table can be shifted by the parameters HD14 to HD16.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z tool offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD2	1	X axis offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD3	2	Y axis offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD4	3	X axis offset rotary axis A to rotary axis C, origin WCS	1.0 E-4 mm
HD5	4	Y axis offset from rotary axis A to rotary axis C, origin WCS	1.0 E-4 mm
HD6	5	Z axis offset from rotary axis A to rotary axis C, origin WCS	1.0 E-4 mm
HD7	6	X offset from machine origin MZP to rotary axis A	1.0 E-4 mm
HD8	7	Y offset from machine origin MZP to rotary axis A	1.0 E-4 mm
HD9	8	Z offset from machine origin MZP to rotary axis A	1.0 E-4 mm
HD10	9	Rotary offset A axis	1.0 E-4°
HD11	10	Rotary offset C axis	1.0 E-4°
HD12	11	Rotation direction flag A axis	[-]
HD13	12	Rotation direction flag C axis	[-]
HD14	13	X offset origin WCS	1.0 E-4 mm
HD15	14	Y offset origin WCS	1.0 E-4 mm
HD16	15	Z offset origin WCS	1.0 E-4 mm

2.29 Cardanic kinematics

2.29.1 KIN_TYP_59 – Cardanic kinematics with C/A head

The kinematic structure consists of 3 translatory and 3 rotary NC axes in the tool. The A axis is rotated about the Y axis by an angle!= 90 degrees; typically the angle is between 30 and 60 degrees.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z,C,A	-

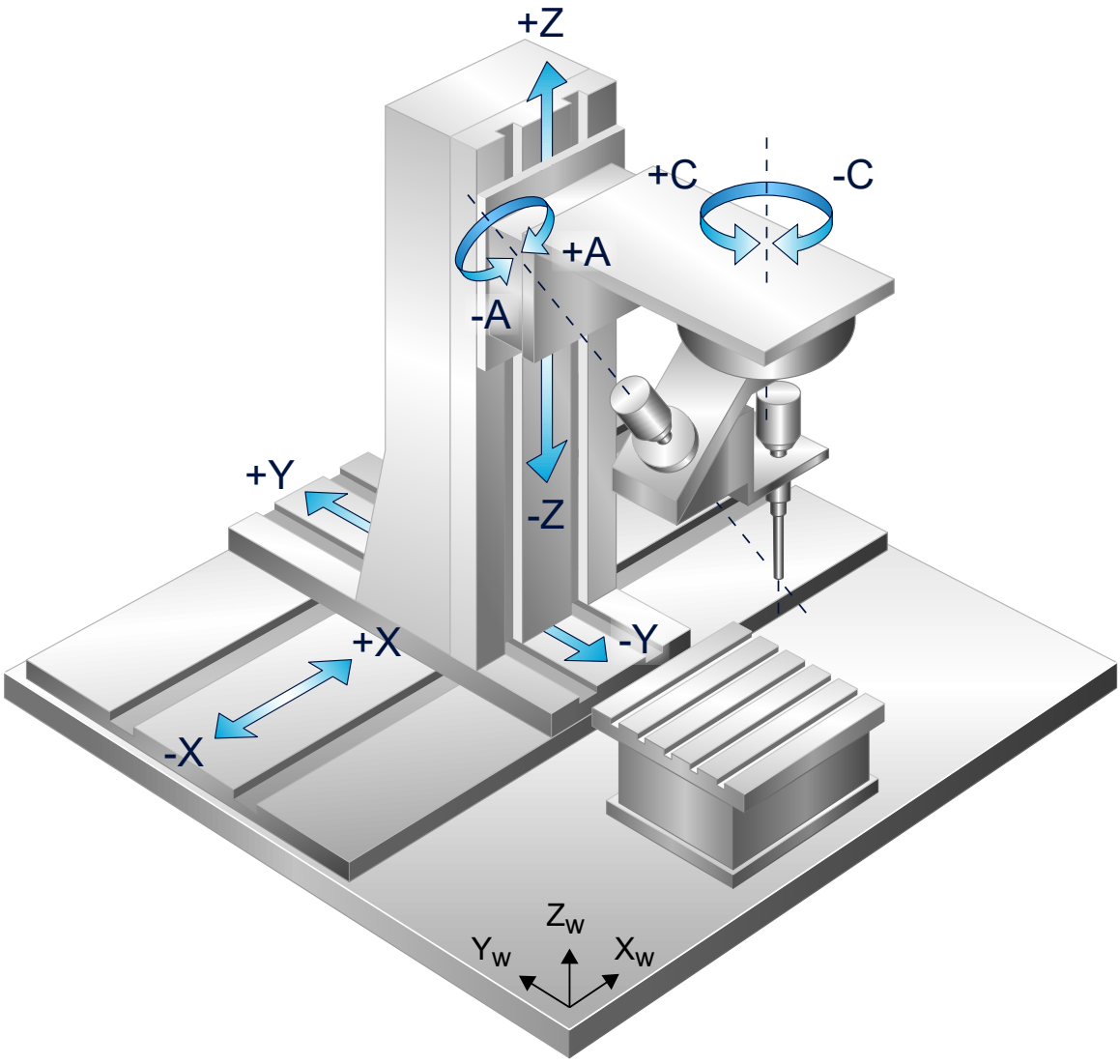


Fig. 68: Cardanic kinematic with CA head

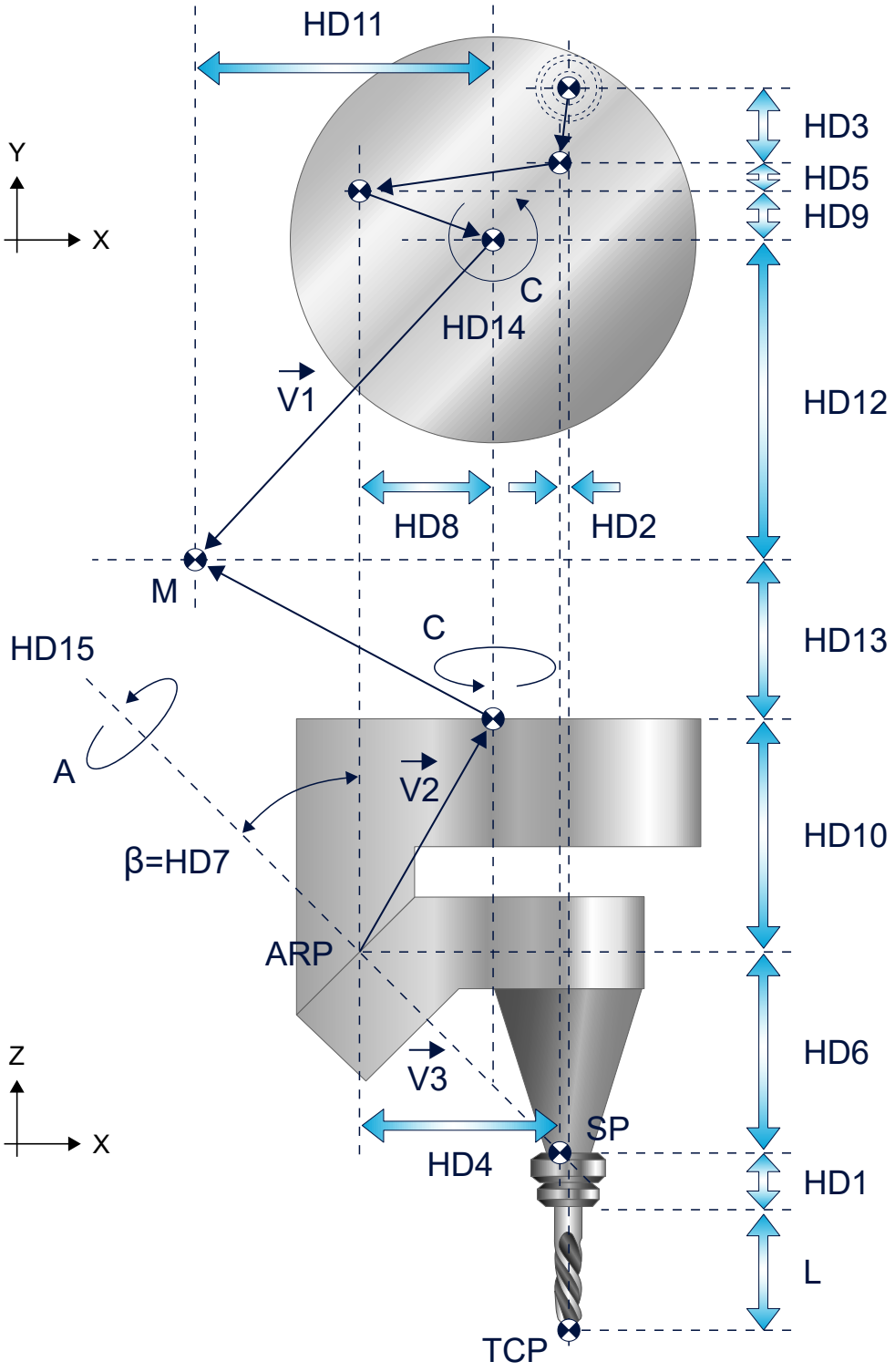


Fig. 69: Offsets of cardanic CA 5-axis head

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset to tool holding device	1.0 E-4 mm
HD2	1	X offset to tool holding device	1.0 E-4 mm
HD3	2	Y offset to tool holding device	1.0 E-4 mm
HD4	3	X offset compensation point (SP) to A axis	1.0 E-4 mm
HD5	4	Y offset compensation point (SP) to A axis	1.0 E-4 mm
HD6	5	Z offset compensation point (SP) to A axis	1.0 E-4 mm
HD7	6	Angle between A axis and Z axis	1.0 E-4°
HD8	7	X offset A axis to C axis	1.0 E-4 mm
HD9	8	Y offset A axis to C axis	1.0 E-4 mm
HD10	9	Z offset A axis to C axis	1.0 E-4 mm
HD11	10	X offset C axis to machine point M	1.0 E-4 mm
HD12	11	Y offset C axis to machine point M	1.0 E-4 mm
HD13	12	Z offset C axis to machine point M	1.0 E-4 mm
HD14	13	Rotary internal offset C axis (*)	1.0 E-4°
HD15	14	Rotary internal offset A axis (*)	1.0 E-4°
HD16	15	Rotary offset C axis (*)	1.0 E-4°
HD17	16	Rotary offset A axis (*)	1.0 E-4°
HD21	20	Control flag: 0: Transformation of rotary axes C and A, default. 1: The rotary axes C and A are machine angles.	[-]

In general the reference point referred to as ARP (rotation point of A axis) wanders to reference point SP, i.e. the vector V3 is 0 and the point SP is located in the tool axis which has the same rotary axis as the C axis. In this case only the parameters L, HD1, HD7 and HD10 are required. The kinematics can transform an A spatial angle of maximum 2*HD7.

(*) The rotary offsets HD14 and HD15 only act on the internal kinematic model, i.e. these offsets are not transferred to the rotary axes. By contrast, the offsets HD16 and HD17 act like a zero offset when kinematic transformation is active. They also lead to a re-positioning of the cardanic head with rotary offset when an angular position is programmed.

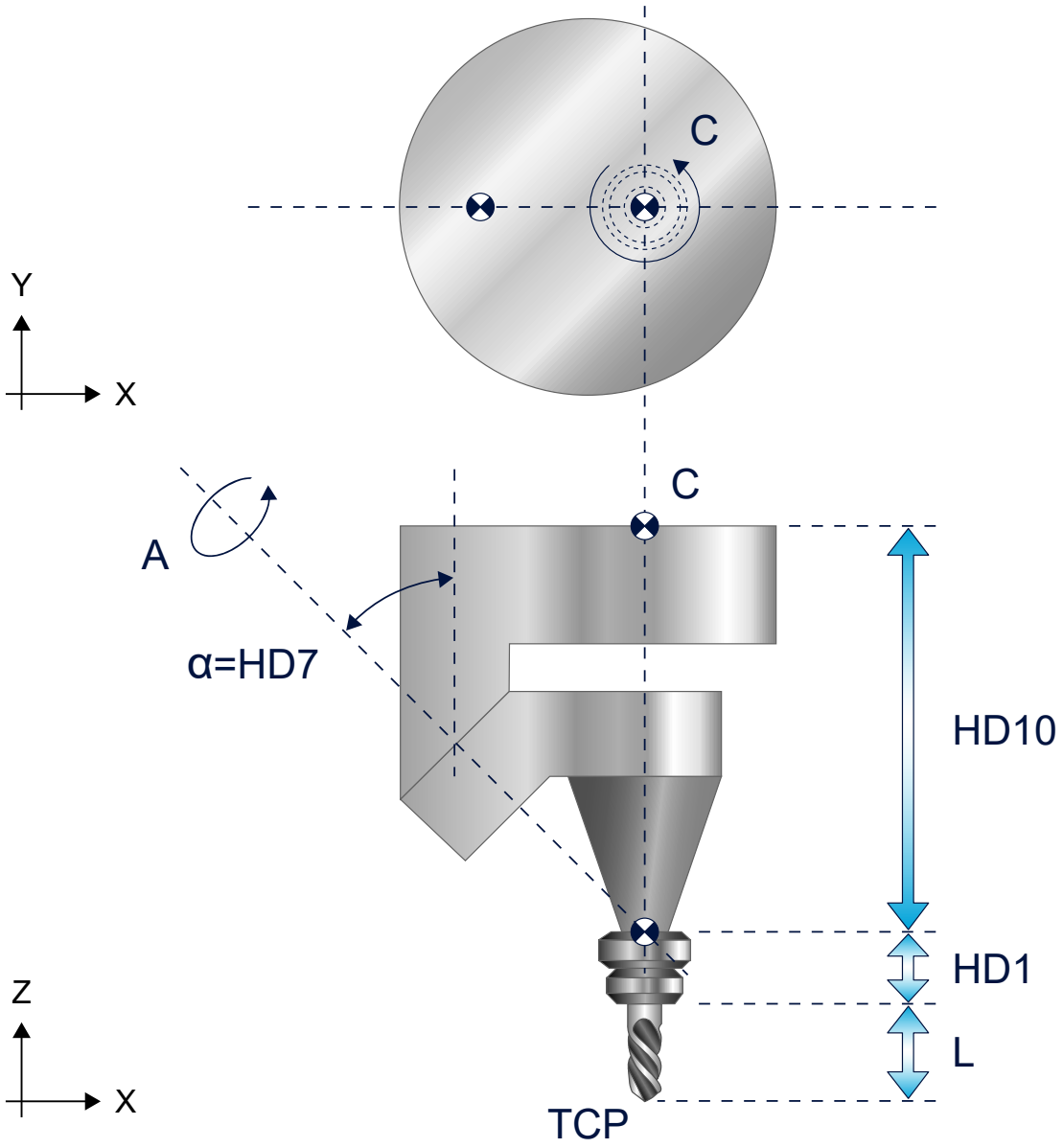


Fig. 70: Cardanic head with ideal head geometry (intersection of C-A axis is located in tool axis)

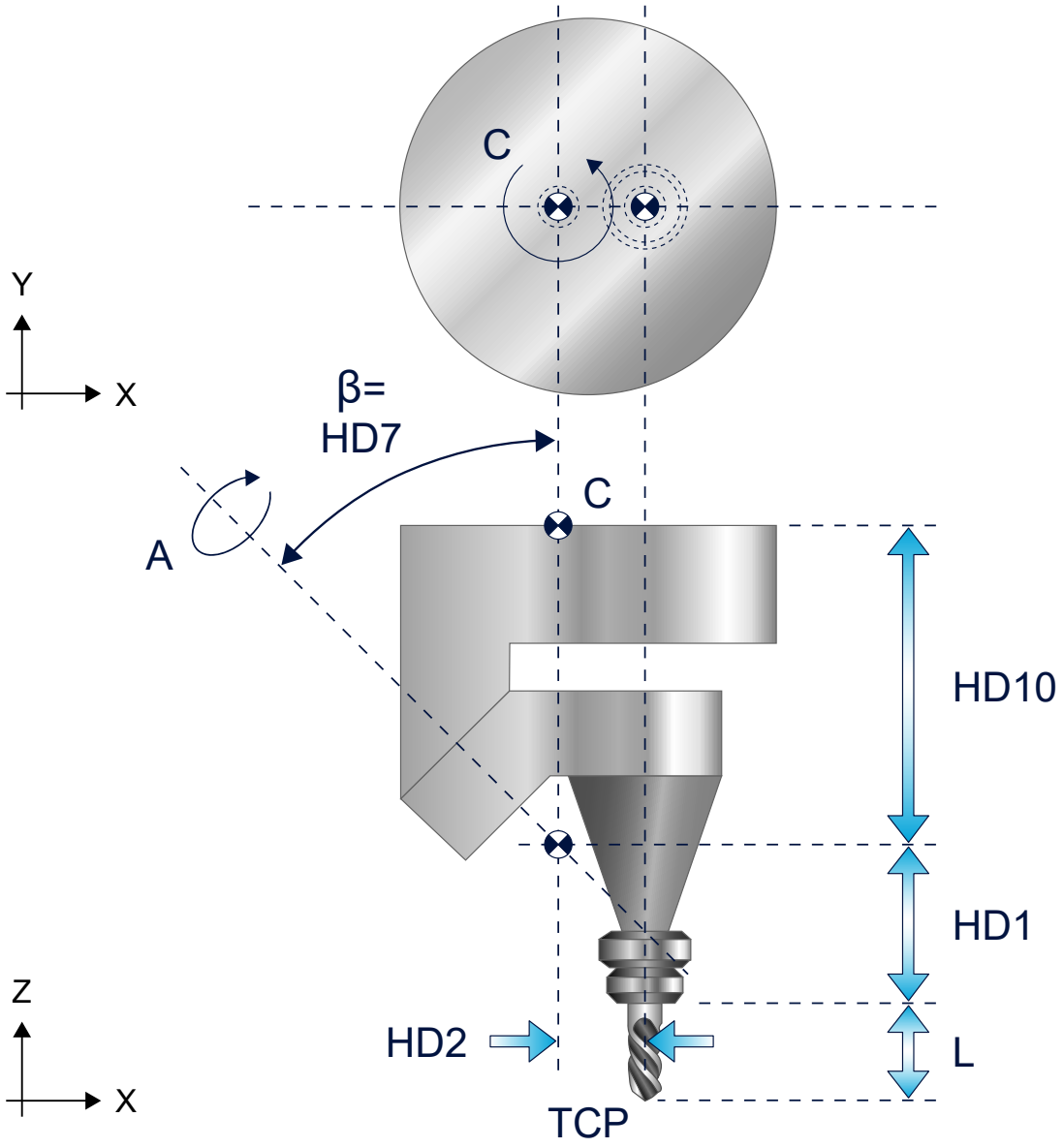


Fig. 71: Cardanic head with offset C axis (C axis not located in tool axis)

2.29.1.1 Saw blade with TCP function

When parameter HD20 is activated, kinematic transformation can be used to calculate TCP offsets dependent on the target angle A of the cardanic head. This is required to program the correct cutting depth of the saw blade when A != 0. The TCP is then located at the lowest point of the saw blade.

Set the target angle A in parameter HD19.

After target angle A != 0 is approached, the TCP is located at the bottom of the point at minimum distance to the workpiece surface as shown in the figure (when A is in zero position, the TCP is located on the right of the saw blade in X direction)

HD offset	param[i]	Description
HD19	18	Target angle A of head for saw machining
HD20	19	Control flag: 0: Default, cardanic transformation for milling 2: Cardanic transformation with TCP on saw blade When the kinematic is activated, the required tool offsets are calculated depending on the saw blade radius and target angle A. In the target angle position A != 0, the TCP is located at the lowest point on the saw blade (generally at minimum distance to the workpiece).

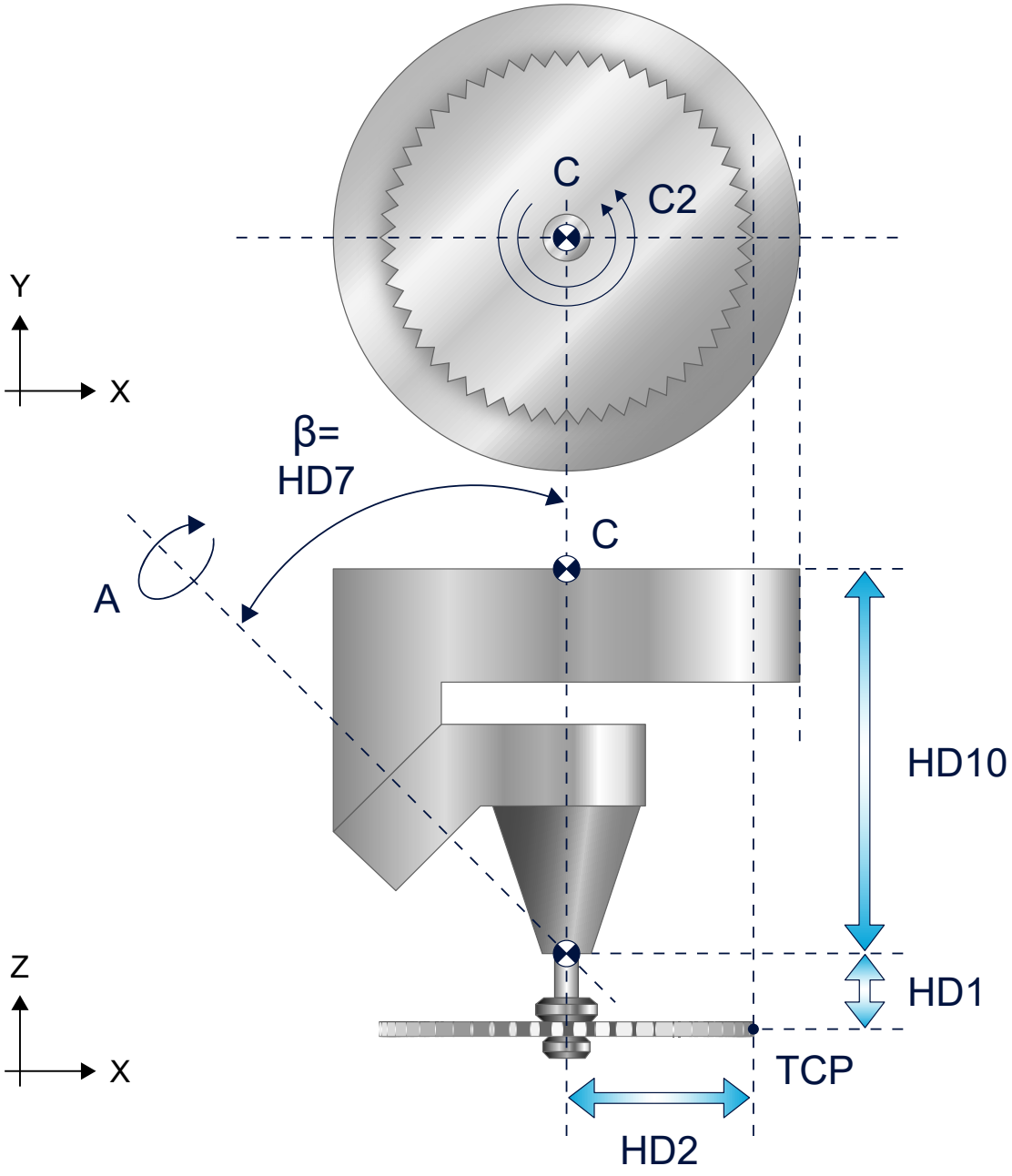


Fig. 72: Cardanic head with saw tool and TCP at saw tooth

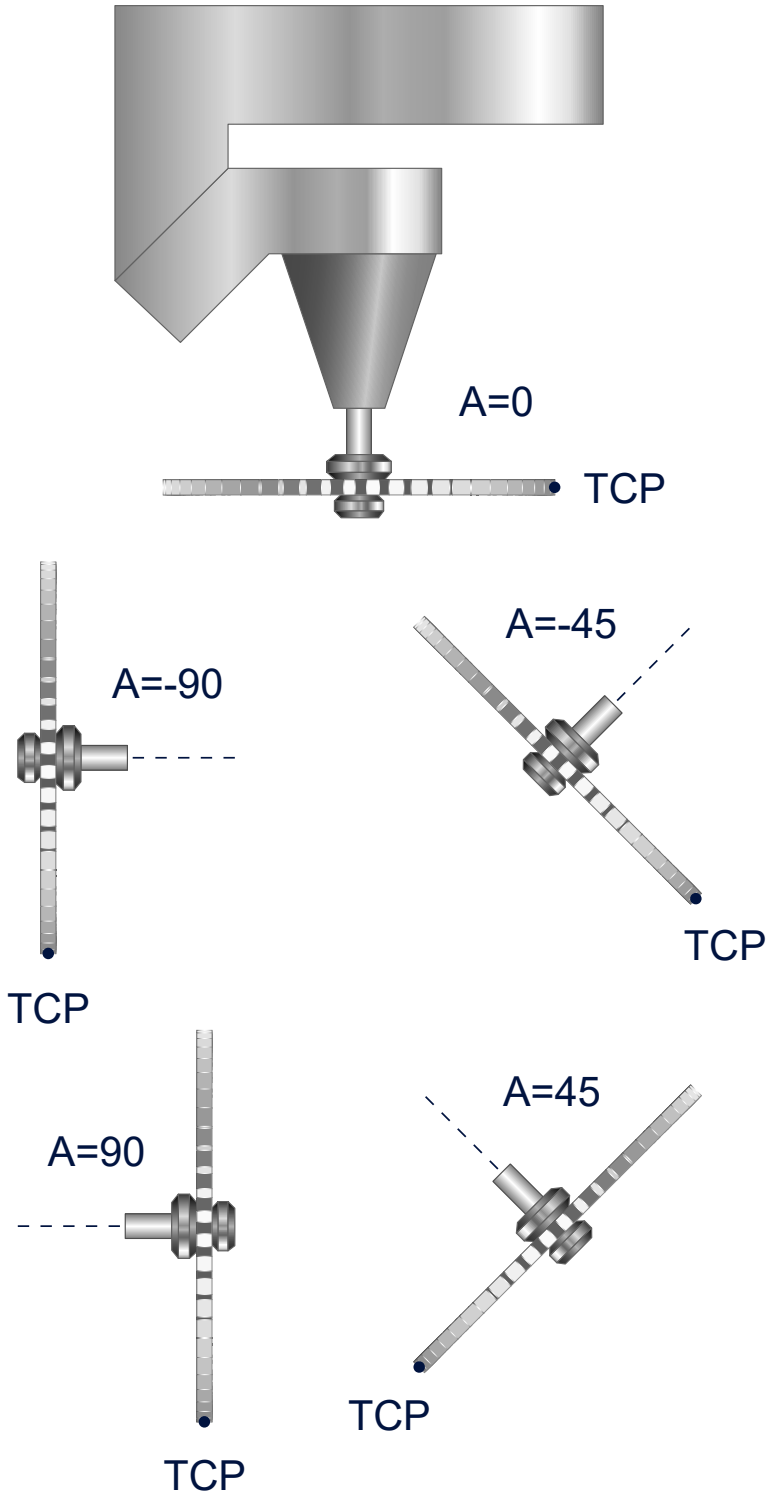


Fig. 73: Angle representations – saw tool and TCP

2.29.1.2 Special function: Flange-mounted underfloor milling tool

Additional offset data:

HD offset	param[i]	Description
HD19	18	C2 angle
HD20	19	Control flag: 0: Default cardanic transformation 1: Utility function for the calculation of the C2 angle with underfloor milling tool flange-mounted to spindle with manually adjustable C2 angle.

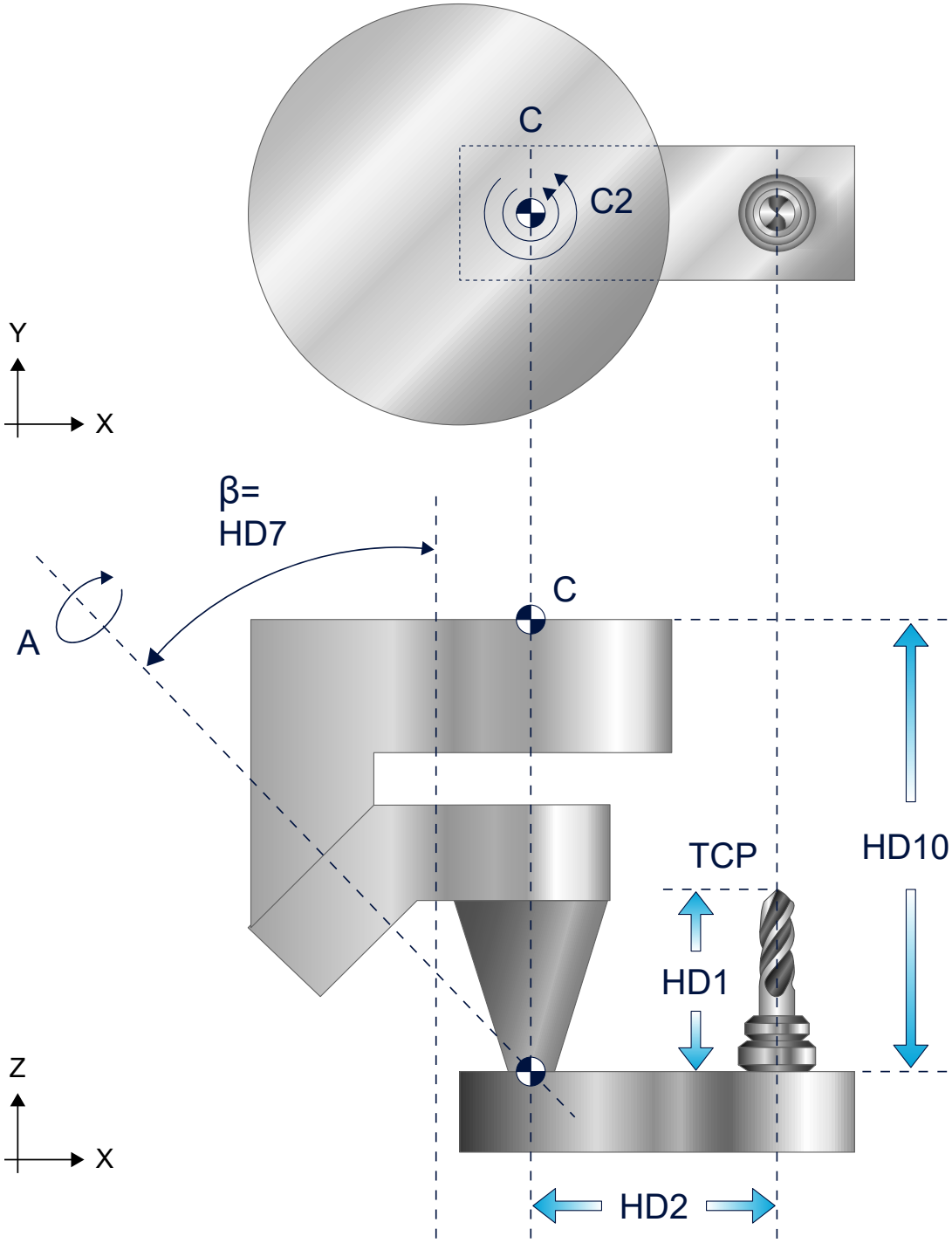


Fig. 74: Cardanic head with underfloor milling tool

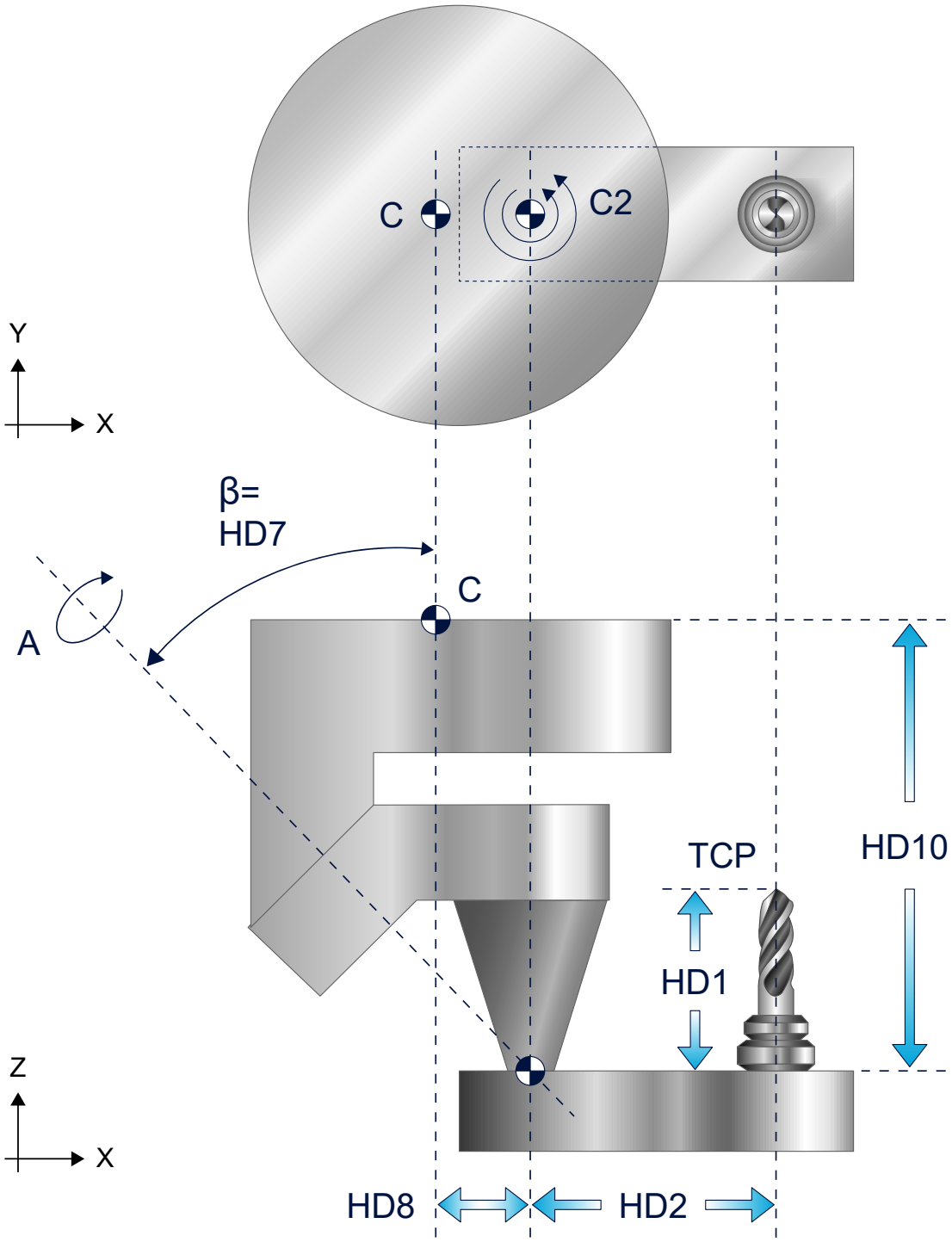


Fig. 75: Cardanic head with underfloor milling tool with offset C

2.29.2 KIN_TYP_60 – Cardanic kinematics with C/B head

The kinematic structure consists of 3 translatory and 3 rotary NC axes in the tool. The B axis is arranged about the X axis rotated by an angle!= 90 degrees; the angle is typically between 30 and 60 degrees.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z,C,B	-

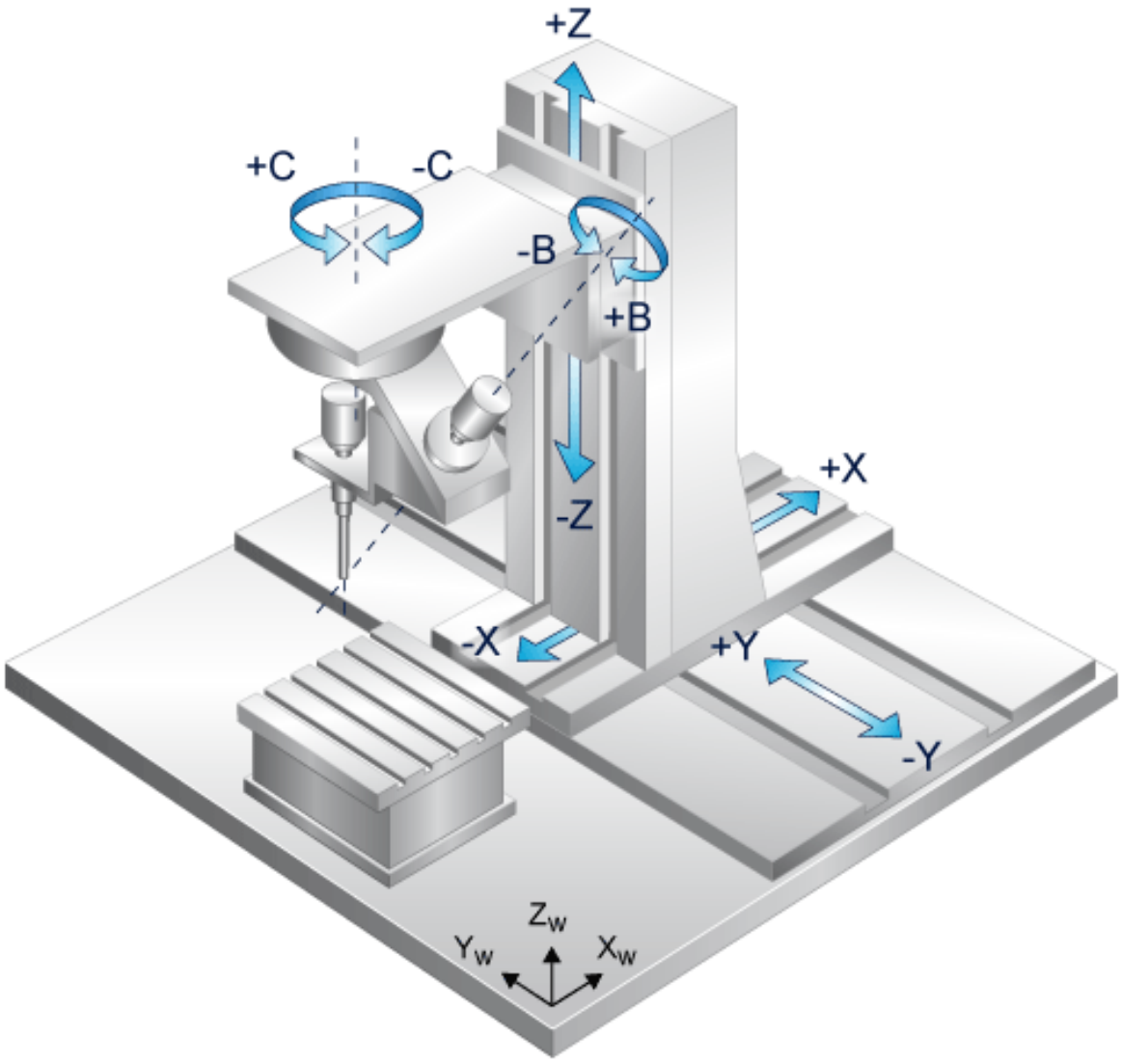


Fig. 76: Cardanic kinematic with CB head

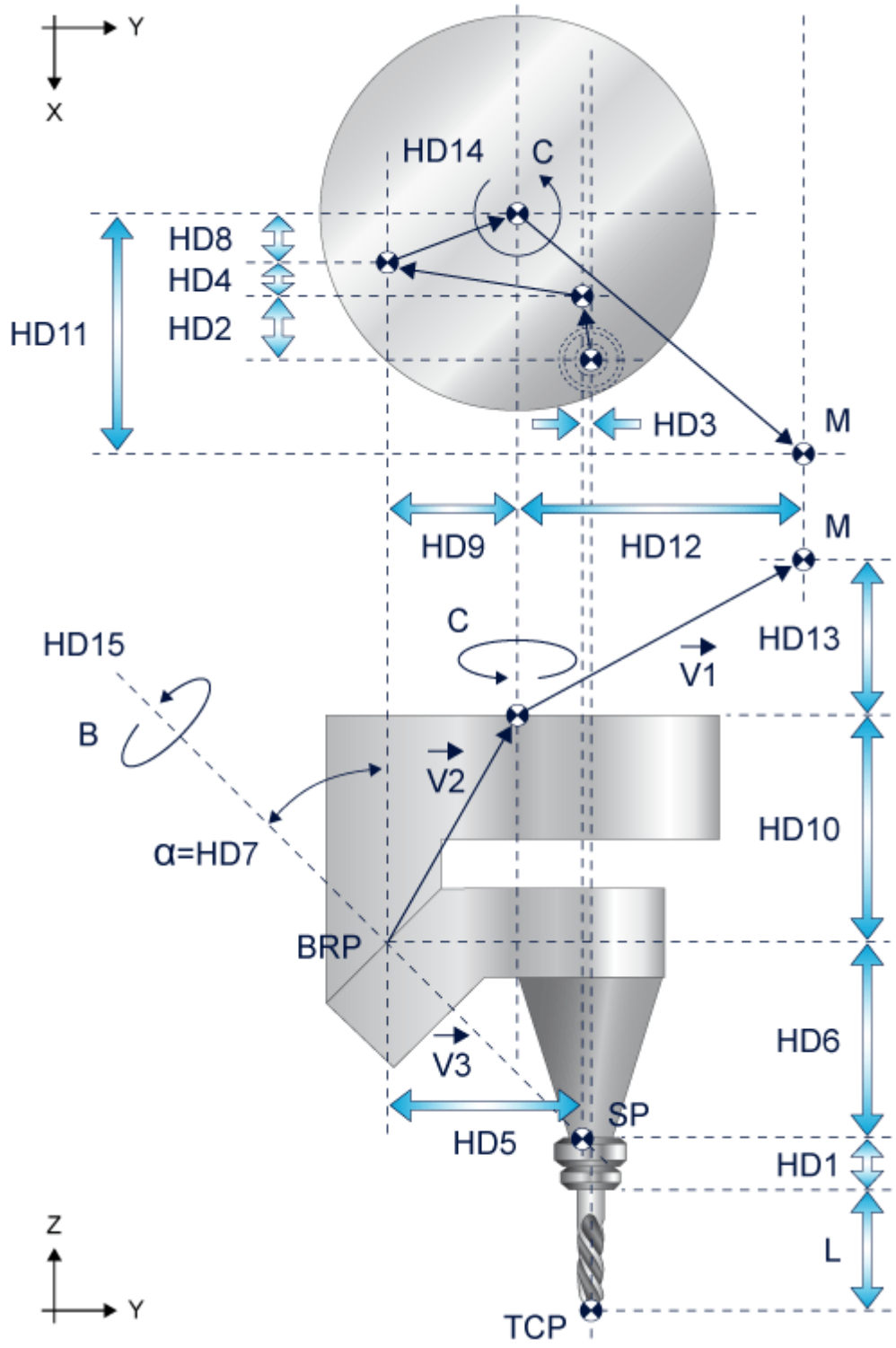


Fig. 77: Offsets of cardanic CB 5-axis head

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset to tool holding device	1.0 E-4 mm
HD2	1	X offset to tool holding device	1.0 E-4 mm
HD3	2	Y offset to tool holding device	1.0 E-4 mm
HD4	3	X offset compensation point (SP) to B axis	1.0 E-4 mm
HD5	4	Y offset compensation point (SP) to B axis	1.0 E-4 mm
HD6	5	Z offset compensation point (SP) to B axis	1.0 E-4 mm
HD7	6	Angle between B axis and Z axis	1.0 E-4°
HD8	7	X offset B axis to C axis	1.0 E-4 mm
HD9	8	Y offset B axis to C axis	1.0 E-4 mm
HD10	9	Z offset B axis to C axis	1.0 E-4 mm
HD11	10	X offset C axis to machine point M	1.0 E-4 mm
HD12	11	Y offset C axis to machine point M	1.0 E-4 mm
HD13	12	Z offset C axis to machine point M	1.0 E-4 mm
HD14	13	Rotary offset C axis	1.0 E-4°
HD15	14	Rotary offset B axis	1.0 E-4°
HD21	20	Control flag for rotary axes C and B 0: Transformation of C and B, default. 1: C and B are machine angles.	[-]

In general the reference point referred to as BRP (rotation point of B axis) wanders to reference point SP, i.e. the vector V3 is 0 and the point SP is located in the tool axis which has the same rotary axis as the C axis. In this case only the parameters L, HD1, HD7 and HD10 are required.

The kinematics can transform a B spatial angle of maximum 2*HD7.

(*) The rotary offsets HS14 and HD 15 only act on the internal kinematic model, i.e. these offsets do not lead to a re-positioning of the cardanic head as for a rotary zero offset and programming of an angle position.

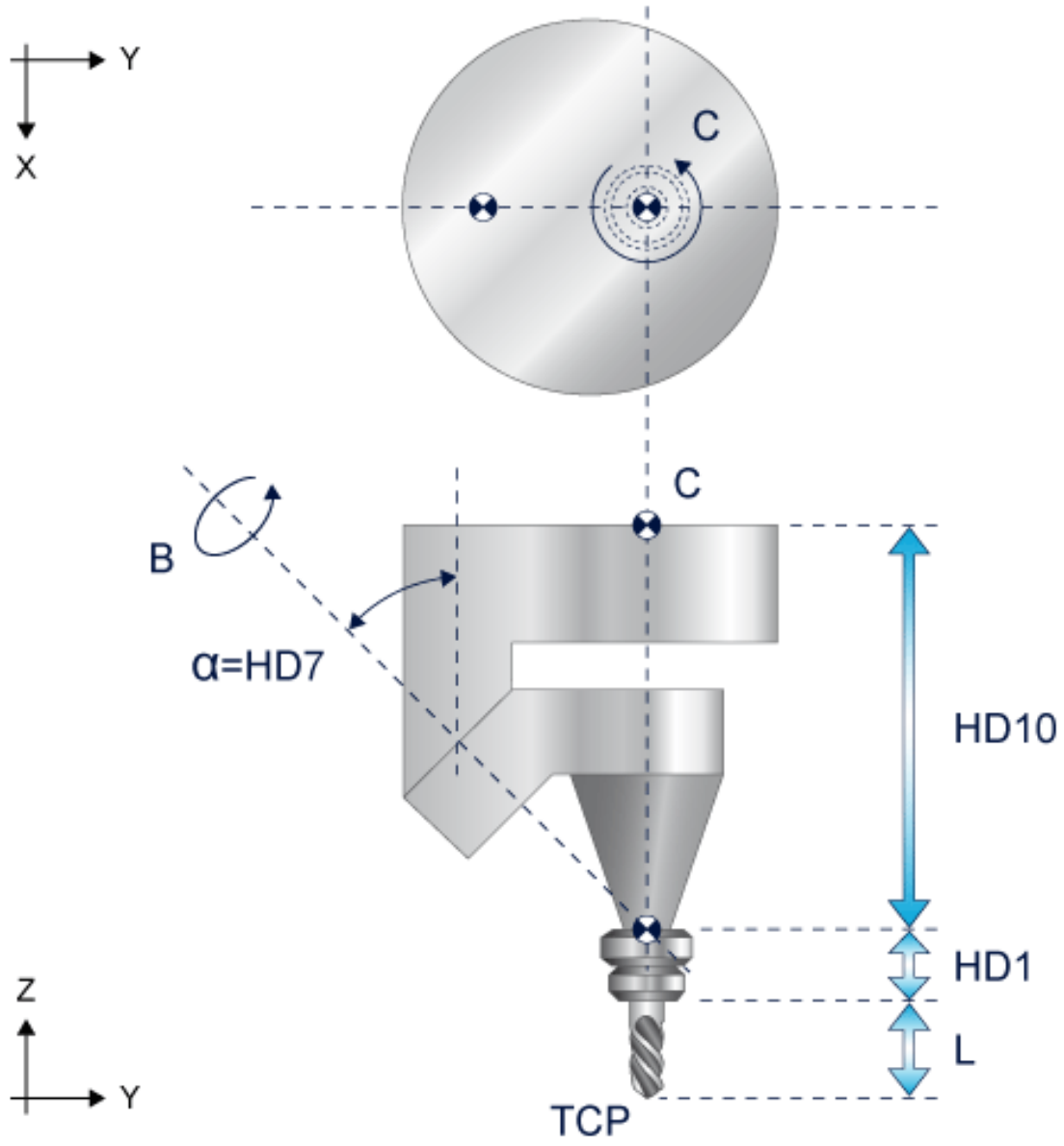


Fig. 78: Cardanic head with ideal head geometry (intersection of C and B axis located in tool axis)

2.30 KIN_TYP_61 – 5-axis kinematics with Y/A workpiece table

Kinematic structure

The kinematic structure consists of one translatory and one rotary NC axis in the workpiece and 2 translatory and one rotary NC axis in the tool.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Z, B	Y, A

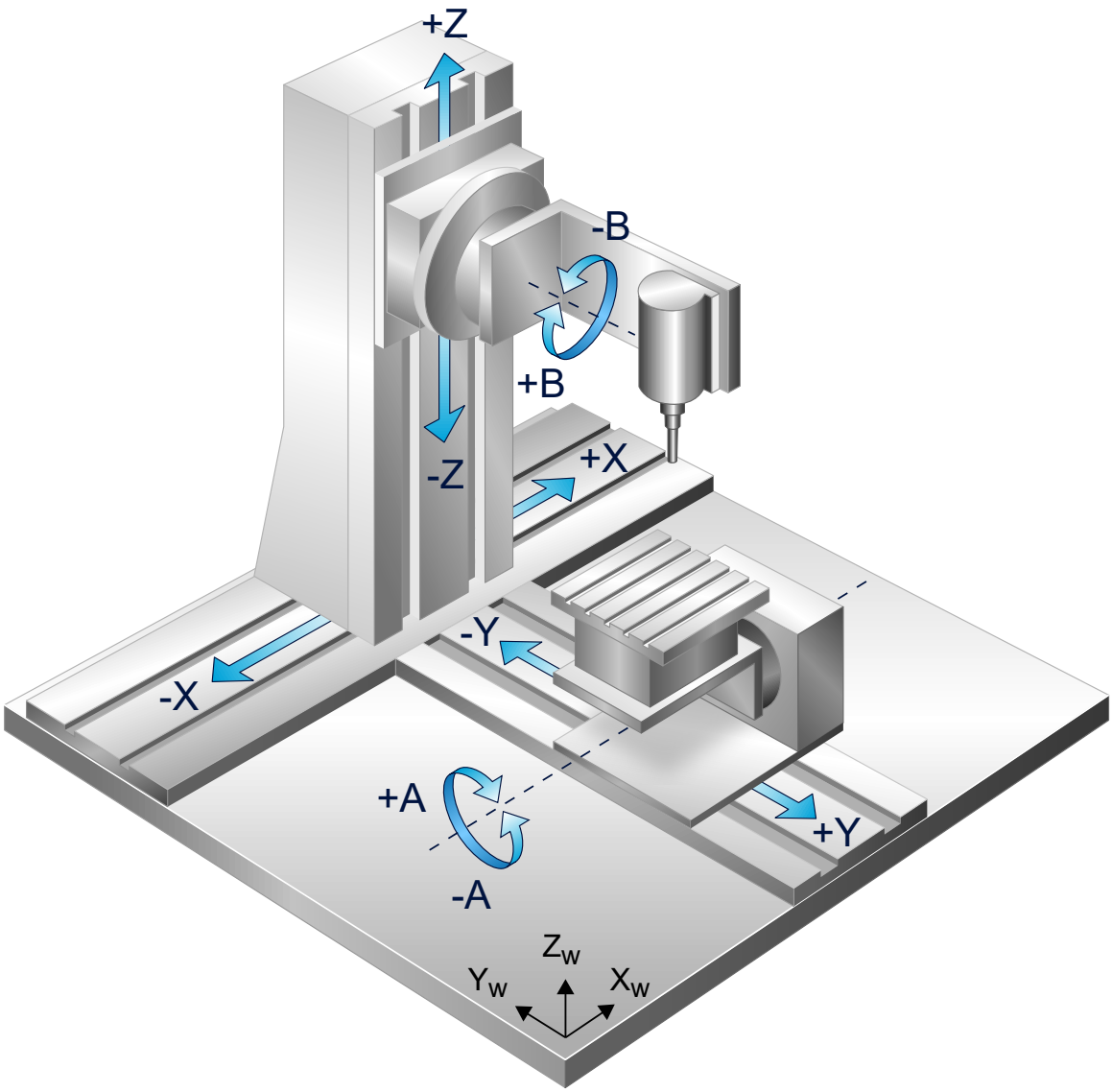


Fig. 79: Axis configuration of 5-axis machine

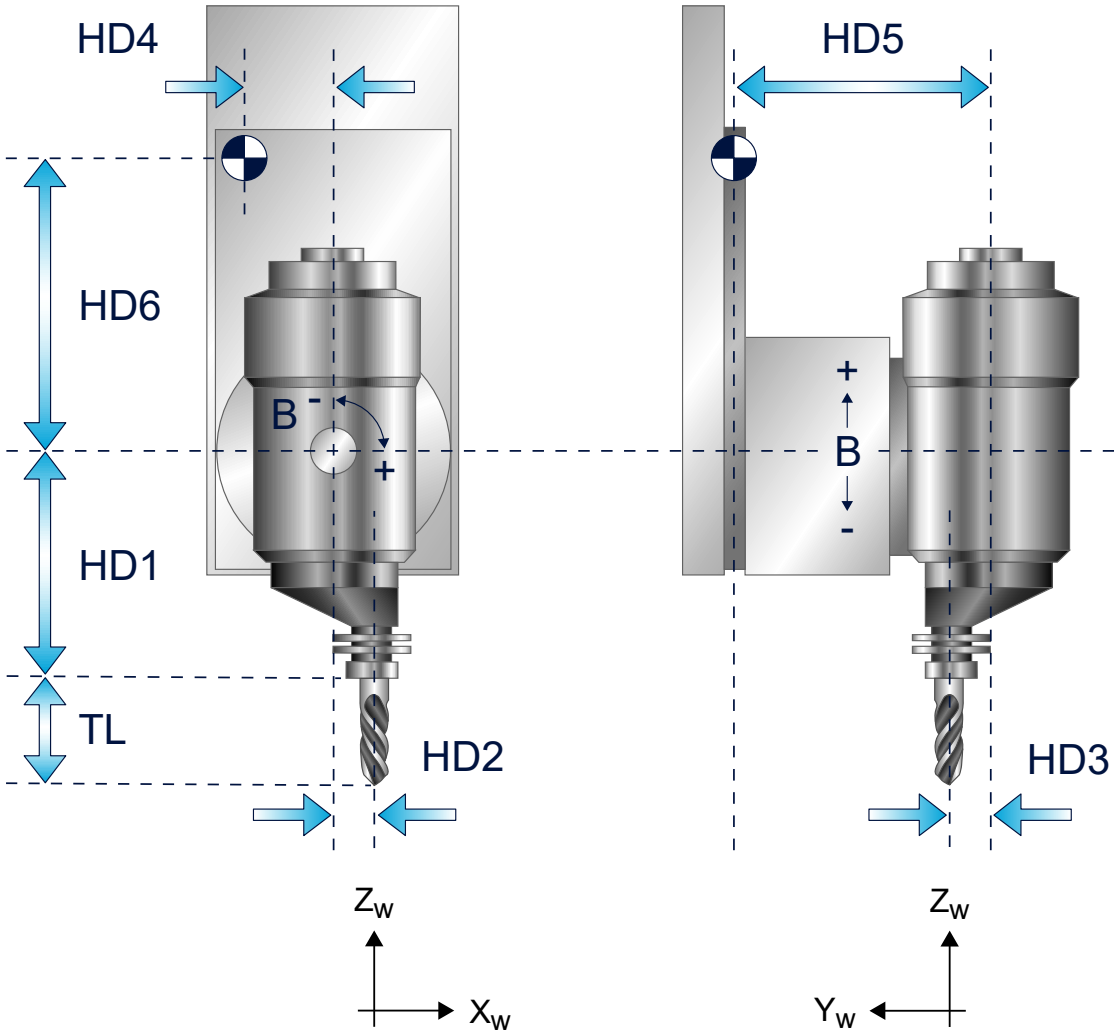


Fig. 80: Offsets of tool head

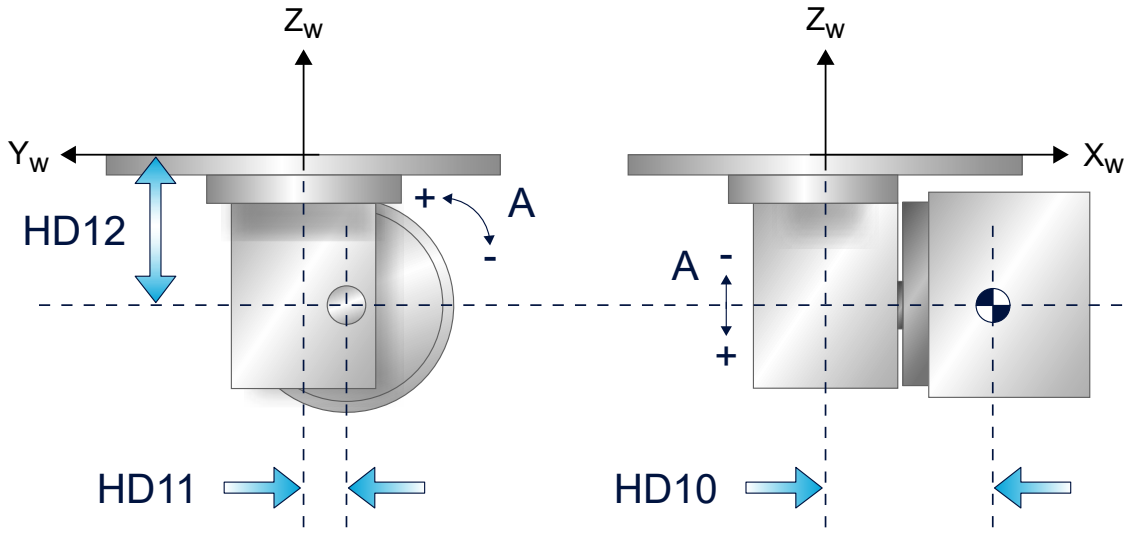


Fig. 81: Offsets of workpiece holder

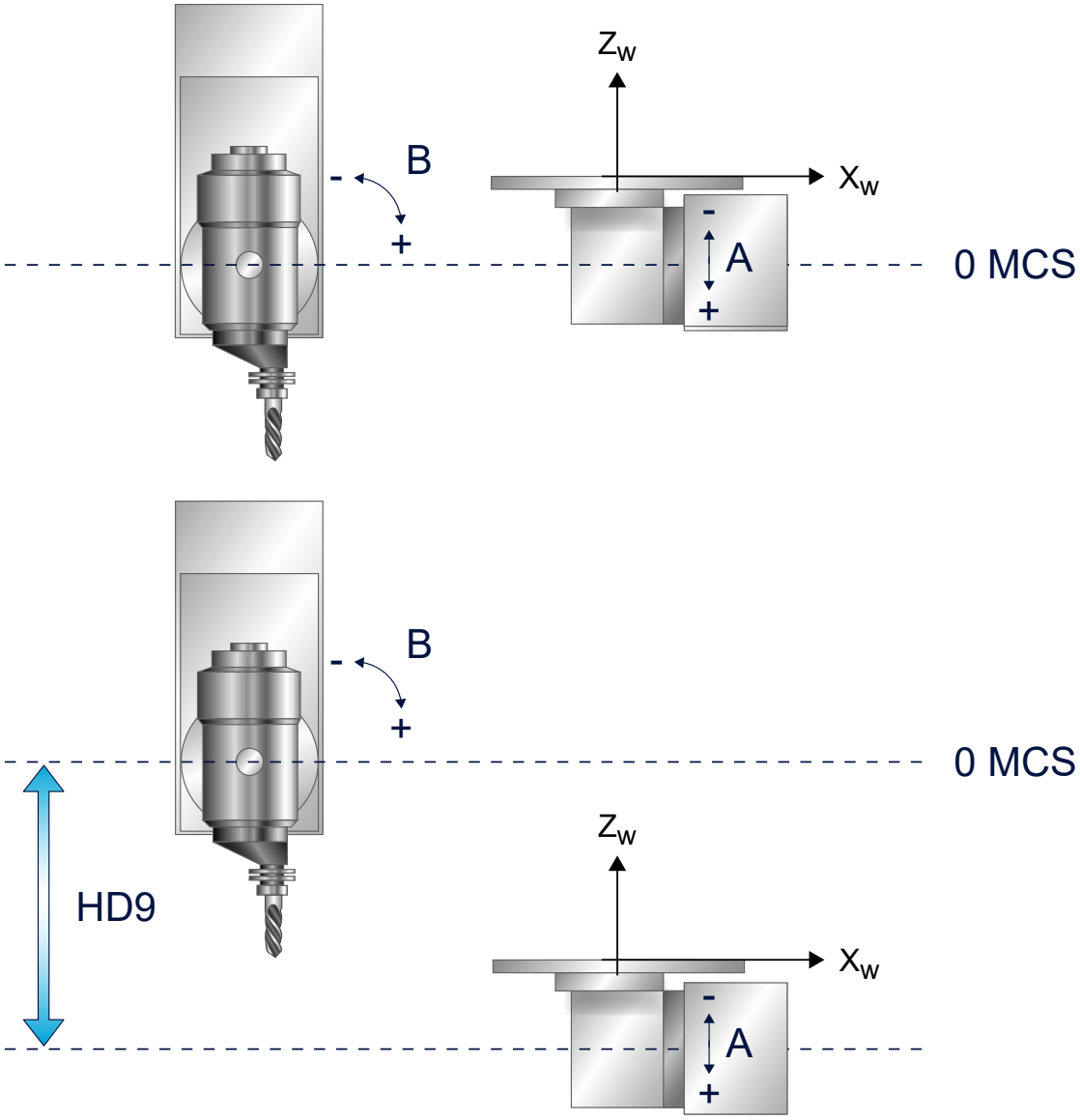


Fig. 82: Ideal and real z zero position

In the ideal zero position of the kinematic structure, the rotary axis A in the workpiece and the rotary axis B in the tool intersect at one point. The machine axis positions of the tool slide are then 0 in this position. Normally these axis positions cannot be approached with a real machine structure. The offsets at tool slide position 0 to this position can be set with parameters HD7, HD8, HD9.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset tool rotation point B axis to tool holder point	1.0 E-4 mm
HD2	1	X offset tool rotation point B axis to tool holder point	1.0 E-4 mm
HD3	2	Y offset tool rotation point B axis to tool holder point	1.0 E-4 mm
HD4	3	X offset rotation point B axis to reference point tool slide	1.0 E-4 mm
HD5	4	Y offset rotation point B axis to reference point tool slide	1.0 E-4 mm
HD6	5	Z offset rotation point B axis to reference point tool slide	1.0 E-4 mm
HD7	6	X offset to machine origin	1.0 E-4 mm
HD8	7	Y offset to machine origin	1.0 E-4 mm
HD9	8	Z offset to machine origin	1.0 E-4 mm
HD10	9	X offset A rotary axis to origin WKS	1.0 E-4 mm
HD11	10	Y offset A rotary axis to origin WKS	1.0 E-4 mm
HD12	11	Z offset A rotary axis to origin WKS	1.0 E-4 mm
HD13	12	Rotary offset A axis	1.0 E-4°
HD14	13	Rotary offset B axis	1.0 E-4°
HD15	14	Rotation direction flag A axis	[-]
HD16	15	Rotation direction flag B axis	[-]
HD17	16	X zero offset in the WCS	1.0 E-4 mm
HD18	17	Y zero offset in the WCS	1.0 E-4 mm
HD19	18	Z zero offset in the WCS	1.0 E-4 mm

2.31 KIN_TYP_63 – 5-axis kinematics with X/Y/B workpiece table

Kinematic structure

The kinematic structure consists of one translatory and one rotary NC axis in the workpiece and 2 translatory and one rotary NC axis in the tool. The transformation supports additional offset parameters for a non-symmetric construction and substitutes the existing kinematic structure KIN_TYP_23.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	Z, A	X,Y, B

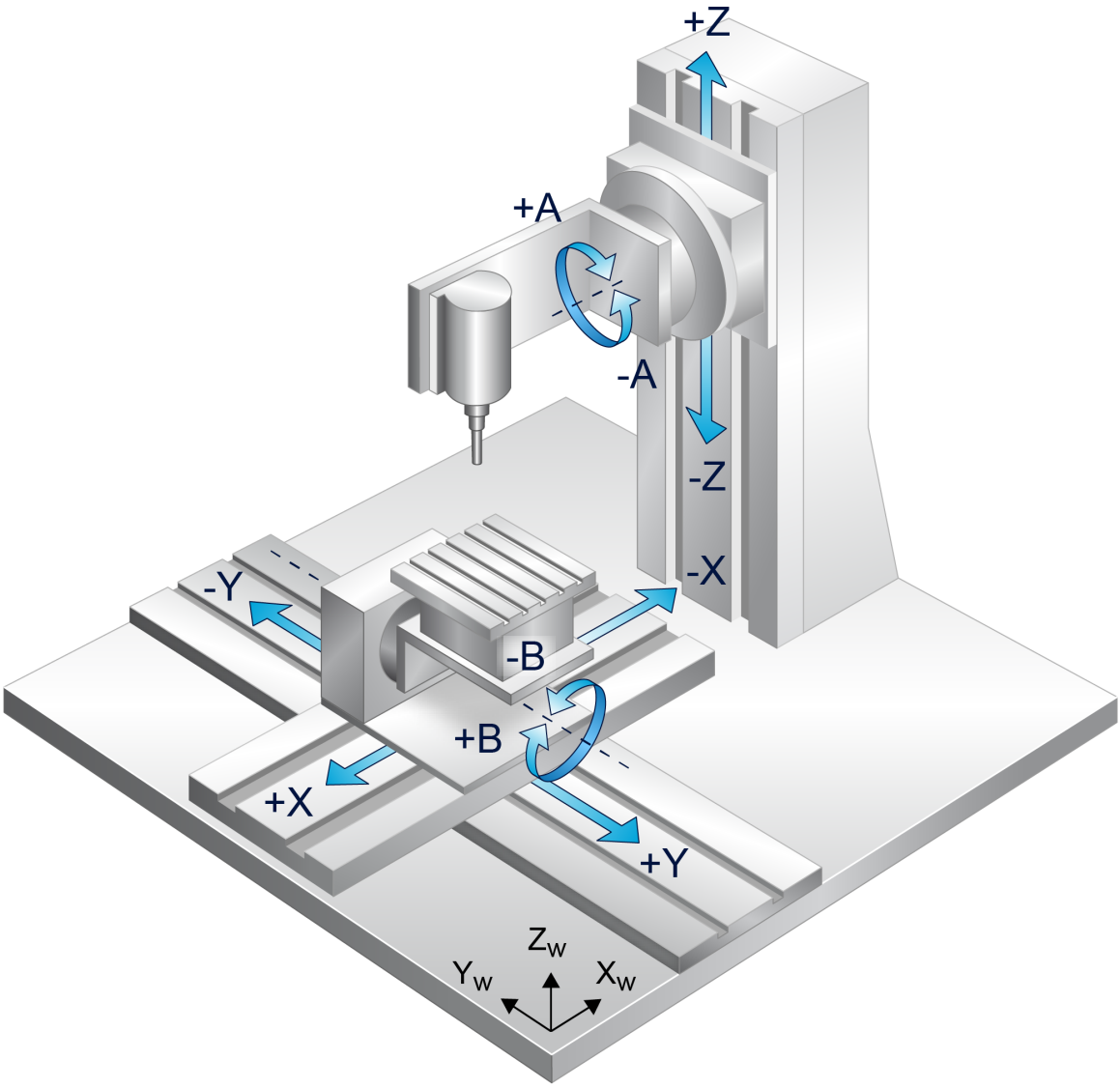


Fig. 83: Axis configuration of 5-axis machine

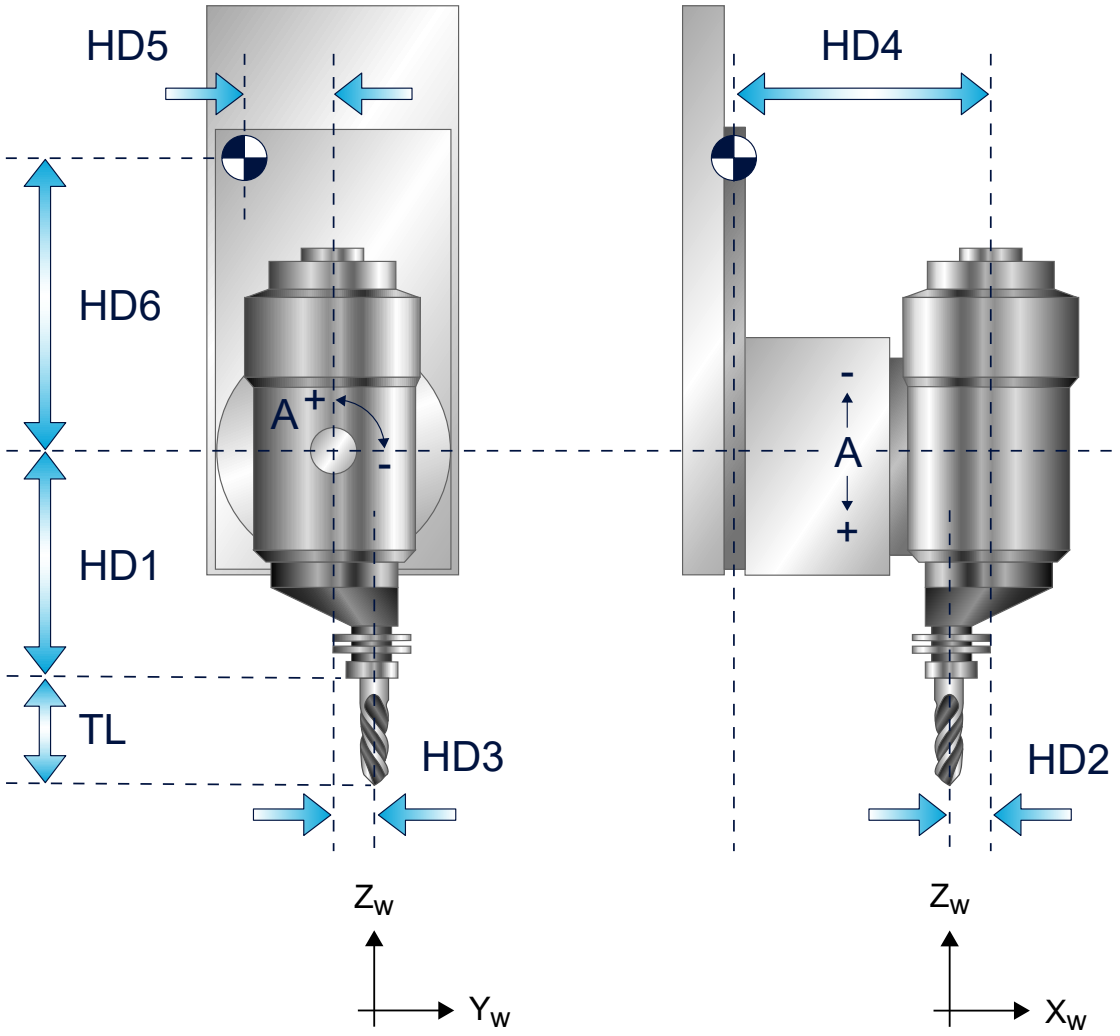


Fig. 84: Offsets of tool head

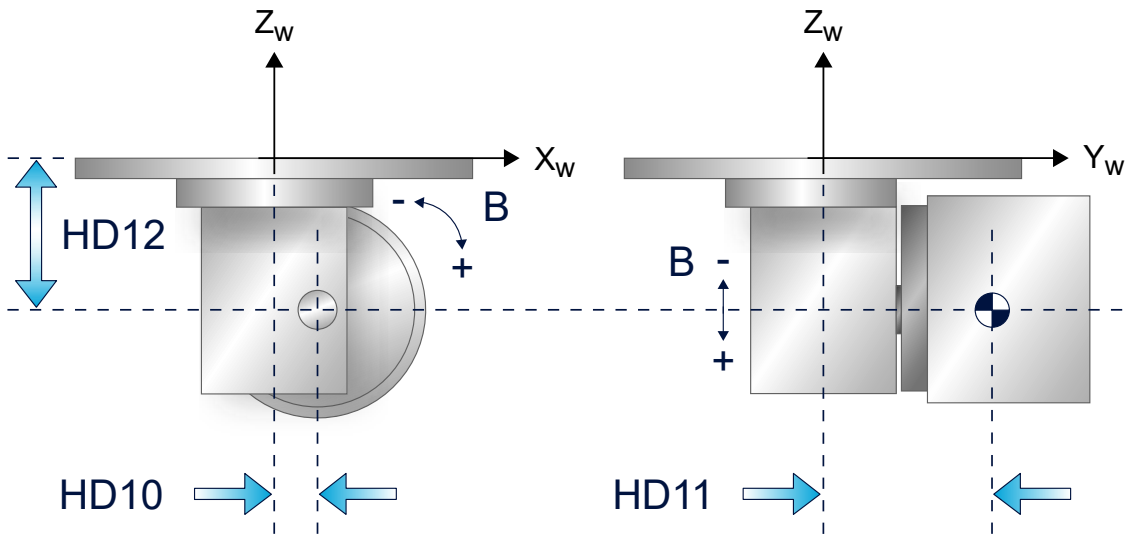


Fig. 85: Offsets of workpiece holder

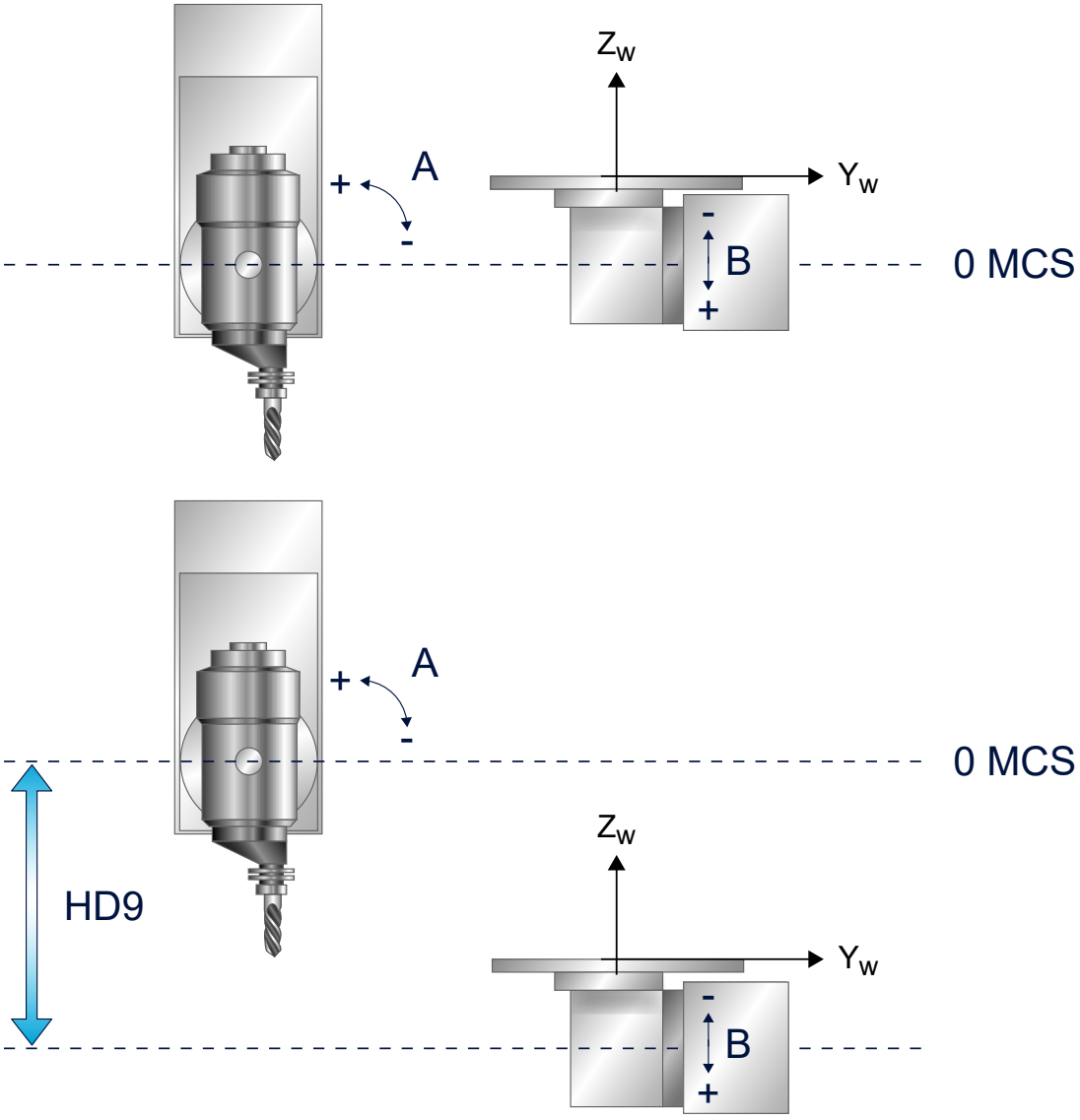


Fig. 86: Ideal and real Z zero position

In the ideal zero position of kinematic structure, the rotary axis B in the workpiece and the rotary axis A in the tool intersect at one point. The machine axis positions of the tool slide are then 0 in this position. Normally these axis positions cannot be approached with a real machine structure. The offsets at tool slide position 0 to this position can be set with parameters HD7, HD8, HD9.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset tool rotation point A axis to tool holder device	1.0 E-4 mm
HD2	1	X offset tool rotation point A axis to tool holder device	1.0 E-4 mm
HD3	2	Y offset tool rotation point A axis to tool holder device	1.0 E-4 mm
HD4	3	X offset rotation point A axis to reference point tool slide	1.0 E-4 mm
HD5	4	Y offset rotation point A axis to reference point tool slide	1.0 E-4 mm
HD6	5	Z offset rotation point A axis to reference point tool slide	1.0 E-4 mm
HD7	6	X offset to machine origin	1.0 E-4 mm
HD8	7	Y offset to machine origin	1.0 E-4 mm
HD9	8	Z offset to machine origin	1.0 E-4 mm
HD10	9	X offset B rotary axis to origin WKS	1.0 E-4 mm
HD11	10	Y offset B rotary axis to origin WKS	1.0 E-4 mm
HD12	11	Z offset B rotary axis to origin WKS	1.0 E-4 mm
HD13	12	Rotary offset A axis	1.0 E-4°
HD14	13	Rotary offset B axis	1.0 E-4°
HD15	14	Rotation direction flag A axis	[-]
HD16	15	Rotation direction flag B axis	[-]
HD17	16	X zero offset in the WCS	1.0 E-4 mm
HD18	17	Y zero offset in the WCS	1.0 E-4 mm
HD19	18	Z zero offset in the WCS	1.0 E-4 mm

2.32 KIN_TYP_64 – 6-axis kinematics with C/A/C workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory axes in the tool and 3 rotary axes in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C1, A, C2	
Axis index	0, 1, 2, 3, 4, 5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	C1, A, C2

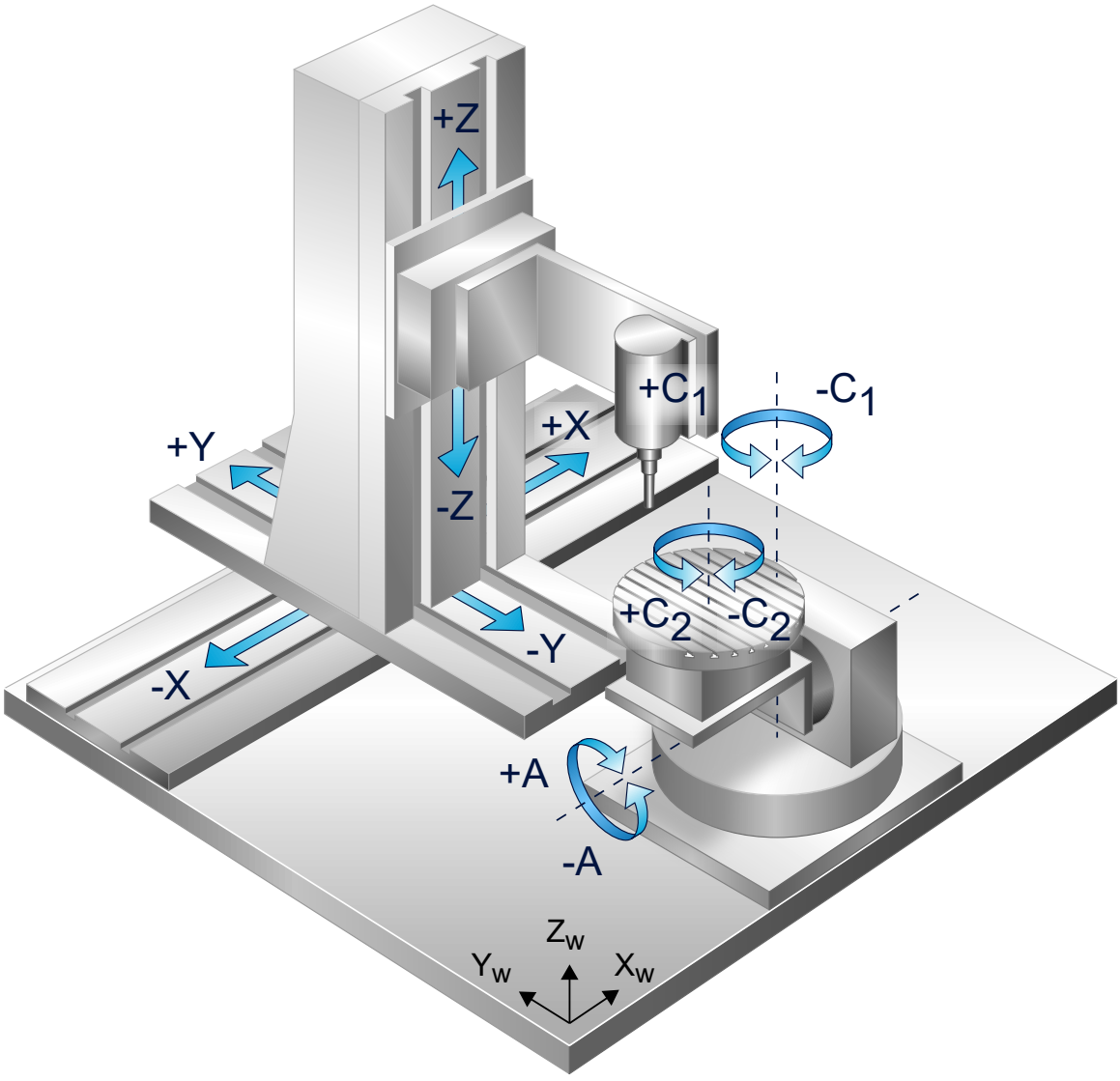


Fig. 87: Kinematic structure of 6-axis machine with CAC workpiece table.

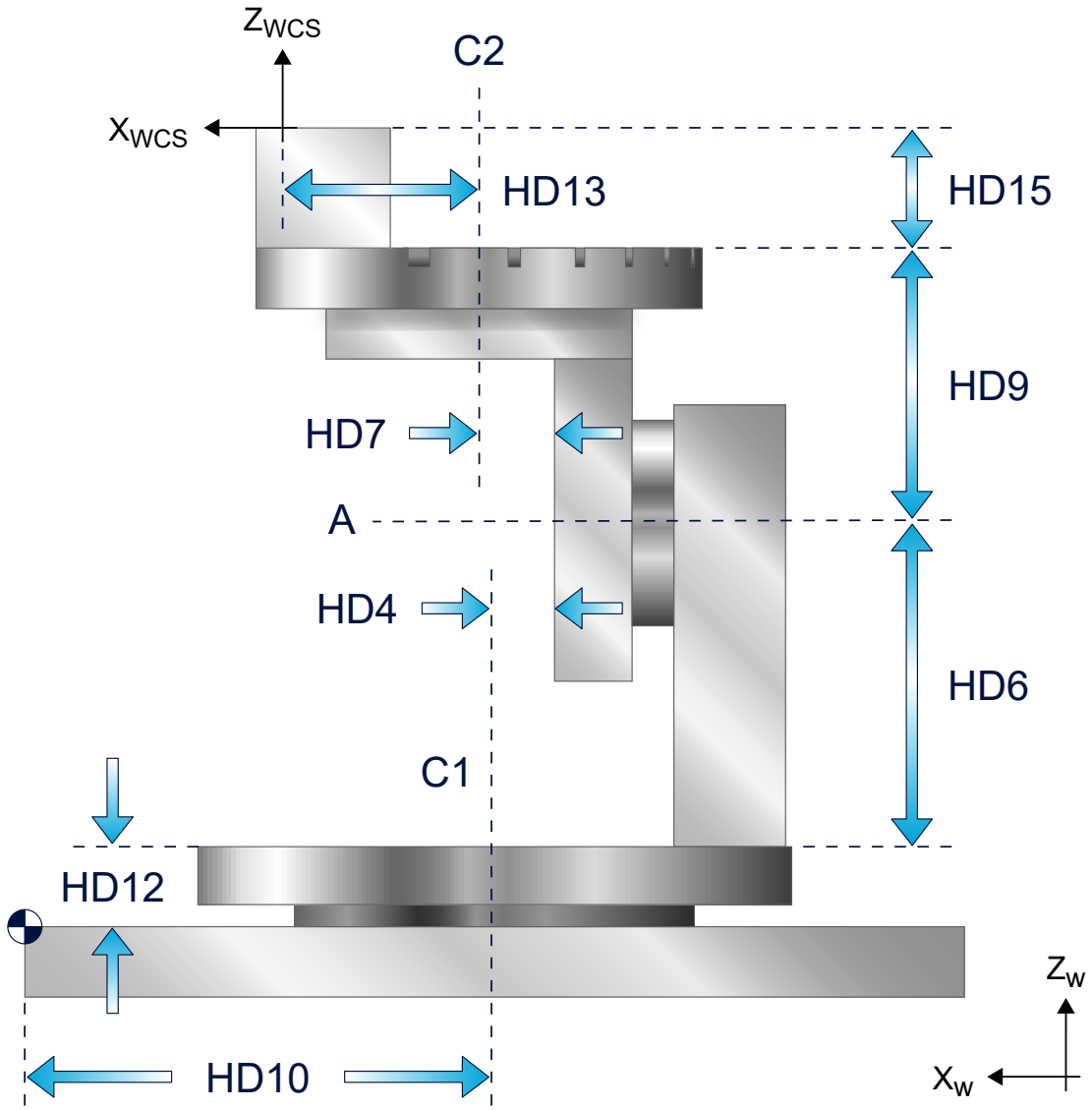


Fig. 88: Parameters of CAC workpiece table in X/Z representation

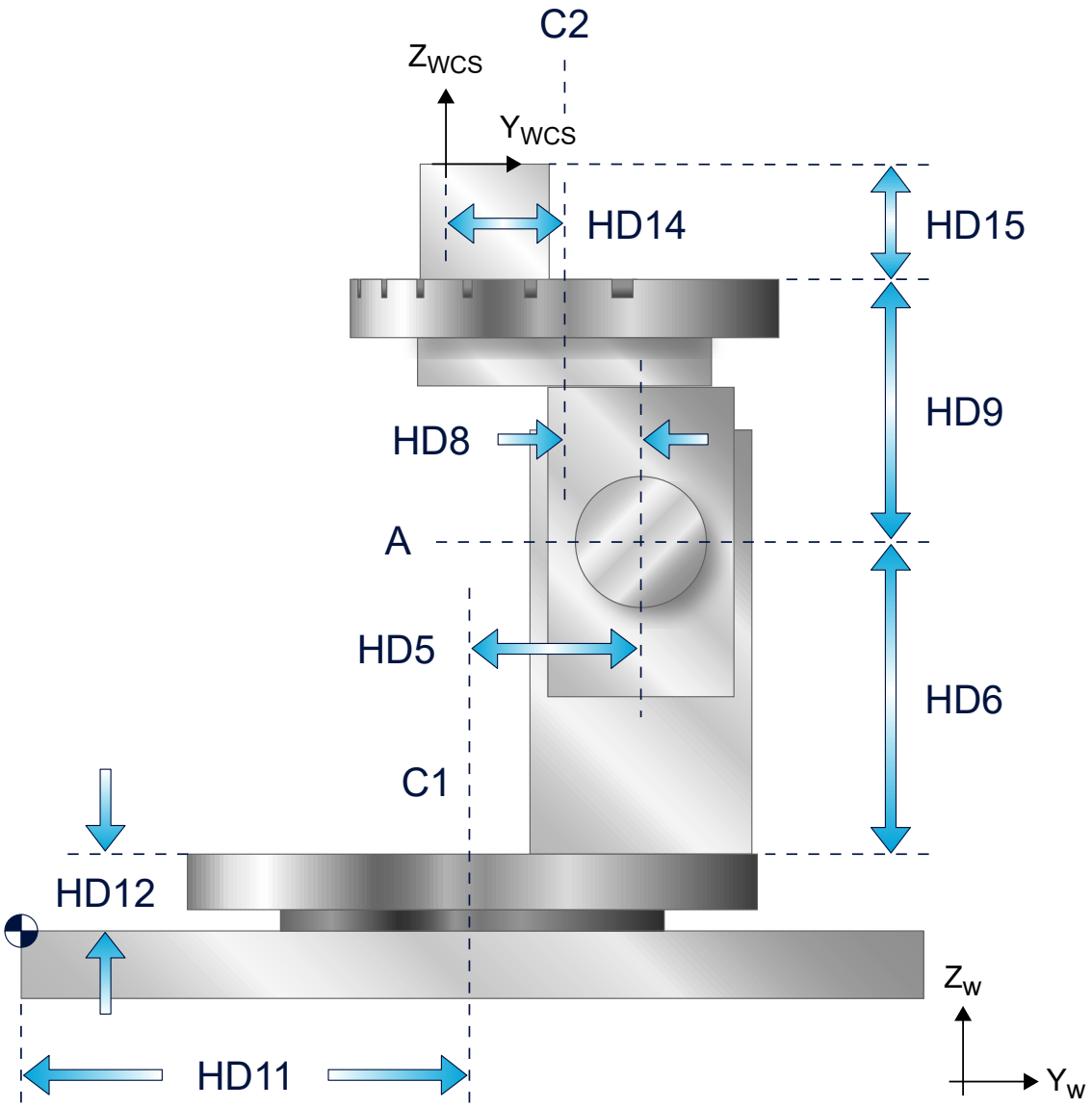


Fig. 89: Parameters of CAC workpiece table in Y/Z representation

Typically, the machine origin is located in the rotary axis C1. If required, it can be shifted using parameters HD10 to HD12. Differing origin positions of rotary axes C1 and A or A and C2 can be set using parameters HD4 to HD9 so that the internal kinematic model matches the real machine kinematics. In the same way, differing directions of rotation of the axes C1, A and C2 can be set using the parameters HD16 to HD18. In general, the signs of command and actual parameters must also be modified accordingly in the axis parameters.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z tool offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD2	1	X axis offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD3	2	Y axis offset holding device to reference point tool slide SRP	1.0 E-4 mm
HD4	3	X axis offset rotary axis C1 to rotary axis A, origin WCS	1.0 E-4 mm
HD5	4	Y axis offset rotary axis C1 to rotary axis A, origin WCS	1.0 E-4 mm
HD6	5	Z axis offset rotary axis C1 to rotary axis A, origin WCS	1.0 E-4 mm
HD7	6	X axis offset rotary axis A to rotary axis C2, origin WCS	1.0 E-4 mm
HD8	7	Y axis offset rotary axis A to rotary axis C2, origin WCS	1.0 E-4 mm
HD9	8	Z axis offset rotary axis A to rotary axis C2, origin WCS	1.0 E-4 mm
HD10	9	X offset machine origin MZP to rotary axis C1	1.0 E-4 mm
HD11	10	Y offset machine origin MZP to rotary axis C1	1.0 E-4 mm
HD12	11	Z offset machine origin MZP to rotary axis C1	1.0 E-4 mm
HD13	12	X offset origin CS	1.0 E-4 mm
HD14	13	Y offset origin CS	1.0 E-4 mm
HD15	14	Z offset origin CS	1.0 E-4 mm
HD16	15	Rotary offset C1 axis	1.0 E-4°
HD17	16	Rotary offset A axis	1.0 E-4°
HD18	17	Rotary offset C2 axis	1.0 E-4°
HD19	18	Rotation direction flag C1 axis	[-]
HD20	19	Rotation direction flag A axis	[-]
HD21	20	Rotation direction flag C2 axis	[-]

2.33 KIN_TYP_70 – 5-axis kinematics

Kinematic structure

The kinematic structure consists of 3 translatory and 2 rotary NC axes in the tool. With these kinematics, tool head rotation about Z can be set in the case of non-axis-parallel orientation of the BA rotary head. A virtual axis CV can be used to affect tool orientation.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B, A, CV	
Axis index	0, 1, 2, 3, 4, 5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, B, A, CV	-

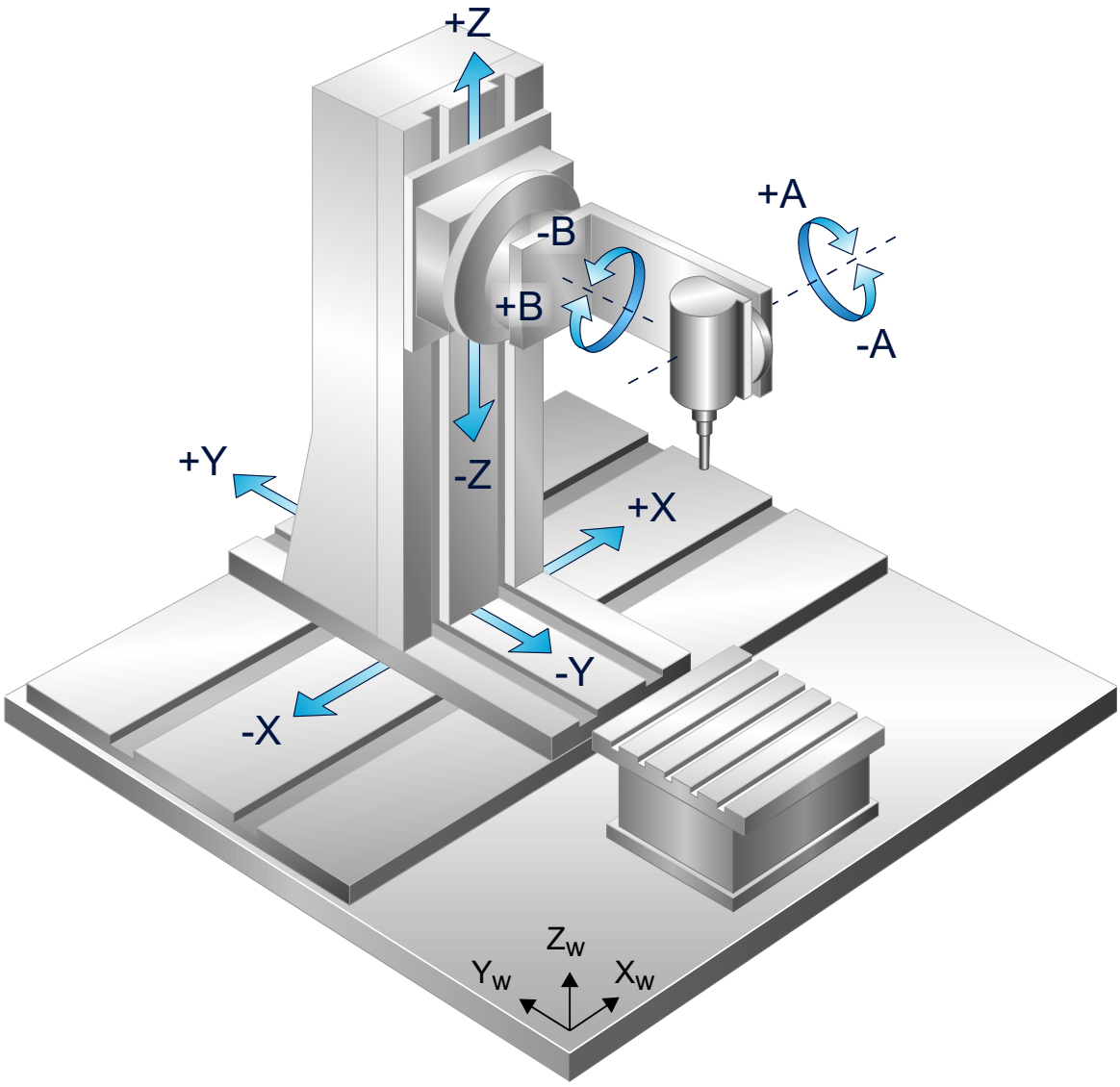


Fig. 90: Axis configuration of 5-axis machine

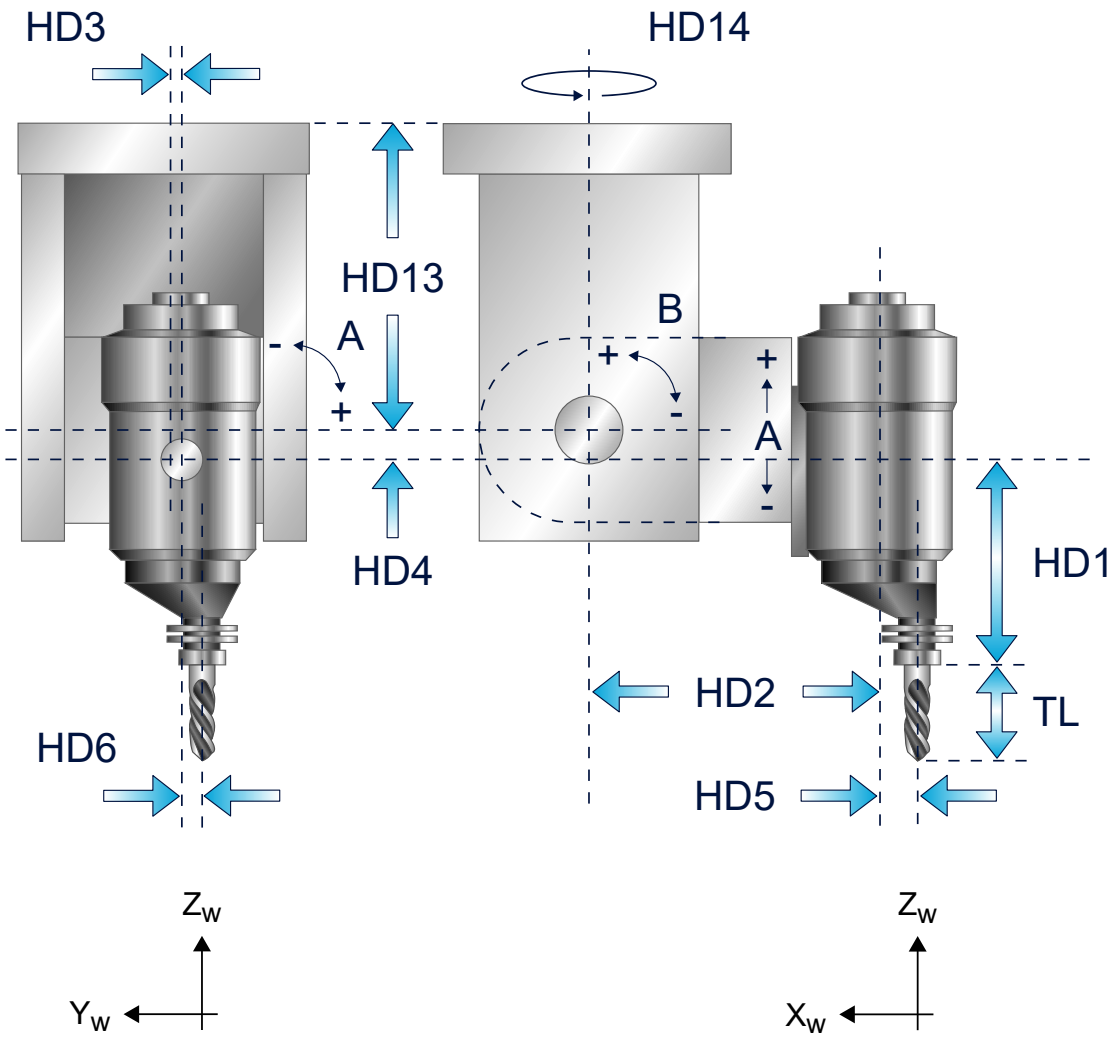


Fig. 91: Tool head parameters

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset up to tool fixing point	1.0 E-4 mm
HD2	1	X offset	1.0 E-4 mm
HD3	2	Y offset	1.0 E-4 mm
HD4	3	Z offset	1.0 E-4 mm
HD5	4	X offset	1.0 E-4 mm
HD6	5	Y axis offset to tool	1.0 E-4 mm
HD7	6	Rotary offset A axis	1.0 E-4°
HD8	7	Rotary offset B axis	1.0 E-4°
HD9	8	Sign for direction of rotation A axis	[-]
HD10	9	Sign for direction of rotation B axis	[-]
HD14	13	Rotary offset about Z (head position)	1.0 E-4°

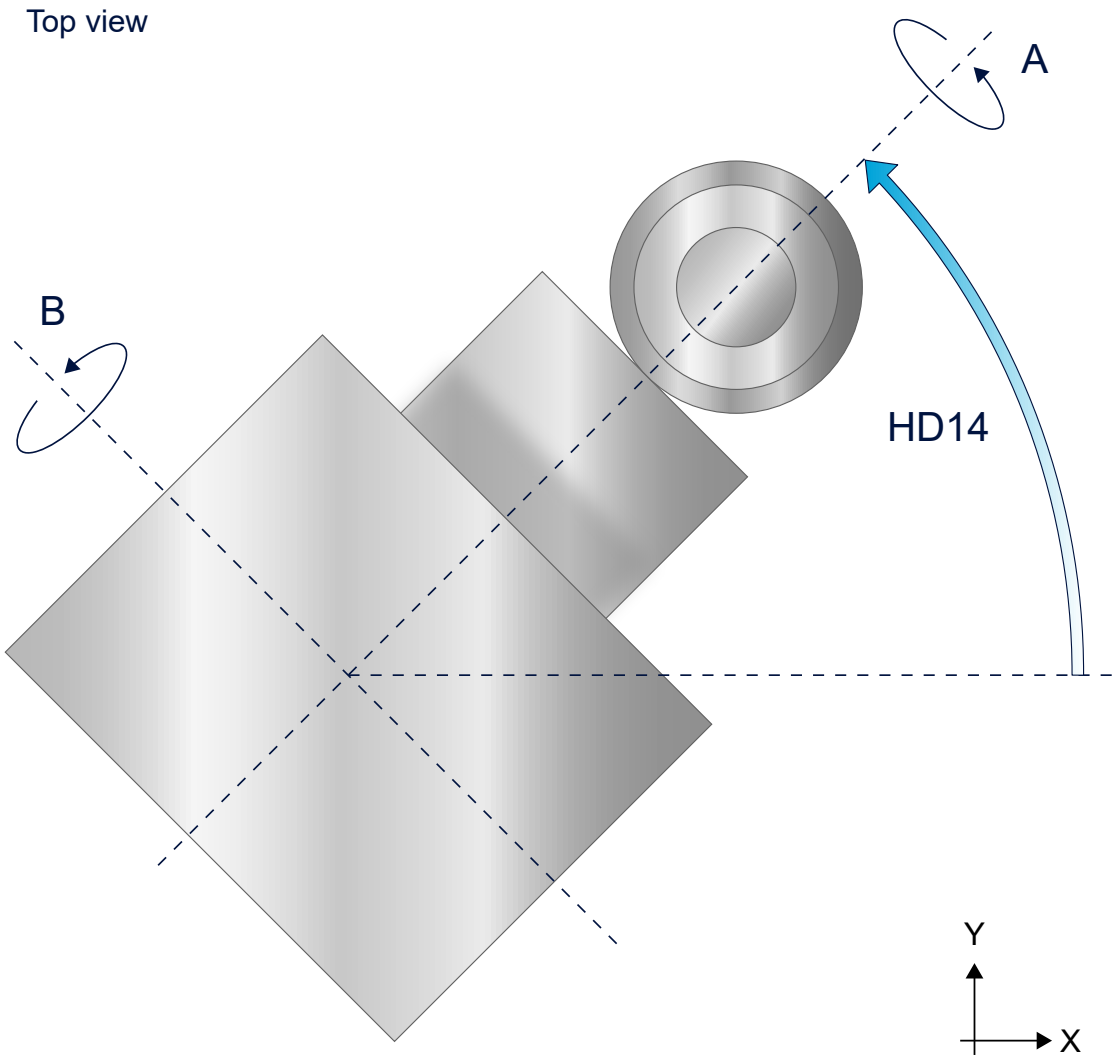


Fig. 92: Angular offset of rotary/swivel head

The CV axis is not a physical real axis existing in the kinematic structure. The CV axis executes a rotation of the tool direction vector about Z, i.e. the angles A and B are calculated depending on CV. One application can be the perpendicular alignment of one component of the XY tool direction to the programmed contour. This axis must therefore be configured as a simulation axis and can then be addressed in the NC program as usual.

The permitted angle range of the A and B axes is in the range of +- 90 degrees.

2.34 KIN_TYP_76 – 5-axis kinematics with MTCP oblique tool head

Kinematic structure

The kinematic structure consists of 3 translatory and 2 rotary NC axes in the tool. The A and B axes are arranged about the Y axis at an angle!= 90 degrees. Due to the design structure the TCP is mechanically compensated (MTCP). As required, a tool length can also be set but this leads to compensation motions in the Cartesian axes.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z,A,B	-

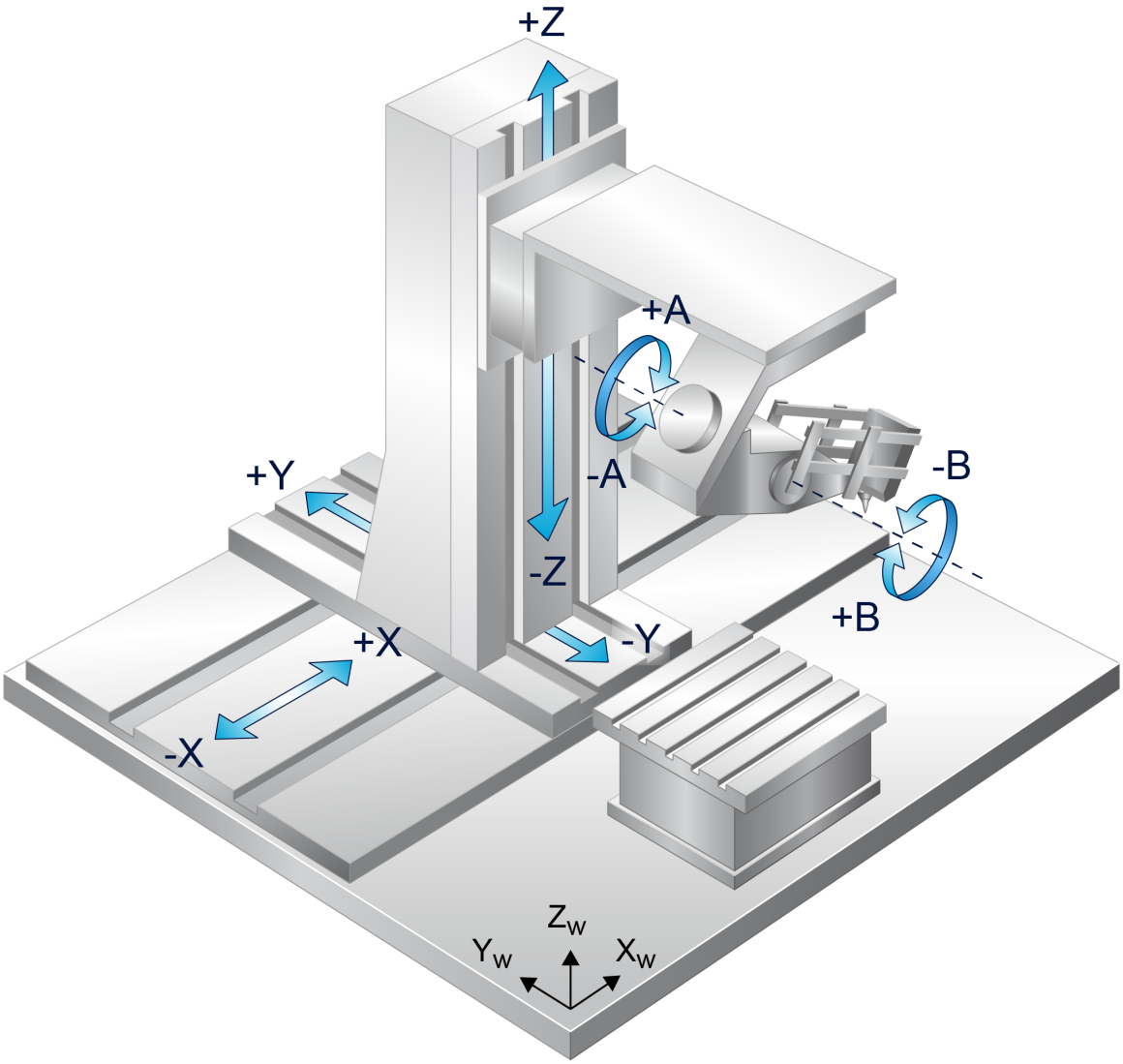


Fig. 93: Axis configuration of 5-axis machine

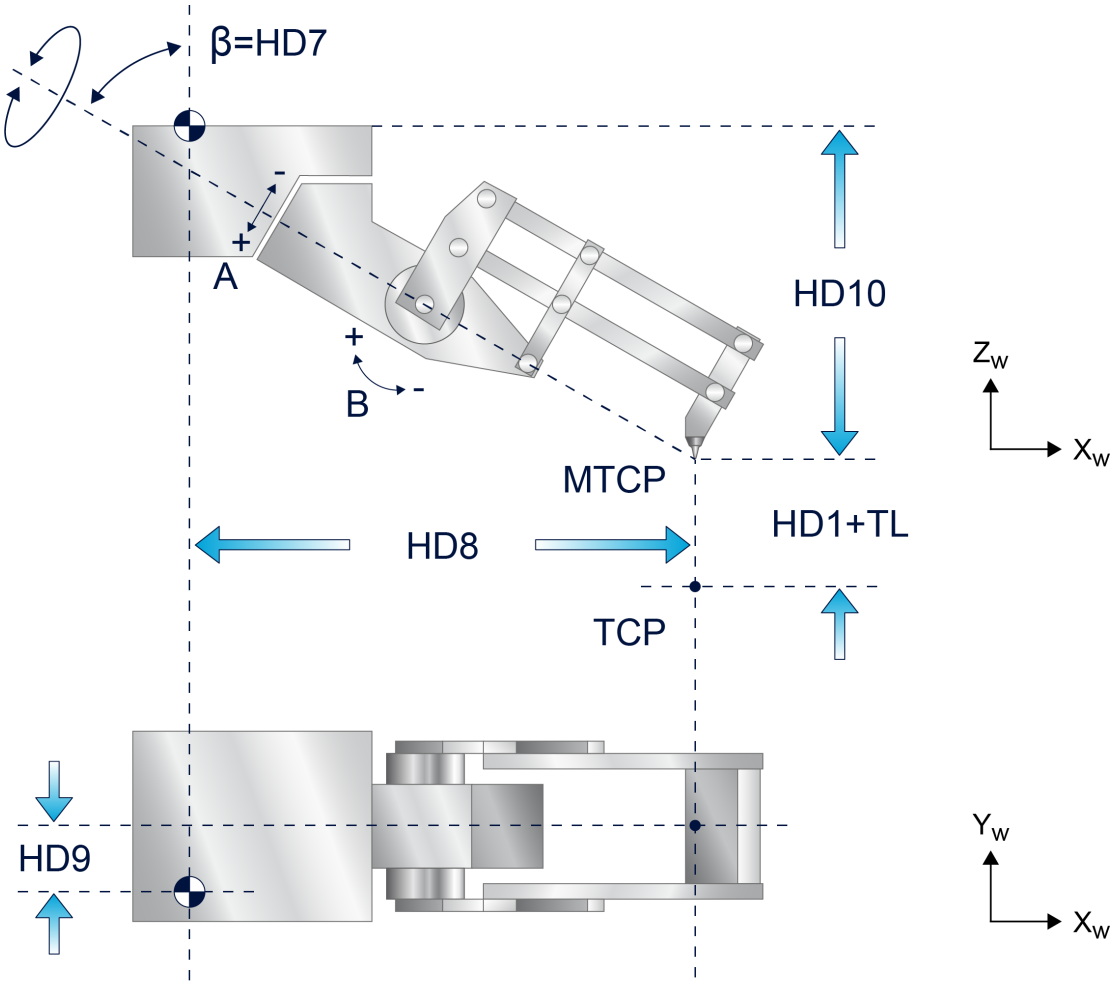


Fig. 94: Tool head parameters

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset to tool holding device	1.0 E-4 mm
HD6	5	Angle offset between Cartesian MCS and cutting head CS	1.0 E-4°
HD7	6	Angle between A axis and Z axis	1.0 E-4°
HD8	7	X offset MTCP to machine origin	1.0 E-4 mm
HD9	8	Y offset MTCP to machine origin	1.0 E-4 mm
HD10	9	Z offset MTCP to machine origin	1.0 E-4 mm

Tool orientation is programmed using rotation angles C and A with a rotation sequence in the listed sequence. With HD6 = 65 degrees the maximum angle position is in range of +-60 degrees.

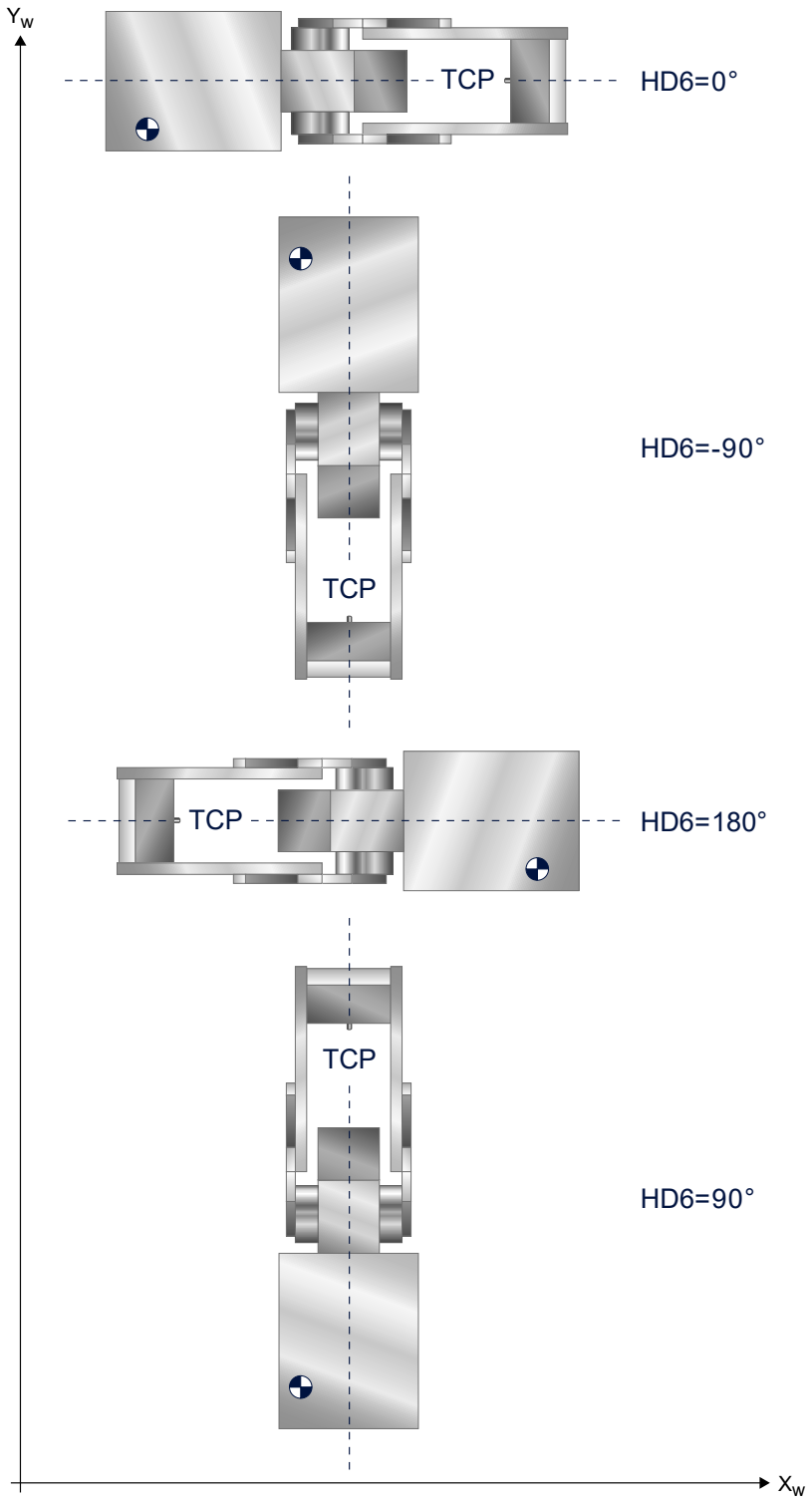


Fig. 95: Angle offset of bevel head with regard to mounting

The orientation of the bevel head with regard to the Cartesian machine coordinate system can be set with parameter HD6.

2.35 KIN_TYP_80 – 5-axis kinematics with A/B workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory NC axes in the tool and two rotary NC axes in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	A, B

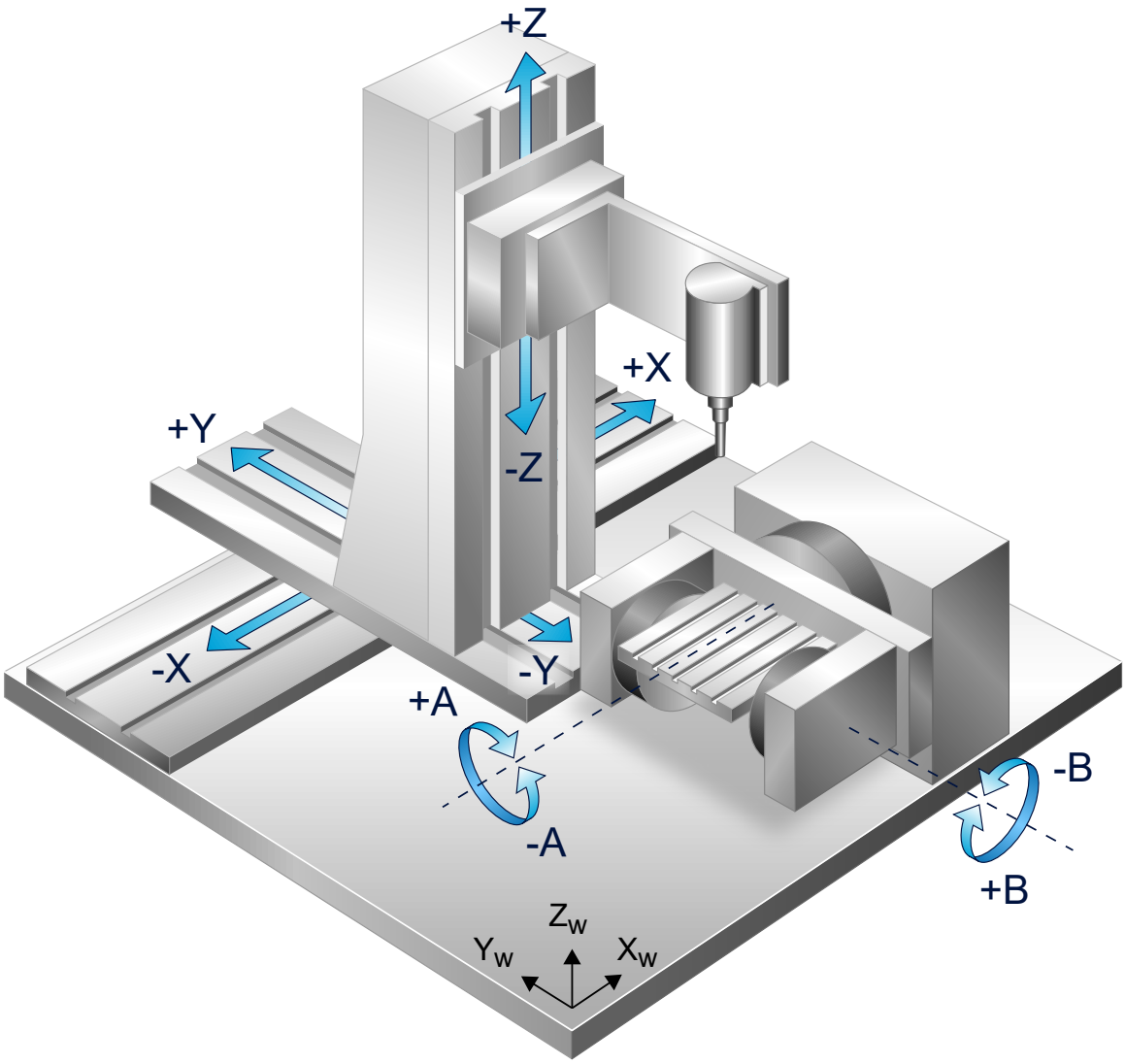


Fig. 96: Axis configuration of 5-axis machine

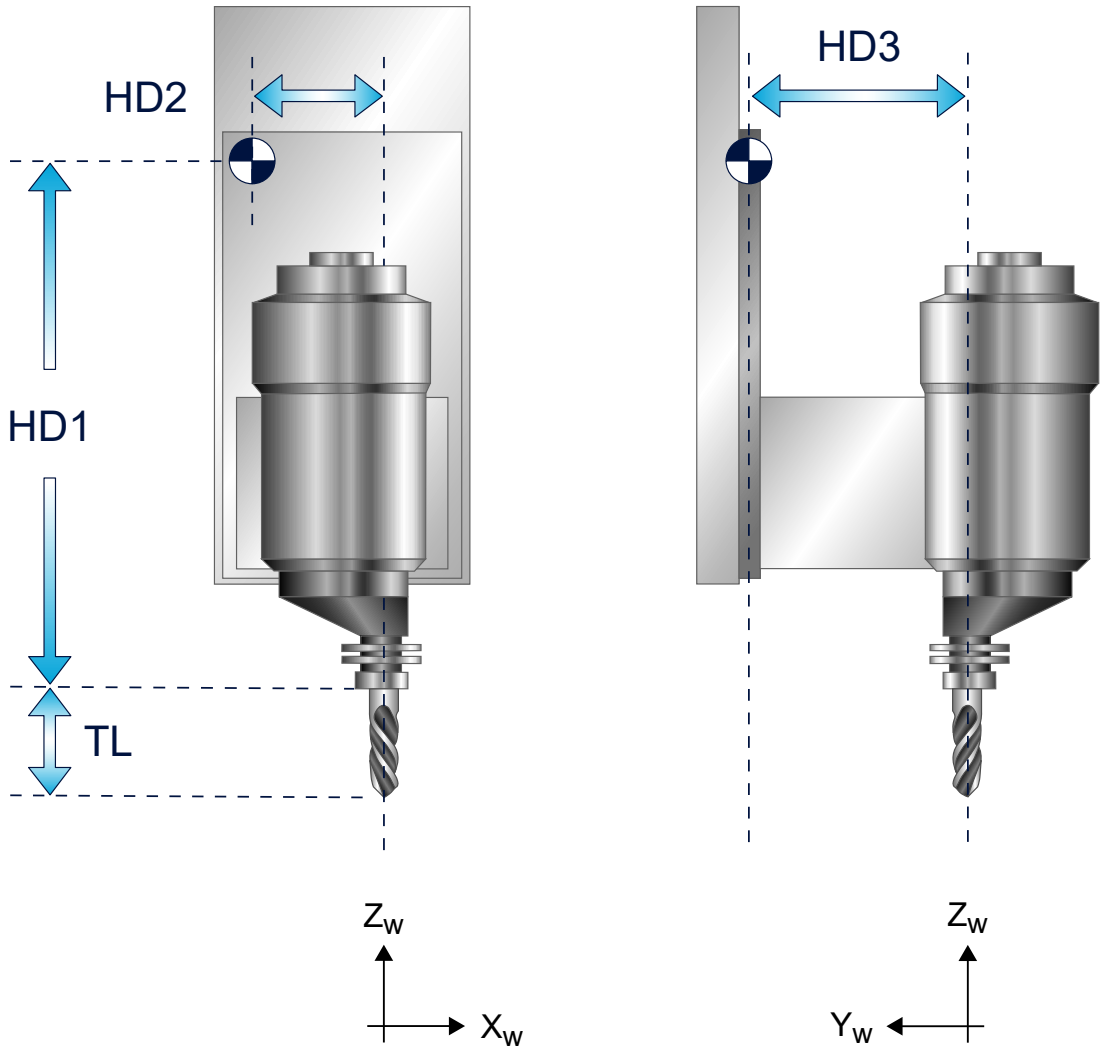


Fig. 97: Offsets of tool head

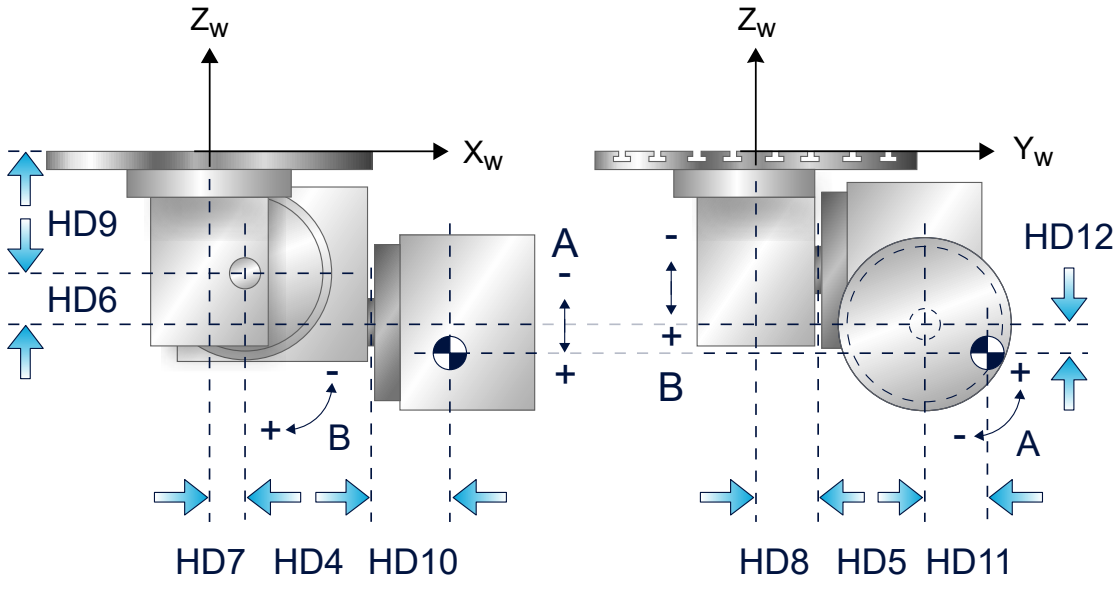


Fig. 98: Offsets of workpiece holder

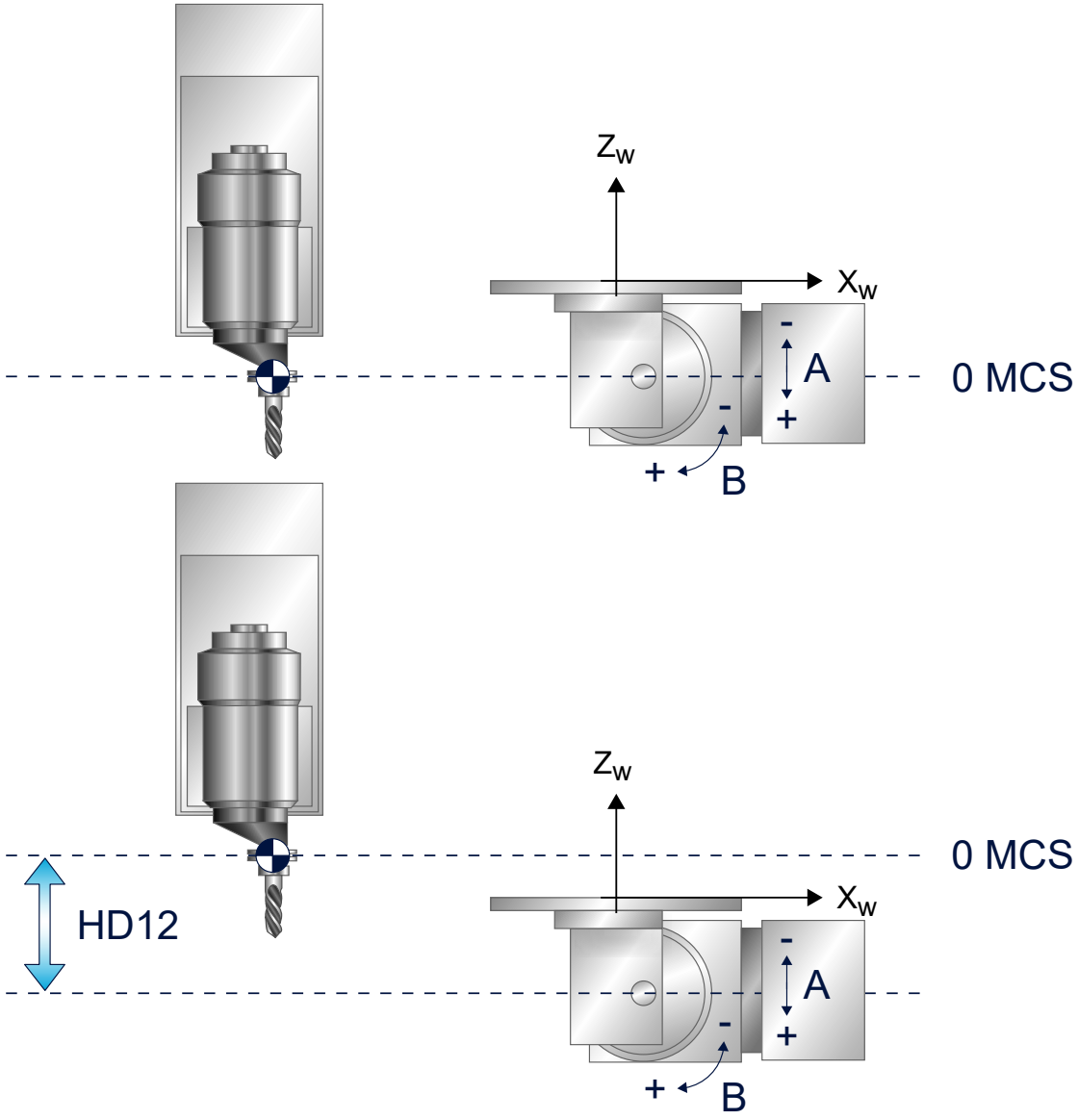


Fig. 99: Ideal and real Z zero position

When the kinematic structure is in ideal zero position, the rotary axis A in the workpiece and the reference point on the tool slide (here tool holding device) intersect at one point. The machine axis positions of the tool slide are then 0 in this position. In general these axis positions cannot be approached with a machine. The offsets to this position at tool slide position 0 can be set with parameters HD10, HD11, HD12.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset reference point tool slide to tool holding device	1.0 E-4 mm
HD2	1	X offset reference point tool slide to tool holding device	1.0 E-4 mm
HD3	2	Y offset reference point tool slide to tool holding device	1.0 E-4 mm
HD4	3	X axis offset rotary axis A to rotary axis B	1.0 E-4 mm
HD5	4	Y axis offset rotary axis A to rotary axis B	1.0 E-4 mm
HD6	5	Z axis offset rotary axis A to rotary axis B	1.0 E-4 mm
HD7	6	X axis offset rotary axis B to origin WCS	1.0 E-4 mm
HD8	7	Y axis offset rotary axis B to origin WCS	1.0 E-4 mm
HD9	8	Z axis offset rotary axis B to origin WCS	1.0 E-4 mm
HD10	9	X offset to machine origin MZP	1.0 E-4 mm
HD11	10	Y offset to machine origin MZP	1.0 E-4 mm
HD12	11	Z offset to machine origin MZP	1.0 E-4 mm
HD13	12	Rotary offset A axis	1.0 E-4°
HD14	13	Rotary offset B axis	1.0 E-4°
HD15	14	Rotation direction flag A axis	[-]
HD16	15	Rotation direction flag B axis	[-]

2.36 KIN_TYP_81 – 5-axis kinematics with B/A workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory NC axes in the tool and 2 rotary NC axes in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B, A	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	B, A

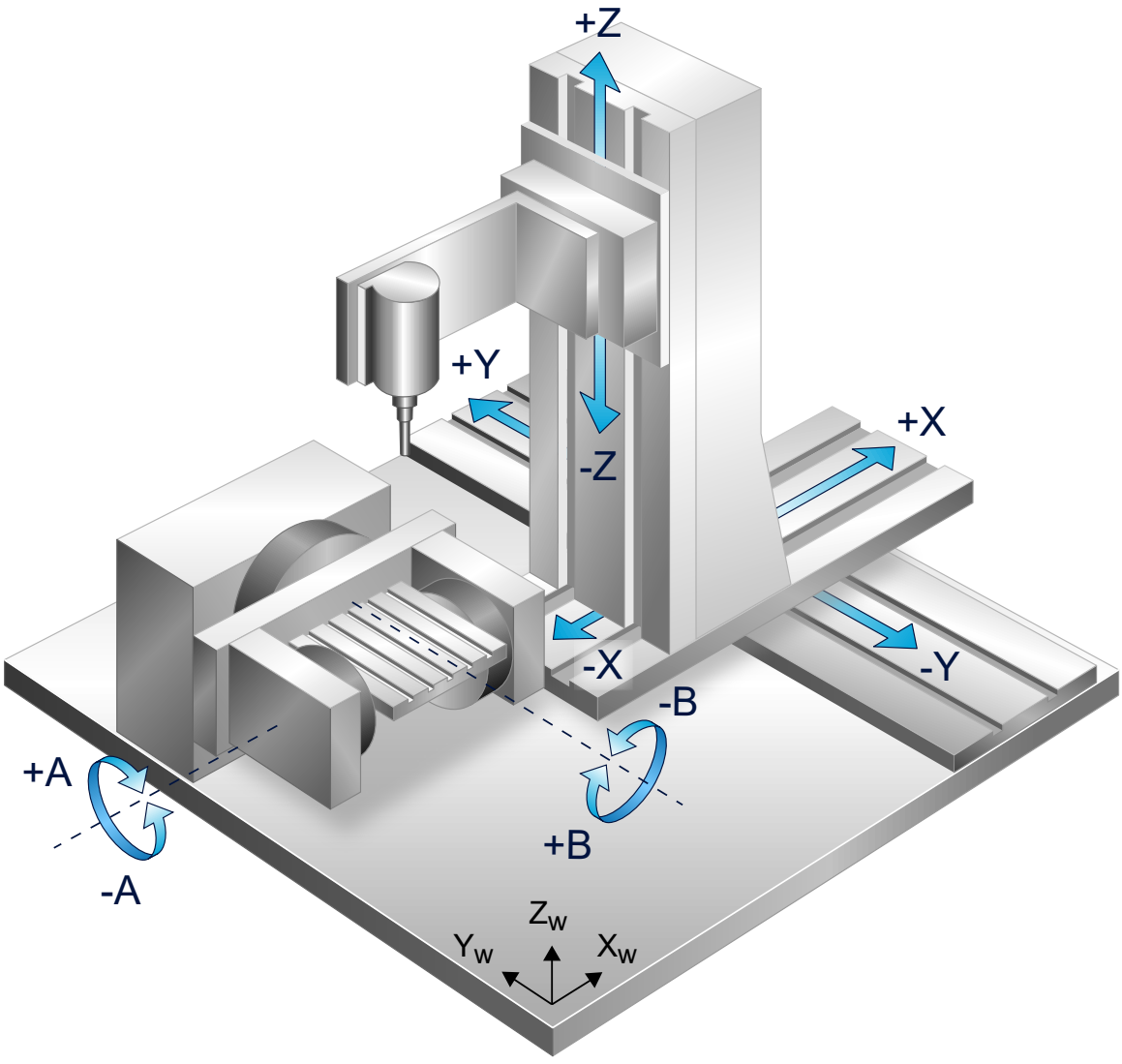


Fig. 100: Axis configuration of 5-axis machine

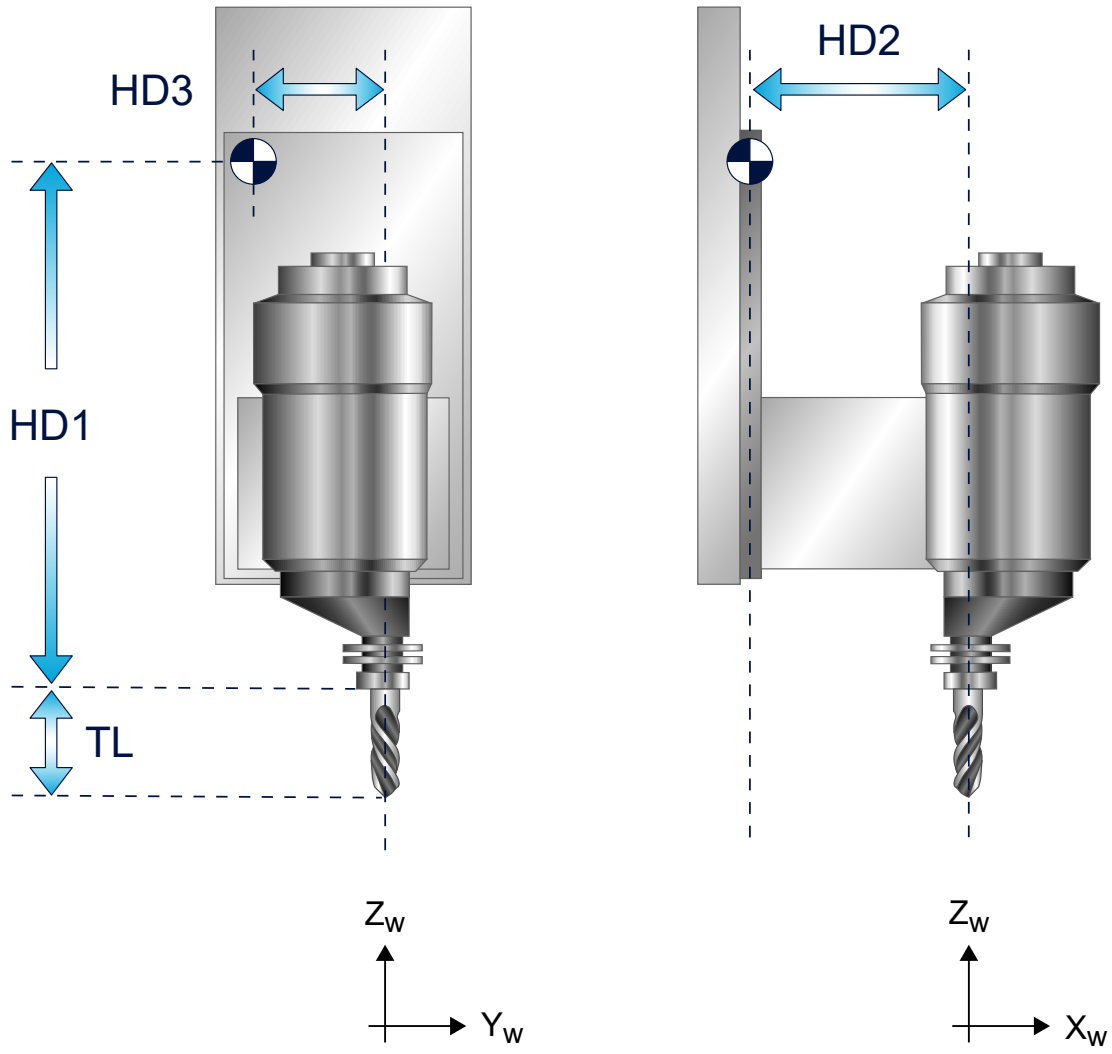


Fig. 101: Offsets of tool head

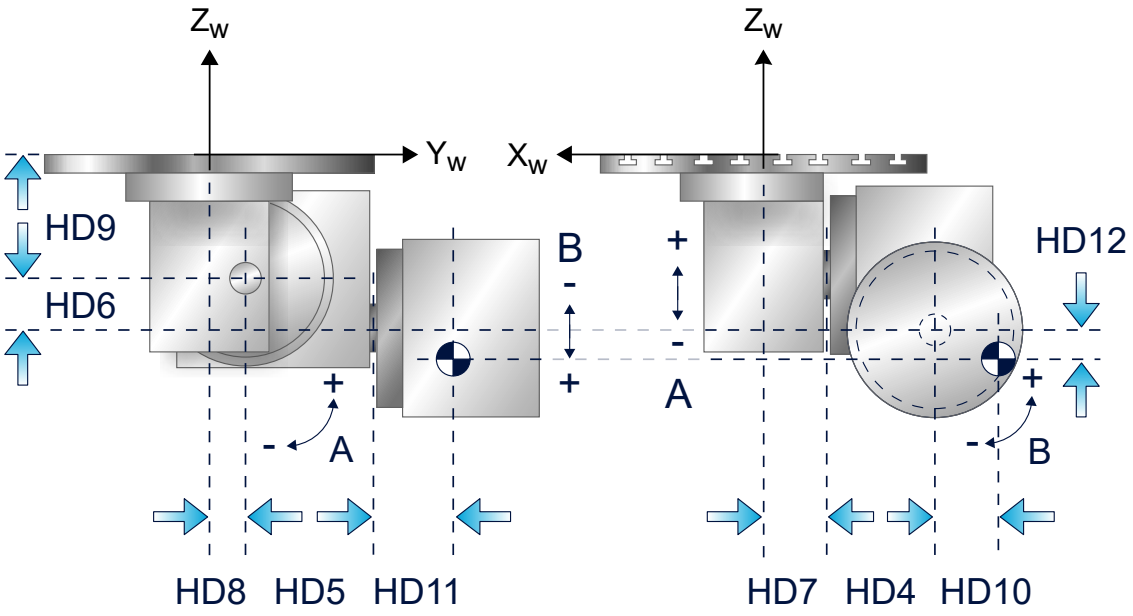


Fig. 102: Offsets of workpiece holder

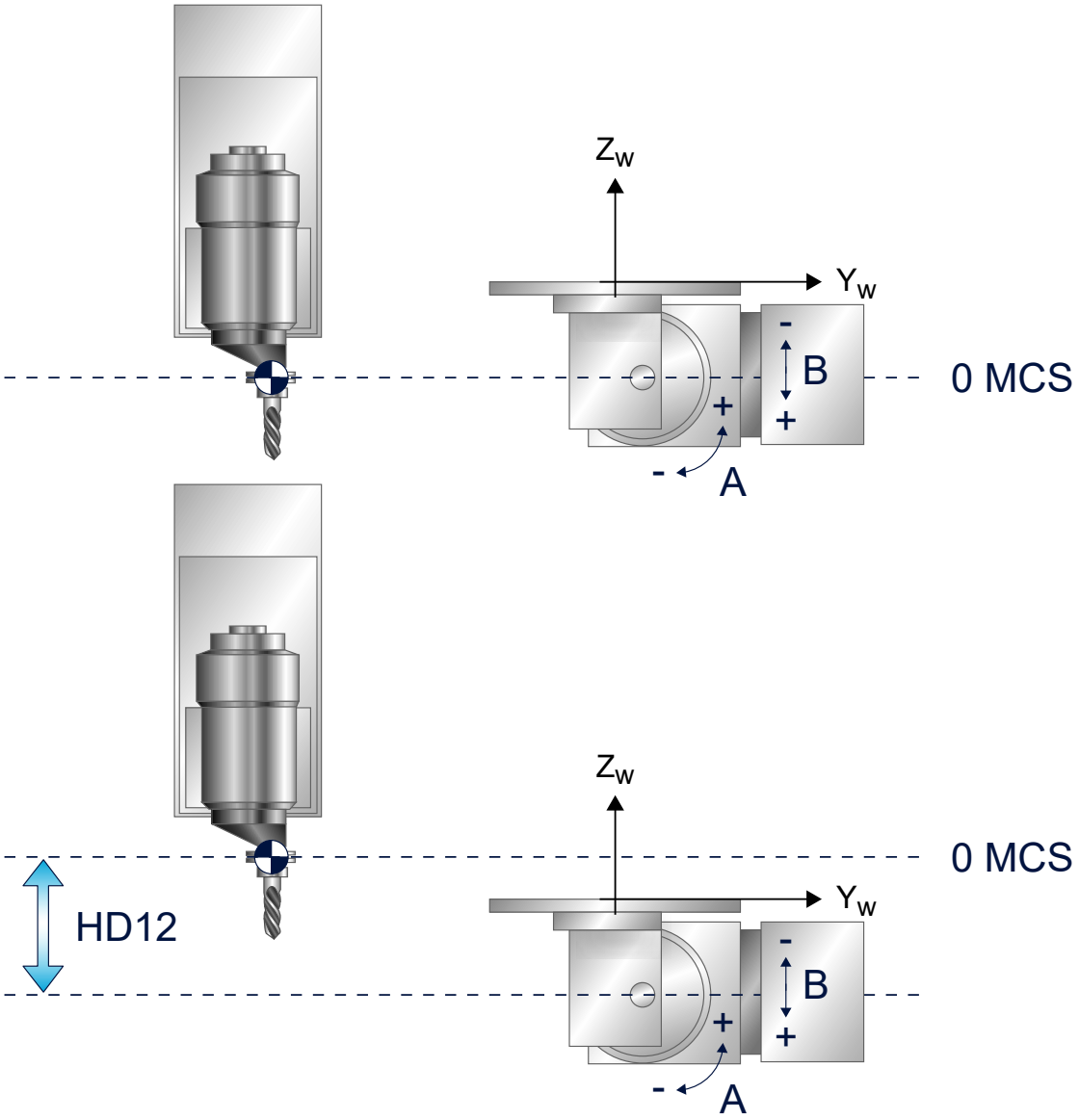


Fig. 103: Ideal and real Z zero position

In the ideal zero position of the kinematic structure, the rotary axis B in the workpiece and the reference point on the tool slide (here tool holding device) intersect at one point. The machine axis positions of the tool slide are then 0 in this position. In general these axis positions cannot be approached with a machine. The offsets to this position at tool slide position 0 can be set with parameters HD10, HD11, HD12.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z axis offset reference point tool slide to tool fixing point	1.0 E-4 mm
HD2	1	X axis offset reference point tool slide to tool fixing point	1.0 E-4 mm
HD3	2	Y axis offset reference point tool slide to tool fixing point	1.0 E-4 mm
HD4	3	X axis offset rotary axis B to rotary axis A	1.0 E-4 mm
HD5	4	Y axis offset rotary axis B to rotary axis A	1.0 E-4 mm
HD6	5	Z axis offset rotary axis B to rotary axis A	1.0 E-4 mm
HD7	6	X axis offset rotary axis A to origin WCS	1.0 E-4 mm
HD8	7	Y axis offset rotary axis A to origin WCS	1.0 E-4 mm
HD9	8	Z axis offset rotary axis A to origin WCS	1.0 E-4 mm
HD10	9	X offset to machine origin MNP	1.0 E-4 mm
HD11	10	Y offset to machine origin MNP	1.0 E-4 mm
HD12	11	Z offset to machine origin MNP	1.0 E-4 mm
HD13	12	Rotary offset B axis	1.0 E-4°
HD14	13	Rotary offset A axis	1.0 E-4°
HD15	14	Rotation direction flag B axis	[-]
HD16	15	Rotation direction flag A axis	[-]

2.37 KIN_TYP_82 – 6-axis kinematics with C workpiece table

Kinematic structure

The kinematic structure consists of 3 translatory axes in the tool, 2 rotary NC axes in the tool and 1 rotary axis in the workpiece.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B, C, A	
Axis index	0, 1, 2, 3, 4, 5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, B, A	C

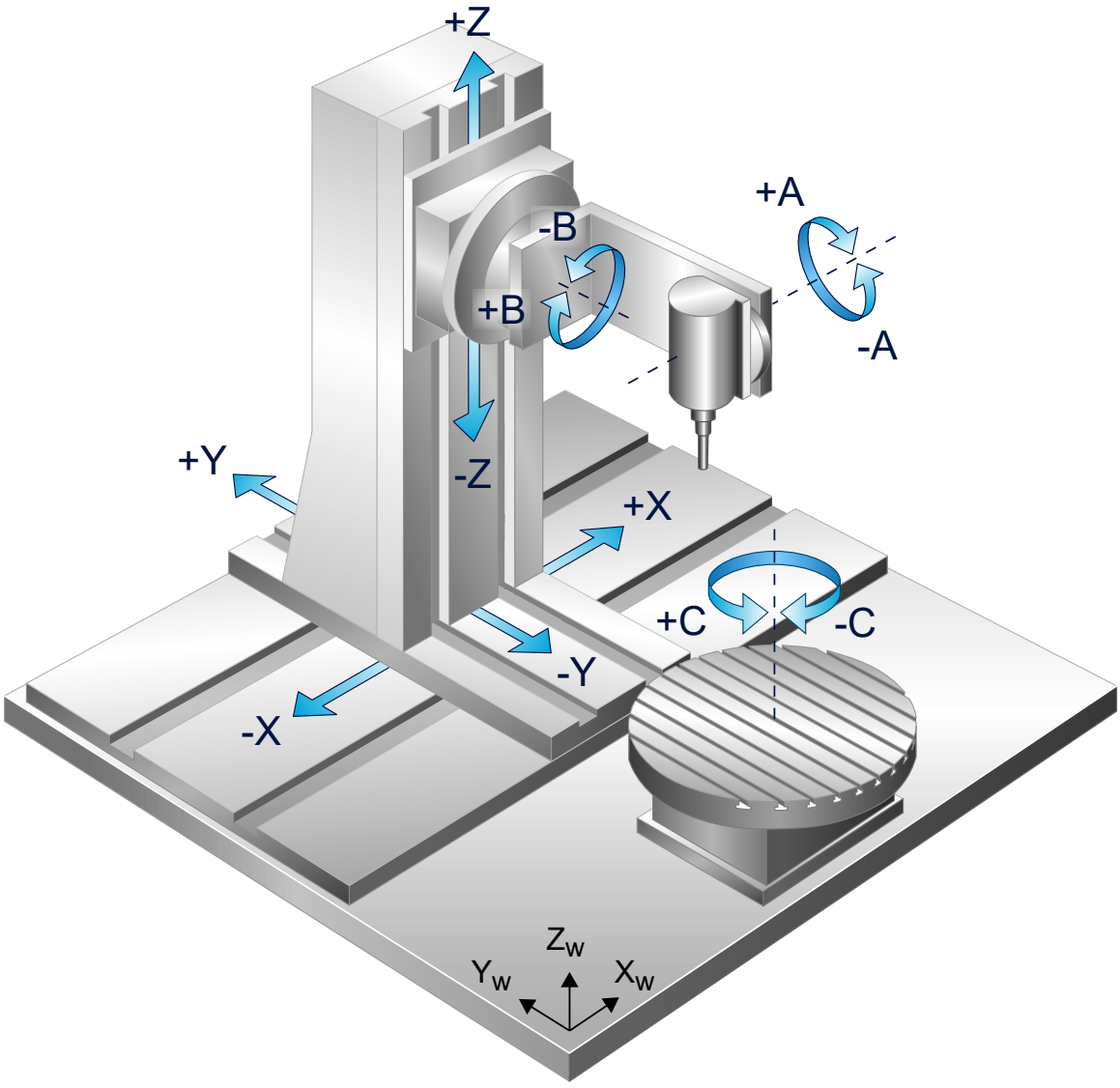


Fig. 104: Axis configuration of 6-axis machine

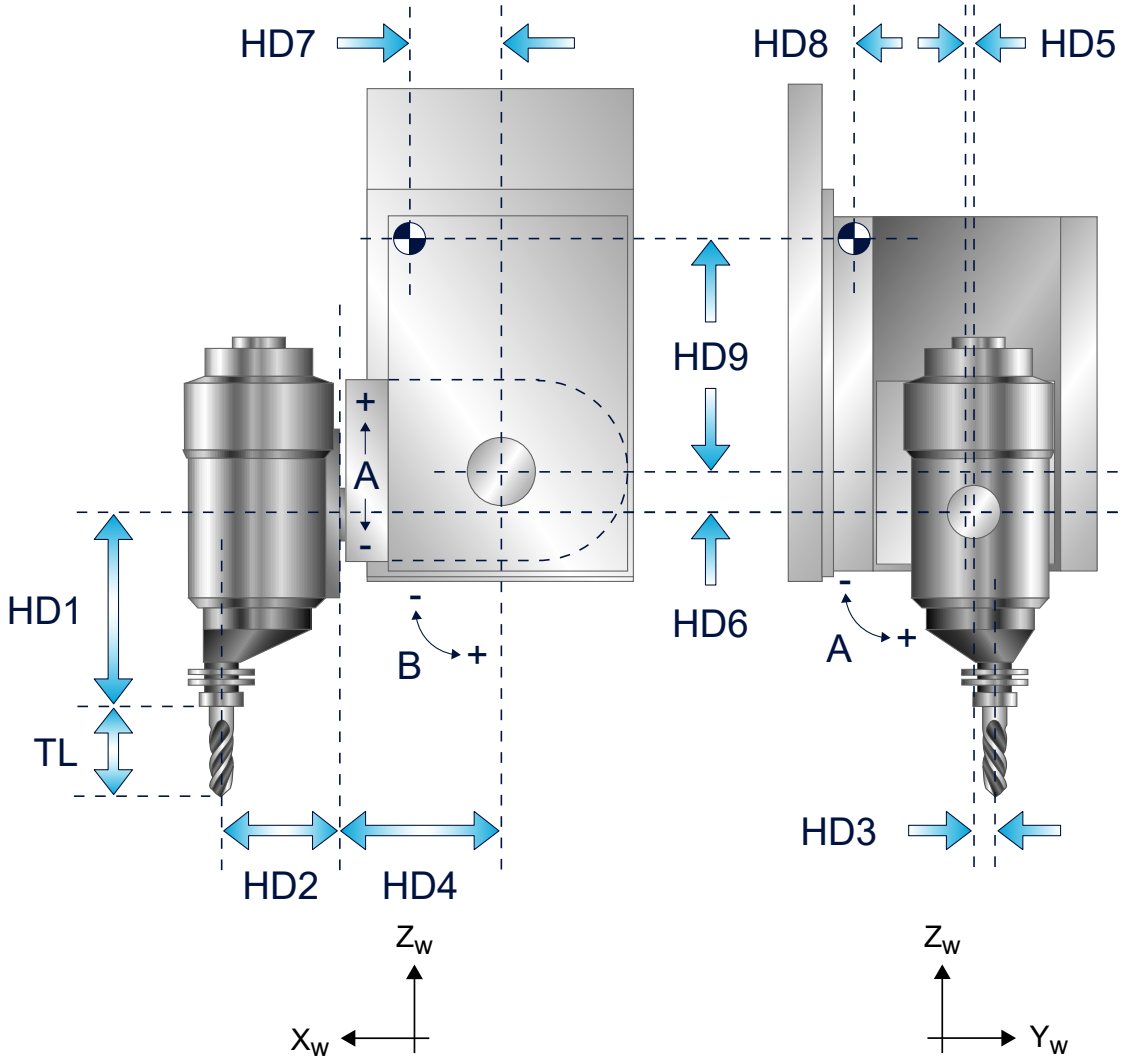


Fig. 105: Tool head parameters

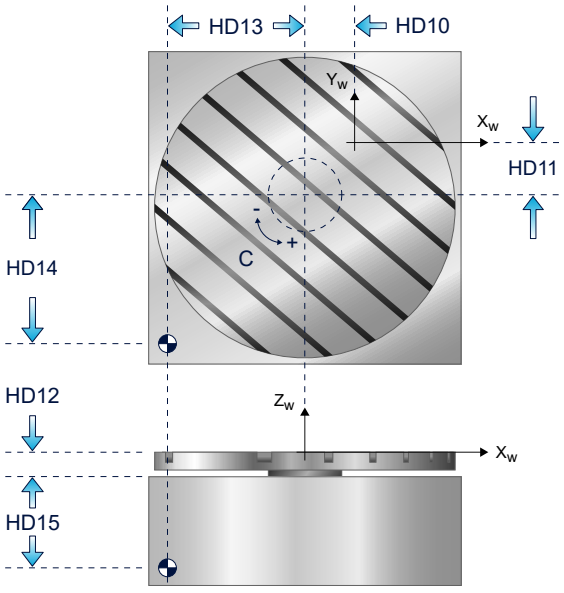


Fig. 106: Offsets on workpiece holder

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset tool to rotation point A axis	1.0 E-4 mm
HD2	1	X offset tool to rotation point A axis	1.0 E-4 mm
HD3	2	Y offset tool to rotation point A axis	1.0 E-4 mm
HD4	3	X offset rotation point A axis to B axis	1.0 E-4 mm
HD5	4	Y offset rotation point A axis to B axis	1.0 E-4 mm
HD6	5	Z offset rotation point A axis to B axis	1.0 E-4 mm
HD7	6	X offset B axis to reference point tool slide	1.0 E-4 mm
HD8	7	Y offset B axis to reference point tool slide	1.0 E-4 mm
HD9	8	Z offset B axis to reference point tool slide	1.0 E-4 mm
HD10	9	X offset C rotary axis to origin WCS	1.0 E-4 mm
HD11	10	Y offset C rotary axis to origin WCS	1.0 E-4 mm
HD12	11	Z offset C rotary axis to origin WCS	1.0 E-4 mm
HD13	12	X offset to machine origin	1.0 E-4 mm
HD14	13	Y offset to machine origin	1.0 E-4 mm
HD15	14	Z offset to machine origin	1.0 E-4 mm
HD16	15	Rotary offset B axis	1.0 E-4°
HD17	16	Rotary offset C axis	1.0 E-4°
HD18	17	Rotation direction flag B axis	[-]
HD19	18	Rotation direction flag C axis	[-]

2.38 KIN_TYP_85 – Lever arm kinematics

Kinematic structure

The kinematic structure consists of 1 translatory axis and 1 rotary NC axis. The transformation can be selected for any X axis position (ACS). In this case a corresponding machine X position (MCS) is determined.

Depending on the angle position when the transformation is selected, the programmed contour is moved in the left-handed or right-handed pattern. When the transformation is active, the selection side is retained, i.e. there is no swapping between right-handed/left-handed beam. To swap the selection side, the transformation must be switched off.

In the motion range of the transformation used, the rotary axis may not have a modulo transition.

Axis configuration in the NC channel		
Axis identifier	X, Z	
Axis index	0, 1	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, C	-

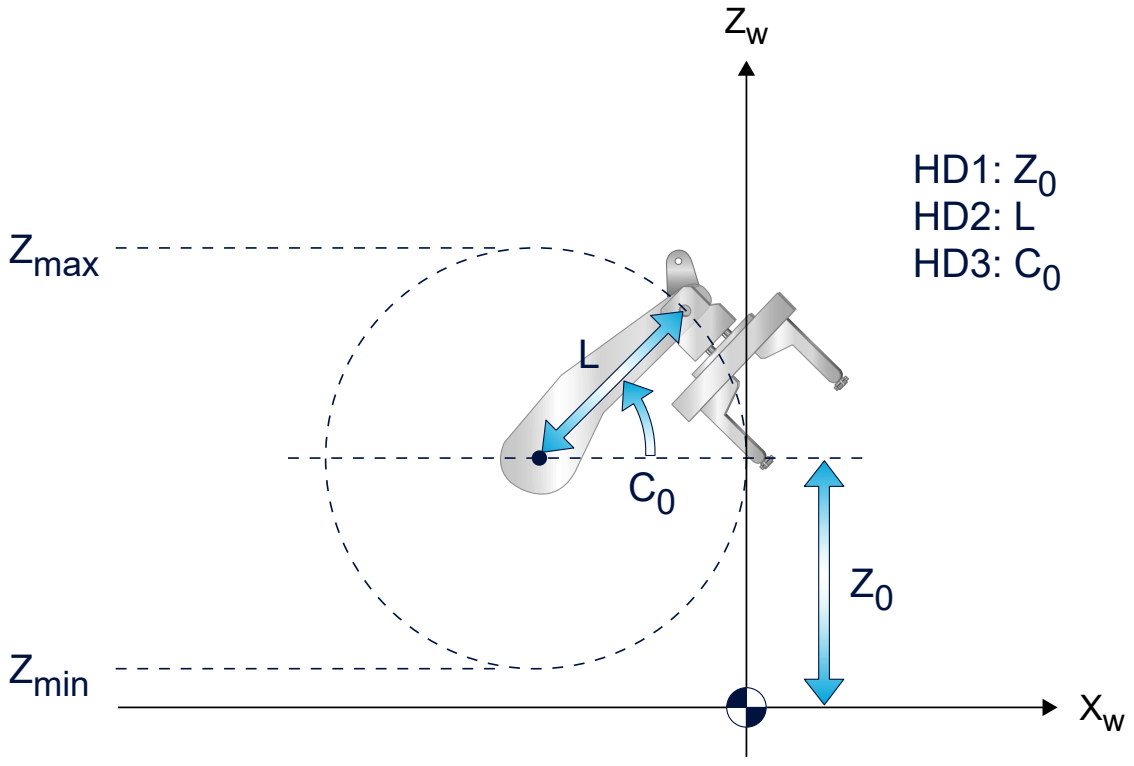


Fig. 107: Position of the coordinate system

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Z offset of rotation centre point	1.0 E-4 mm
HD2	1	Arm length of lever arm	1.0 E-4 mm
HD3	2	Angle offset of C axis to the horizontal	1.0 E-4°

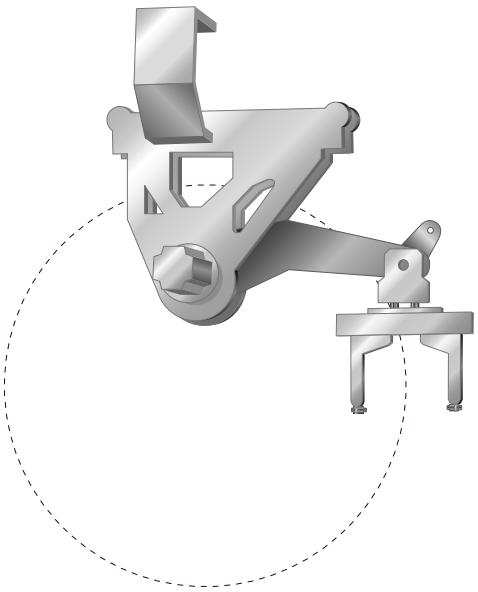


Fig. 108: Axis configuration for left-handed beam

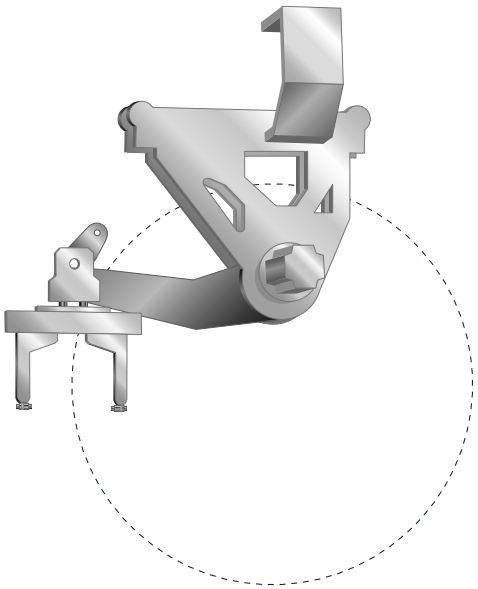


Fig. 109: Axis configuration for right-handed beam

2.39 KIN_TYP_98- Transformation to monitor the minimum distance

Release Note

This function is available as of V3.1.3080.12 or V3.1.3107.44

This transformation can monitor and maintain a defined minimum distance to the workpiece surface at the tool inclination.

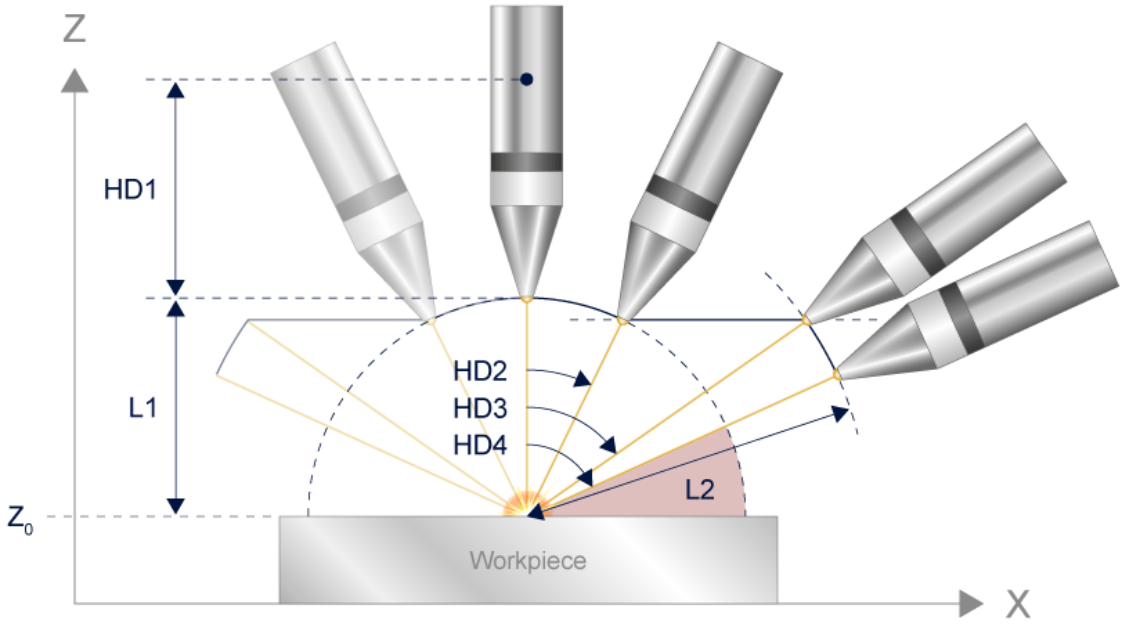


Fig. 110: Monitoring the minimum distance

The laser length L1 must be programmed as the tool length, e.g. programmed via V.G.WZ_AKT.L.

Tool length L2 is the tool length that is extended by the kinematic due to the avoidance motion.

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool clamping point offset up to tool head reference point	1.0 E-4 mm
HD2	1	Inclination angle starting at which the distance of the tool head to the surface is kept constant.	1.0 E-4°
HD3	2	Maximum inclination angle starting at which the distance of the tool head to the surface is kept constant.	1.0 E-4°
HD4	3	Maximum inclination angle. When exceeded, an error message is output with process abort.	1.0 E-4°

KIN_TYP_202 - CYL 2ROT kinematics

Kinematic structure

Turning work in the Cartesian system. The tool is supported by the translatory axes XQ, ZQ and the rotary axis YQ. The workpiece is aligned by the rotary axis CS.

Transformation can be switched by the command #CYL 2ROT. The user programs X, Y, Z in the Cartesian system. In addition, the dimension C of the tool angle is programmed in the X-Y plane. When C=0, the tool is parallel to X and vertical on Y.

The kinematics are available in 2 variants.

1. In the LEFT variant (HD10 = 0) the CS axis is located to the left of the YQ axis. The YQ axis points to the left in zero position. When transformation is selected, the X axis must be located to the right of the CS axis.
2. In the RIGHT variant (HD10 = 1) the CS axis is located to the right of the YQ axis. The YQ axis points to the right in zero position. When transformation is selected, the X axis must be located to the left of the CS axis.

The CS axis must have a modulo range of 0° to 360°, see P-AXIS-00126 and P-AXIS-00127.

Axis configuration in the NC channel		
Axis identifier	XQ, YQ, ZQ, CS	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	XQ, YQ, ZQ	CS

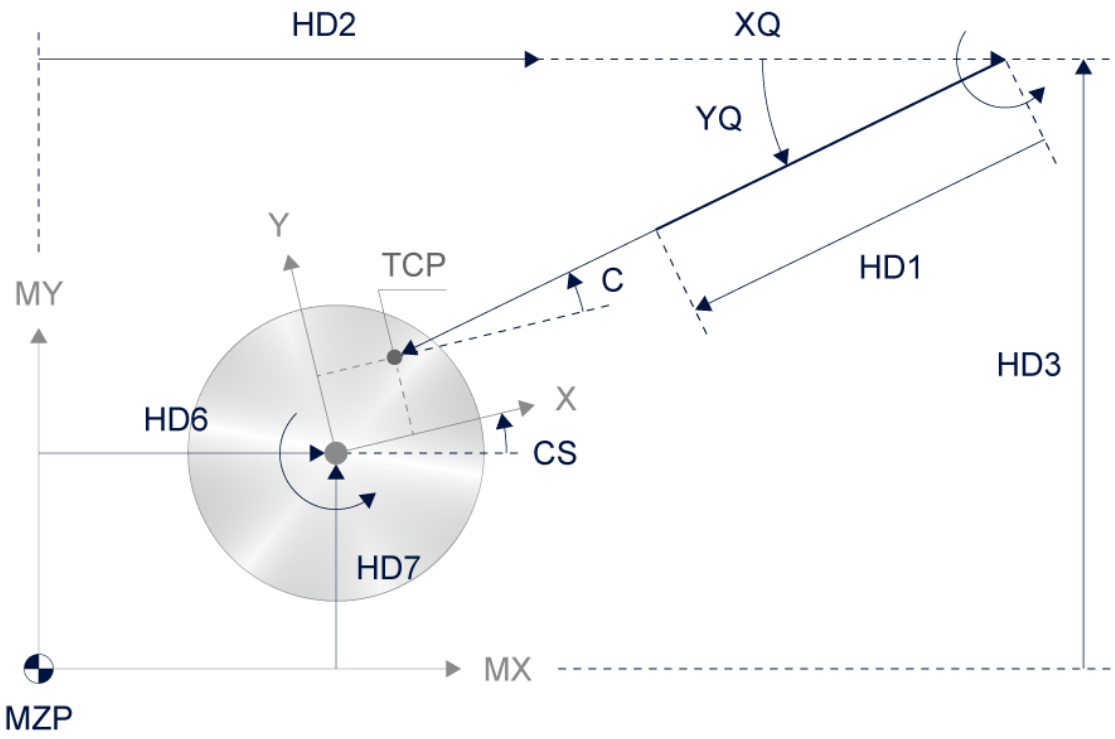


Fig. 111: Kinematics in the LEFT variant

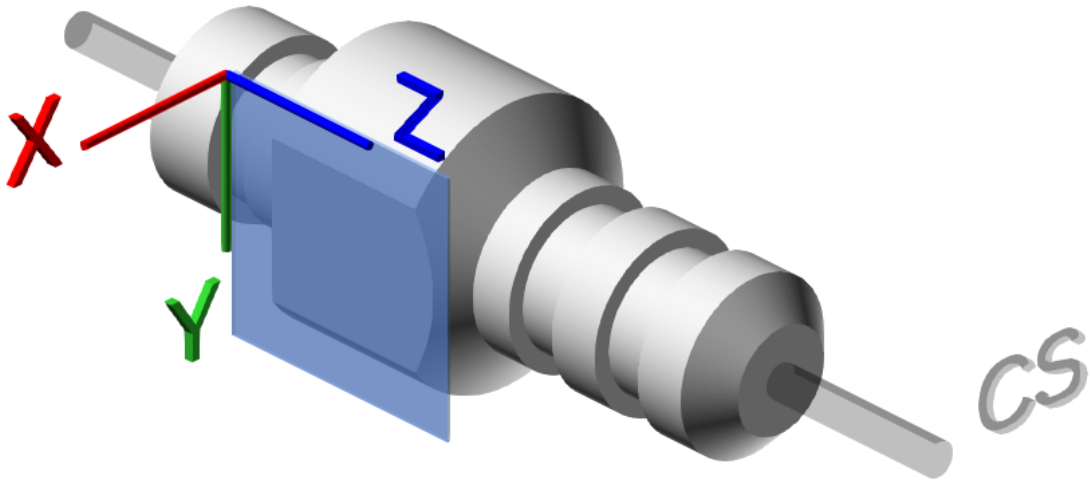


Fig. 112: Offset programming coordinate system in the RIGHT variant

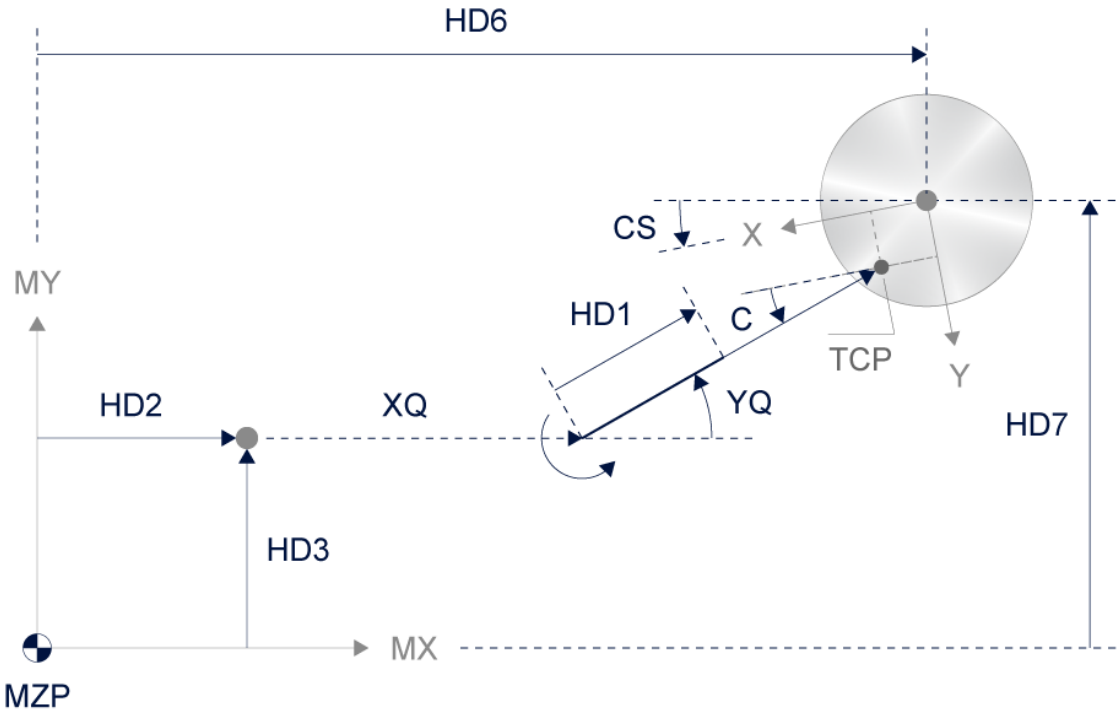


Fig. 113: Kinematics in the RIGHT variant

HD offset	param[i]	Meaning	Unit
HD1	0	Tool length offset	1.0 E-4 mm
HD2	1	X offset from machine origin MNP to rotation centre XQ	1.0 E-4 mm
HD3	2	Y offset from machine origin MNP to rotation centre XQ	1.0 E-4 mm
HD4	3	Z offset from machine origin MNP to rotation centre XQ	1.0 E-4 mm
HD5	4	Angular offset for YQ	1.0 E-4°
HD6	5	X offset from machine origin MNP to rotation centre CS	1.0 E-4 mm
HD7	6	Y offset from machine origin MNP to rotation centre CS	1.0 E-4 mm
HD8	7	Z offset from machine origin MNP to rotation centre CS	1.0 E-4 mm
HD9	8	Angular offset for CS	1.0 E-4°
HD10	9	Kinematics variant 0: LEFT, CS axis is located to the left of the tool axis YQ 1: RIGHT, CS axis is located to the right of the tool axis YQ	[-]

KIN_TYP_203 - FACE 2ROT kinematics

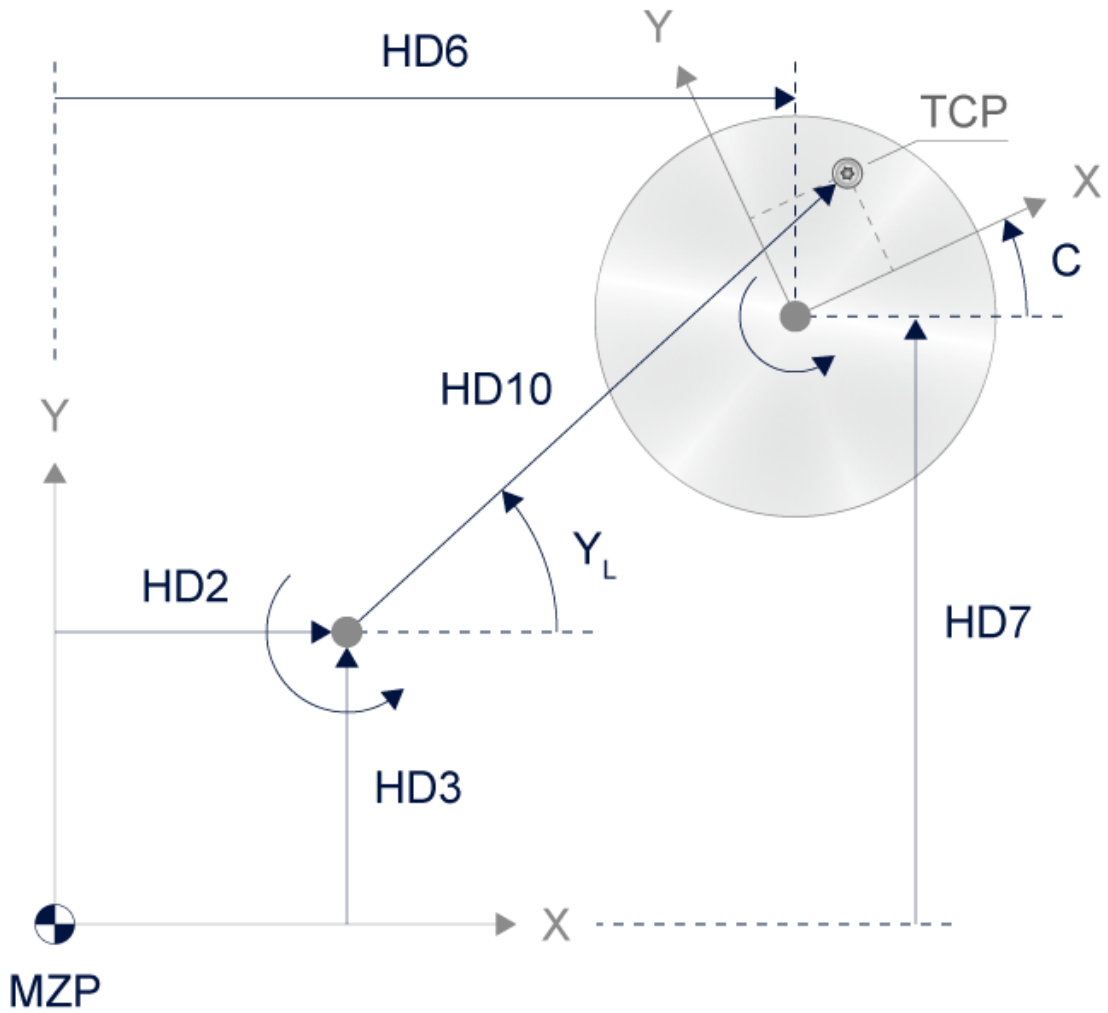
Kinematic structure

Face machining with 2 rotary axes. The tool is supported by the rotary axis YL and the translatory axis ZL. The workpiece is aligned by the rotary axis C.

The transformation can be switched by the command #FACE 2ROT. The user programs X, Y, Z on the tool face in the Cartesian system.

The CS axis must have a modulo range of 0° to 360°, see P-AXIS-00126 and P-AXIS-00127.

Axis configuration in the NC channel		
Axis identifier	C, YL, ZL	
Axis index	0, 1, 2	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	YL, ZL	C



HD offset	param[i]	Meaning	Unit
HD1	0	Tool length offset	1.0 E-4 mm
HD2	1	X offset from machine origin to rotation centre of YL	1.0 E-4 mm
HD3	2	Y offset from machine origin to rotation centre of YL	1.0 E-4 mm
HD4	3	Z offset from machine origin to rotation centre of YL	1.0 E-4 mm
HD5	4	Angular offset for YL	1.0 E-4°
HD6	5	X offset from machine origin to rotation centre of C	1.0 E-4 mm
HD7	6	Y offset from machine origin to rotation centre of C	1.0 E-4 mm
HD8	7	Z offset from machine origin to rotation centre of C	1.0 E-4 mm
HD9	8	Angle offset for C	1.0 E-4°
HD10	9	Length of tool arm	1.0 E-4 mm

KIN_TYP_205 - Eccentric disc kinematics

Kinematic structure

The tool is attached to an eccentric disc that rotates about Z. The eccentric disc is also moved by 2 Cartesian axes in the X or Z direction.

HD parameters HD16 and HD17 to determine the axis about which the eccenter disc rotates with the tool.

The following combinations are permitted:

- HD16 = 0, HD17 = 1 : rotation about X
- HD16 = 1, HD17 = 0 : Rotation about Z
- HD16 = 0, HD17 = 0 : Discontinued status, still available for reasons of downward compatibility. No longer recommended.

Any other combination of parameters HD16 and HD17 is not permitted.

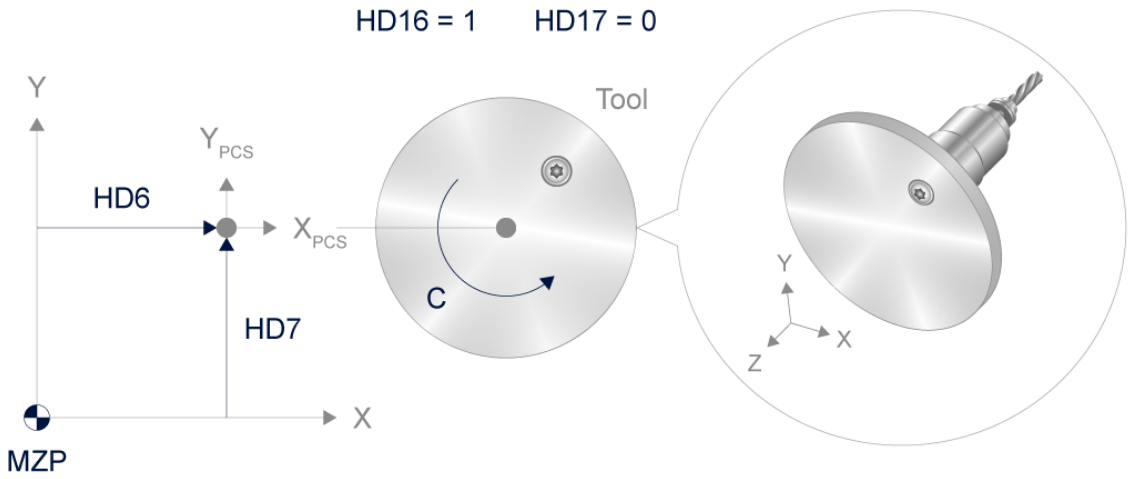


Fig. 114: Eccentric disc kinematic with rotation about Z

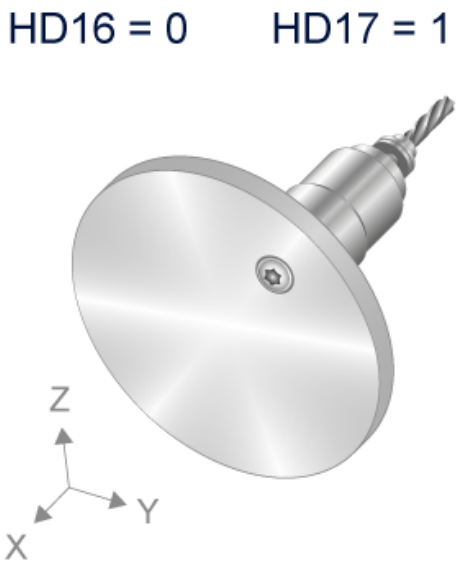
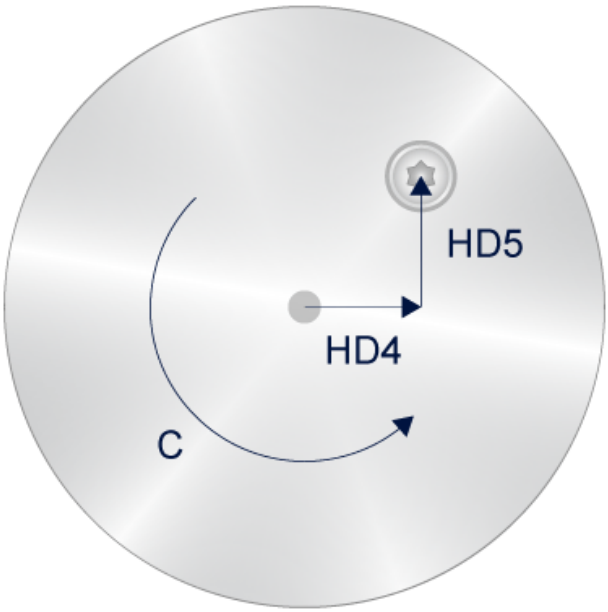
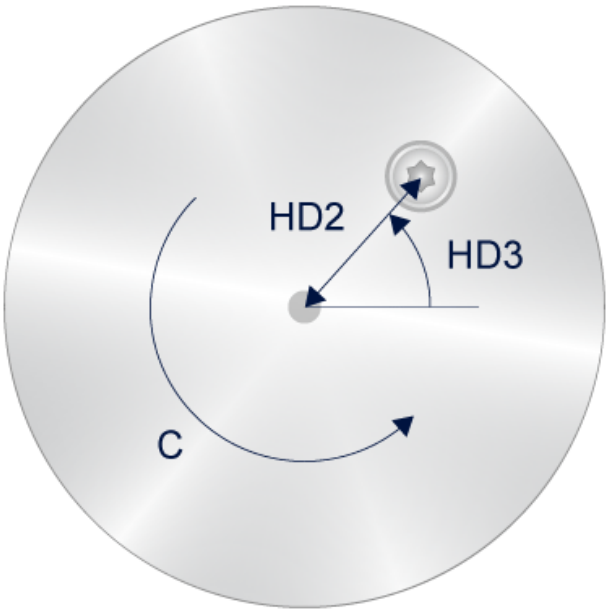


Fig. 115: Eccentric disc kinematic with rotation about X

The tool position relative to the rotation centre can be configured in the following 2 methods.

Cartesian determination	Polar determination
	

Configuring the two methods has an additive effect on the tool position.

The kinematics are programmed in XYZ coordinates.

Axis configuration in the NC channel		
Axis identifier	X, Y(C), Z	
Axis index	0, 1, 2	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y(C), Z	-

The axes can be sorted in the channel, e.g. with # SET AX [X, 1, 0] [Y, 2, 1] [Z, 3, 2].

HD offset	param[i]	Meaning	Unit
HD1	0	Tool length offset	1.0 E-4 mm
HD2	1	polar: Tool distance from rotary axis C	1.0 E-4 mm
HD3	2	polar: Tool zero position angle	1.0 E-4 mm
HD4	3	Cartesian: X offset between tool and C axis	1.0 E-4 mm
HD5	4	Cartesian: Y offset between tool and C axis	1.0 E-4 mm
HD6	5	X offset from machine origin to zero position of X	1.0 E-4 mm
HD7	6	Y offset from machine origin to zero position of X	1.0 E-4 mm
HD8	7	Z offset from machine origin to zero position of X	1.0 E-4 mm
HD9	8	X offset from machine origin to zero position of Z	1.0 E-4 mm
HD10	9	Y offset from machine origin to zero position of Z	1.0 E-4 mm
HD11	10	Z offset from machine origin to zero position of Z	1.0 E-4 mm
HD12	11	Angle offset of C axis	1.0 E-4°
HD13	12	Direction flag for C axis: >= 0: positive rotation direction < 0: negative rotation direction	[-]
HD14	13	Direction flag for X axis (as of V3.1.3080.19 or v3.1.3107.53) >= 0 positive < 0 negative	[-]
HD15	14	Direction flag for Z axis (as of V3.1.3080.19 or v3.1.3107.53) >= 0 positive < 0 negative	[-]
HD16	15	Parameter to determine the axis about which the eccenter disc rotates with the tool. (as of V3.1.3080.19 or v3.1.3107.53).	[-]
HD17	16	Parameter to determine the axis about which the eccenter disc rotates with the tool. (as of V3.1.3080.19 or v3.1.3107.53).	[-]

2.40 KIN_TYP_207- 5-axis kinematics with inclined tool

Kinematic structure

The kinematic structure consists of 3 translatory NC axes and 1 rotary NC axis in the tool. A manually adjustable rotary 5th axis continues to be available. This kinematic allows inclined machining edges at a fixed with manually preset angle (A). This A axis cannot be addressed by the NC program.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, C	-
Auxiliary axes	A	-

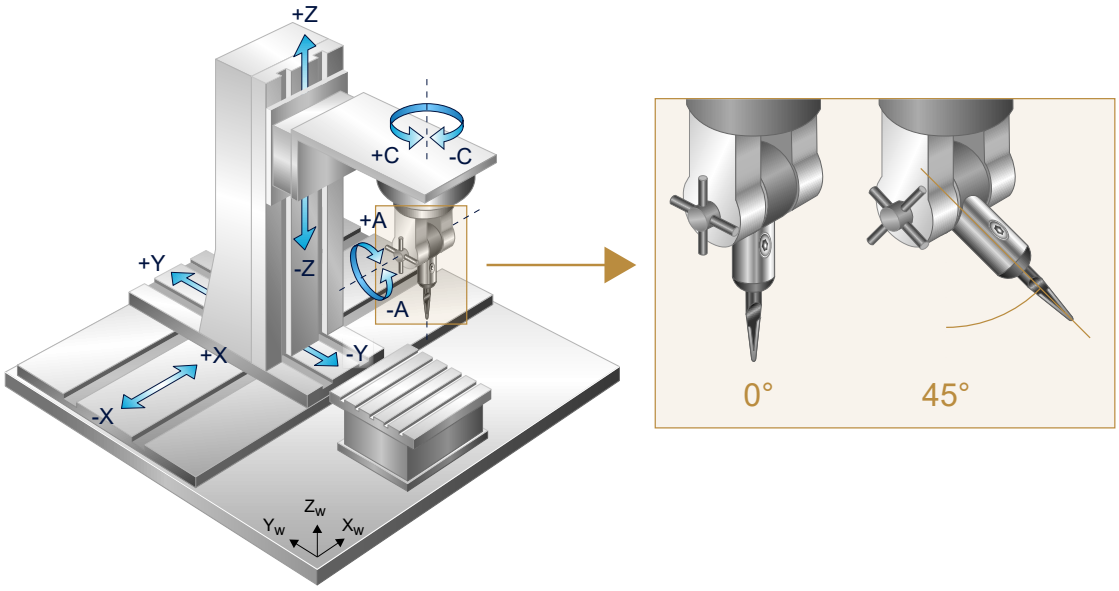


Fig. 116: 5-axis kinematic (metal cutting tool with manual auxiliary axis A)

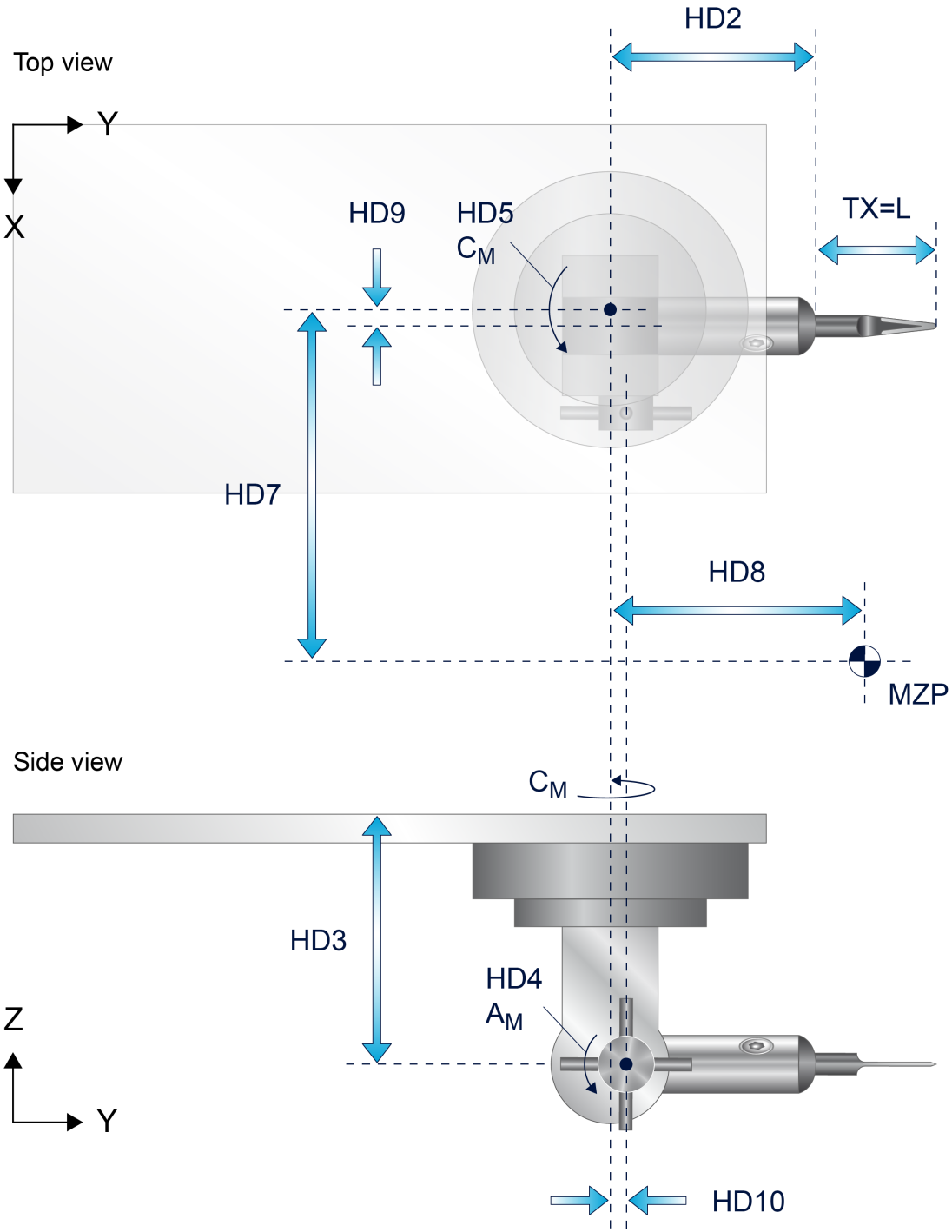


Fig. 117: 5-Axis metal cutting tool with 90 degree angle setting

Additional information to parameter HD11

HD11 specifies the machining depth or the tool thickness used at cutting height Z0. Reference plan for programming the contour is Z0. It is not possible to move deeper than the specified cutting height.

When moving to cutting height Z0, this kinematic executes an inclined plunge or withdrawal of the tool at manually set tool angle A (HD4).

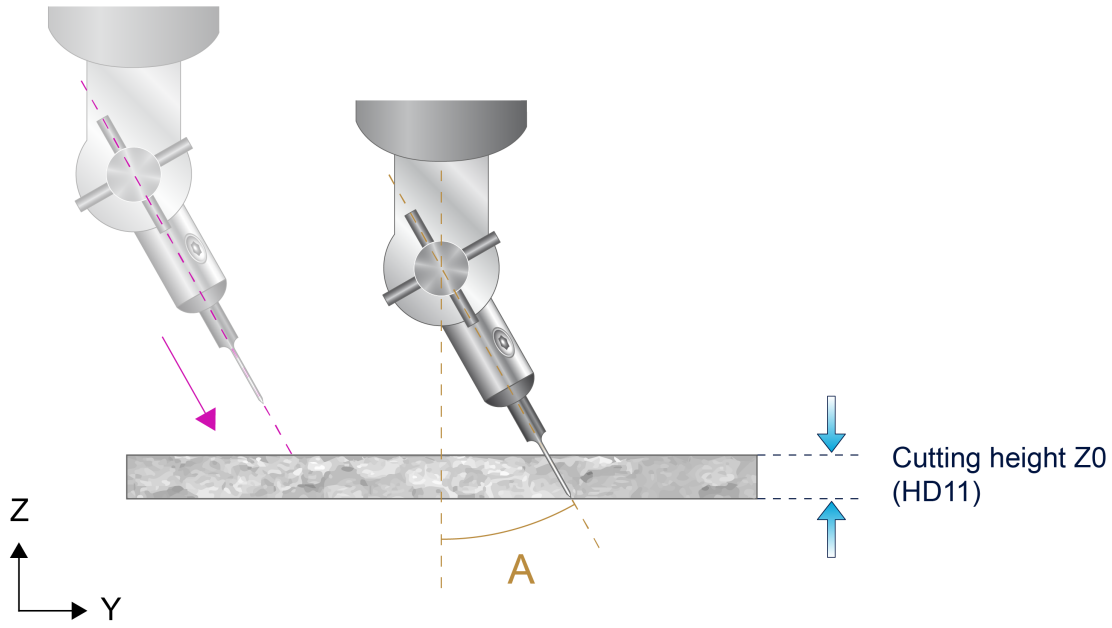


Fig. 118: Cutting height

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD2	1	Y axis offset from tool holding device to rotation point A axis (swivel axis)	1.0 E-4 mm
HD3	2	Z axis offset from rotation point A axis to tool reference point	1.0 E-4 mm
HD4	3	Fixed angle setting of rotary A axis (tool angle)	1.0 E-4°
HD5	4	Rotary angular offset C axis	1.0 E-4°
HD7	6	Static tool offset in X	1.0 E-4 mm
HD8	7	Static tool offset in Y	1.0 E-4 mm
HD9	8	X axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm
HD10	9	Y axis offset rotation point A axis to rotation point C axis	1.0 E-4 mm
HD11	10	Define the cutting height Z0	1.0 E-4 mm

2.41 KIN_TYP_209 - Tripod with rotary/swivel workpiece table

This kinematic is based on the strut kinematic (KIN_TYP_12) and additionally contains a rotary/swivel workpiece table to carry out conventional 5-axis machining.

Release Note

This kinematic is available as of CNC Build V3.01.3078.

Axis configuration in NC channel		
Axis identifier	X, Y, Z (Z1, Z2, Z3), A(B), C	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	A(B), C

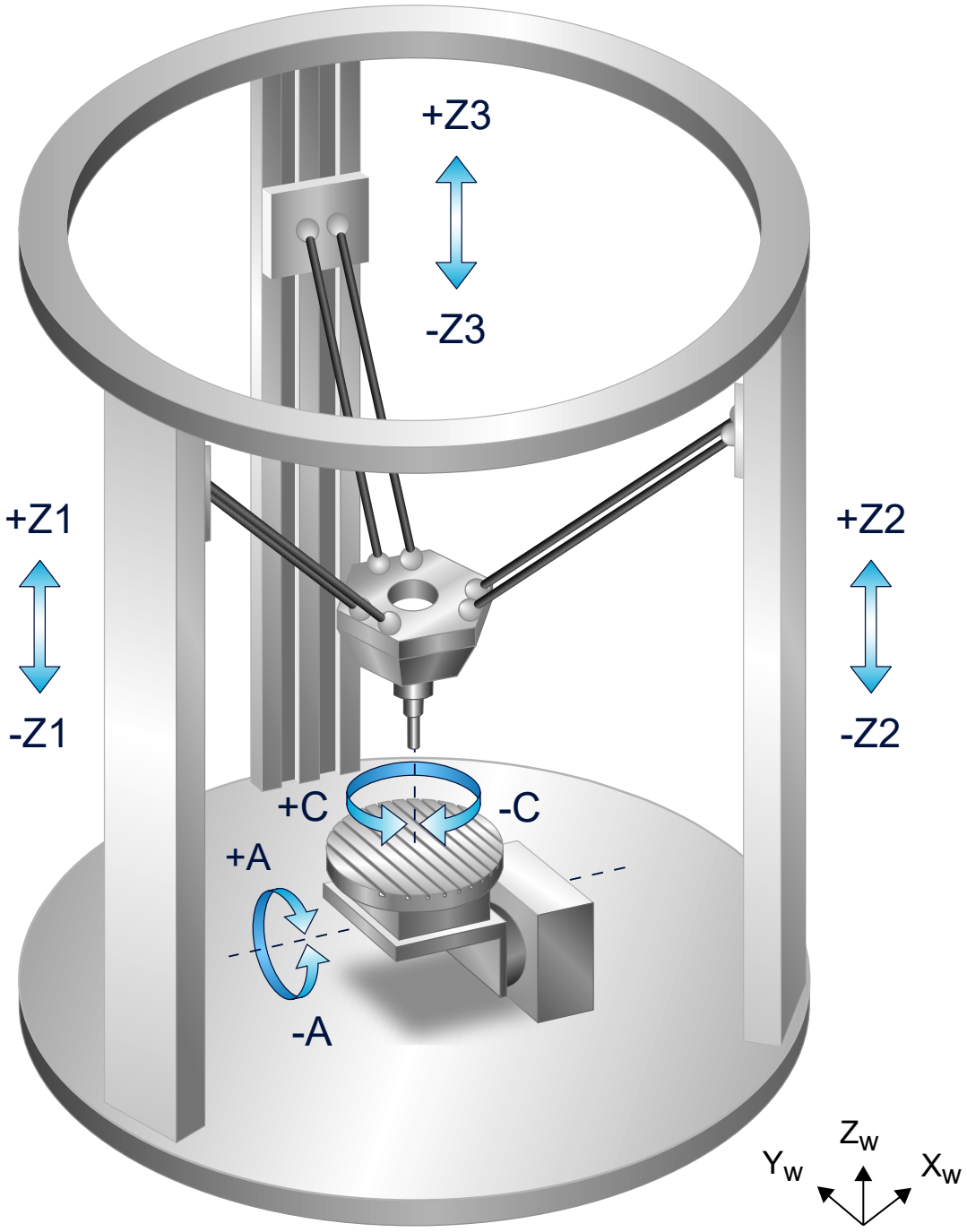


Fig. 119: Trip kinematics with CA rotary/swivel table

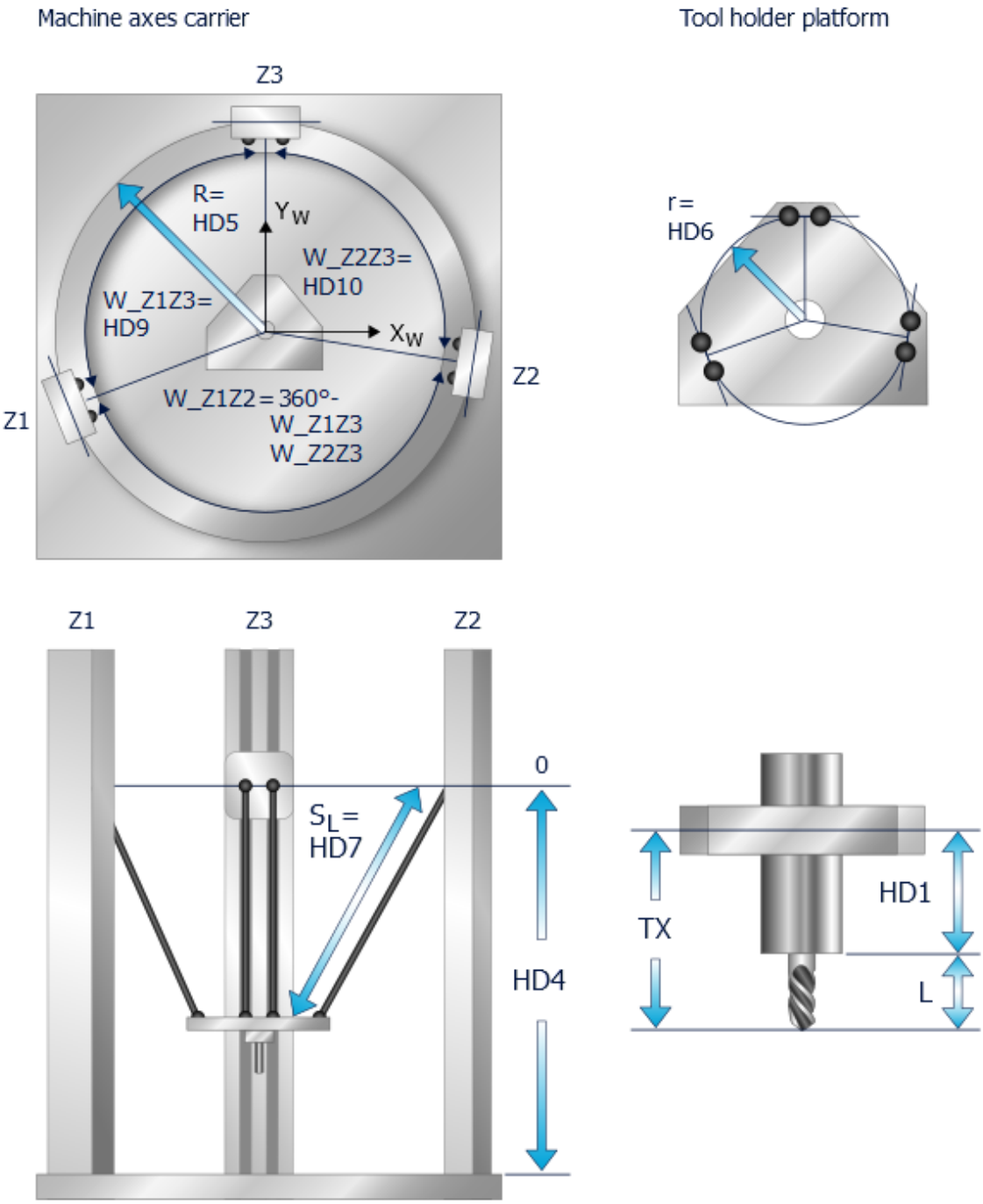


Fig. 120: Offset dimensions of strut kinematics

The parameter HD8 is used to toggle between an ideal (1) and non-ideal (0) tripod. An ideal tripod has an angle of 120° between all columns. A non-ideal tripod must be defined by the angles HD9 and HD10.
The third angle between columns is calculated as follows:

W_Z1Z2 = 360° - HD9 – HD10 = 360° - W_Z2Z3 – W_Z1Z3

An angle offset of the rotary/swivel table due to mounting constraints can be compensated by HD30.

Rotary/swivel table – CA variant

HD31 defines the rotary/swivel table variant. By default the parameter is assigned the value 0 defining the CA variant.

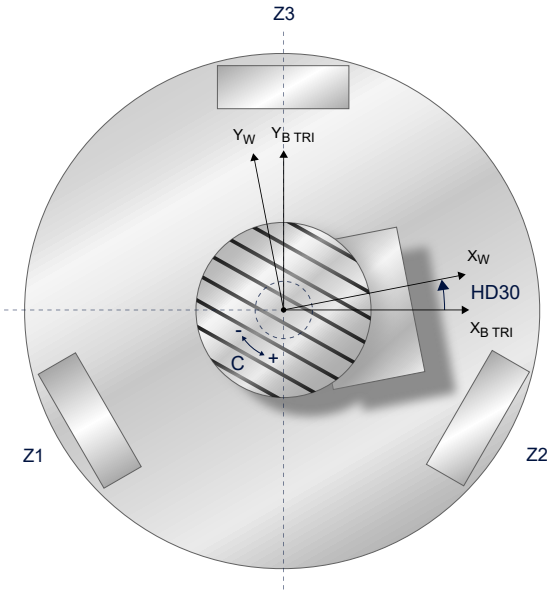


Fig. 121: Angle offset HD30 of the CA rotary/swivel table

CA rotary/swivel table offsets

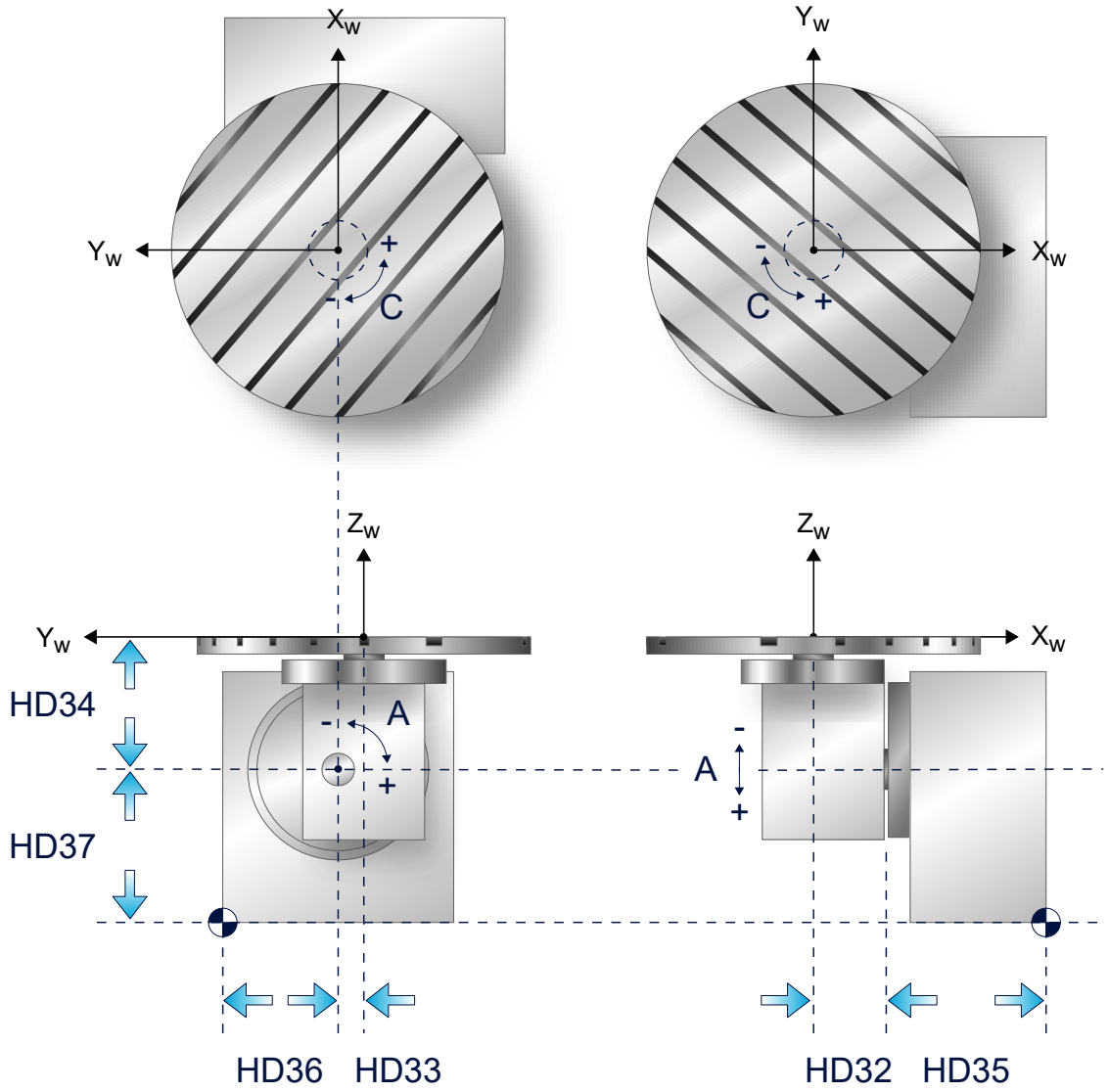


Fig. 122: CA rotary/swivel table offsets

Rotary/swivel table – CB variant

If HD31 is assigned the value 1, the CB variant is defined.

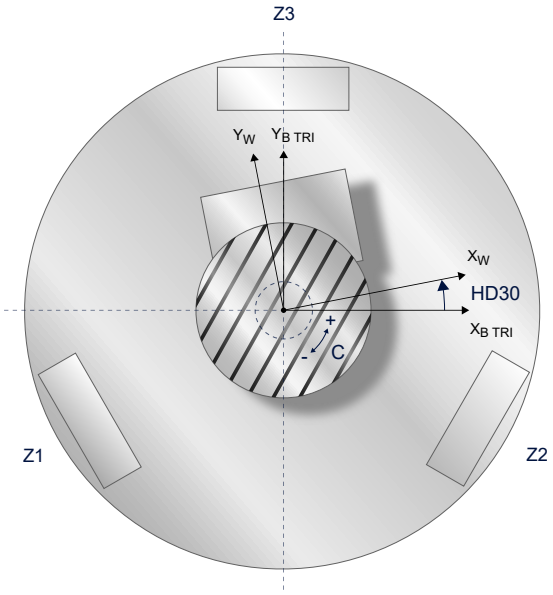


Fig. 123: Angle offset HD30 of the CB rotary/swivel table

CB rotary/swivel table offsets

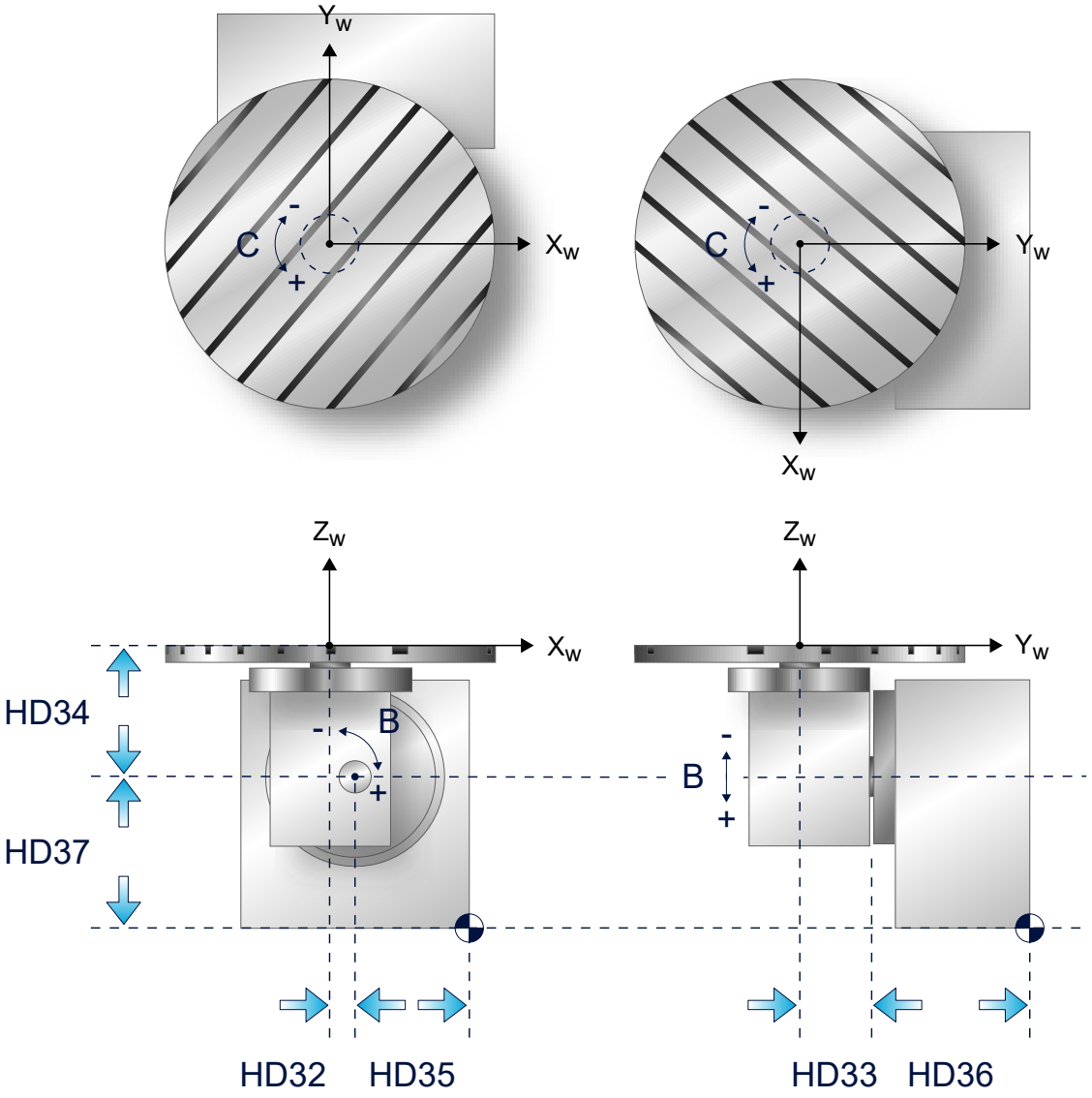


Fig. 124: CB rotary/swivel table offsets

Tripod kinematics offset data

HD offset	param[i]	Description	Unit
HD1	0	Tool offset Z	1.0 E-4 mm
HD2	1	Tool offset Y	1.0 E-4 mm
HD3	2	Tool offset X	1.0 E-4 mm
HD4	3	Z axis offset machine origin	1.0 E-4 mm
HD5	4	Radius to connecting line of the joint centre points on the drive columns (large circle)	1.0 E-4 mm
HD6	5	Radius to connecting line of the joint centre points on the holder platform (small circle)	1.0 E-4 mm
HD7	6	Strut length to each joint centre point	1.0 E-4 mm
HD8	7	Switch to switch over to non-ideal tripod 0 : ideal tripod 1 : non-ideal tripod and enable HD9 / HD 10	[-]
HD9	8	Angle column / joint 3 to column / joint 1	1.0 E-4°
HD10	9	Angle column / joint 3 to column / joint 2	1.0 E-4°

Offset data of the rotary/swivel table

HD offset	param[i]	Description	Unit
HD30	29	Angle offset about Z of Cartesian basic system to tripod column Z3	1.0 E-4°
HD31	30	Type of rotary workpiece holder 0: CA, 1:CB Default value = 0	[-]
HD32	31	X axis offset rotary axis A, (B) to rotary axis C, origin WCS	1.0 E-4 mm
HD33	32	Y axis offset rotary axis A, (B) to rotary axis C, origin WCS	1.0 E-4 mm
HD34	33	Z axis offset rotary axis A, (B) to rotary axis C, origin WCS	1.0 E-4 mm
HD35	34	X offset machine origin MZP to rotary axis A, (B)	1.0 E-4 mm
HD36	35	Y offset from machine origin MZP to rotary axis A, (B)	1.0 E-4 mm
HD37	36	Z offset machine origin MZP to rotary axis A, (B)	1.0 E-4 mm
HD38	37	Rotary offset A (B) axis	1.0 E-4°
HD39	38	Rotary offset C axis	1.0 E-4°
HD40	39	Rotation direction flag A (B) axis	[-]
HD41	40	Rotation direction flag C axis	[-]

3 Robot kinematics

3.1 KIN_TYP_36 – SCARA kinematics

Kinematic structure

The robot kinematics consist of 3 rotary and 1 translatory NC axes in the tool. Tool length compensation takes place in the Z axis. All rotary axes are C axes.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C (C1, C2, Z, C3)	
Axis index	0, 1, 2, 3	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X,Y, Z, C	-

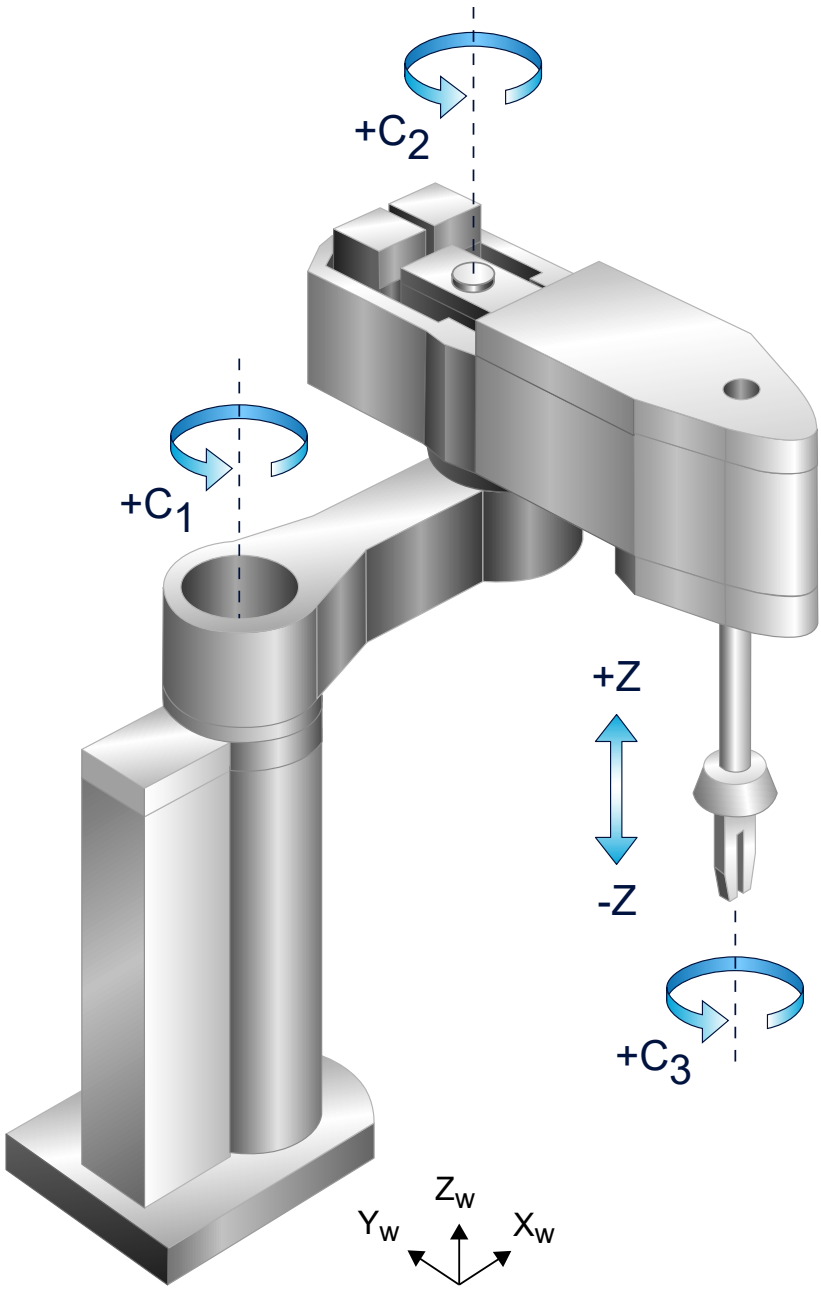


Fig. 125: SCARA kinematics

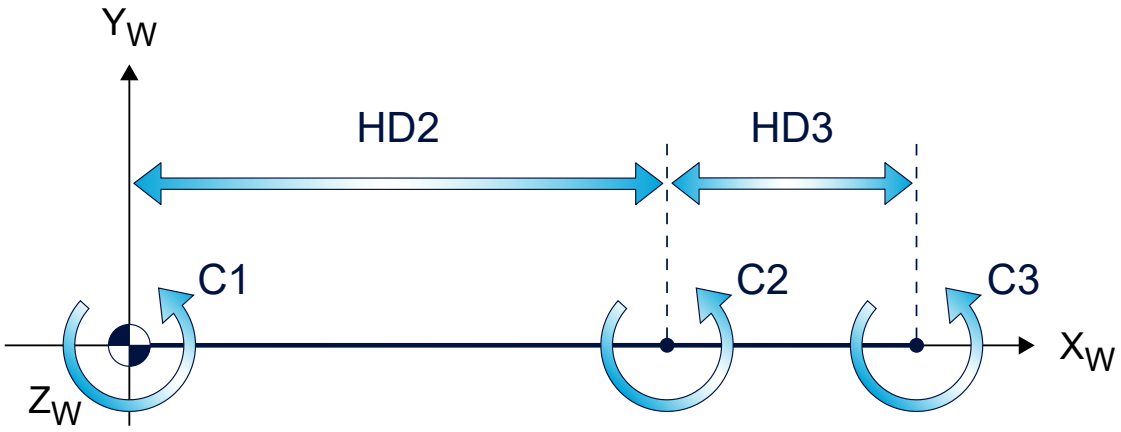


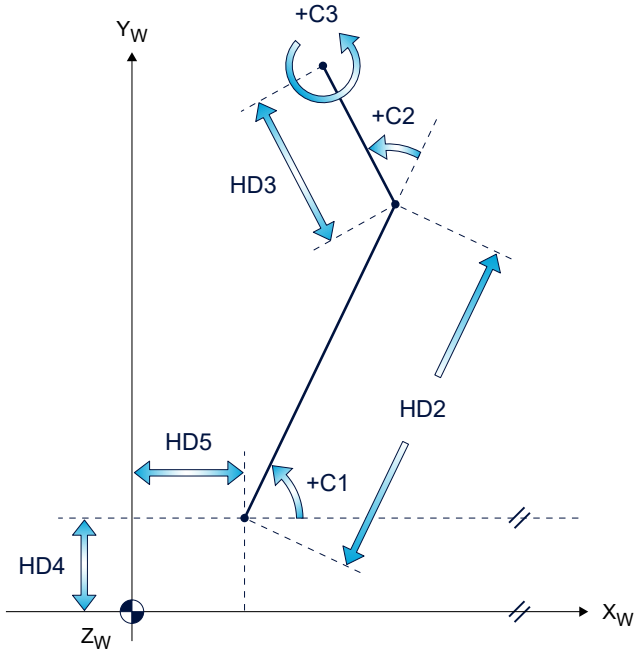
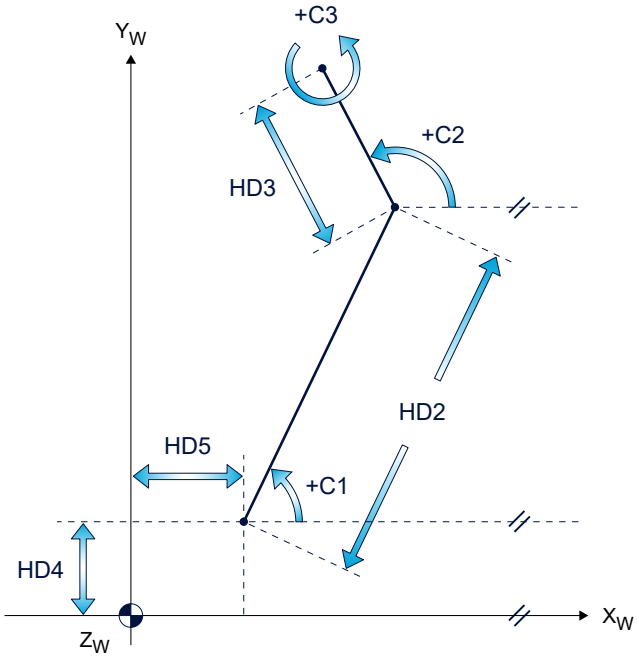
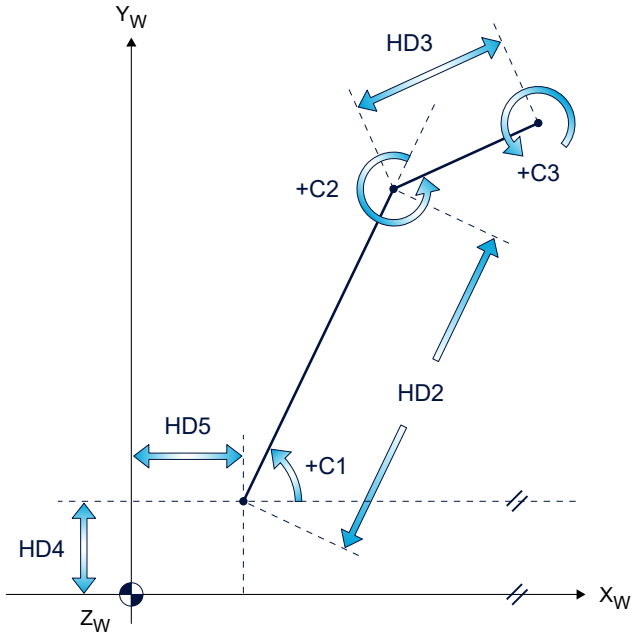
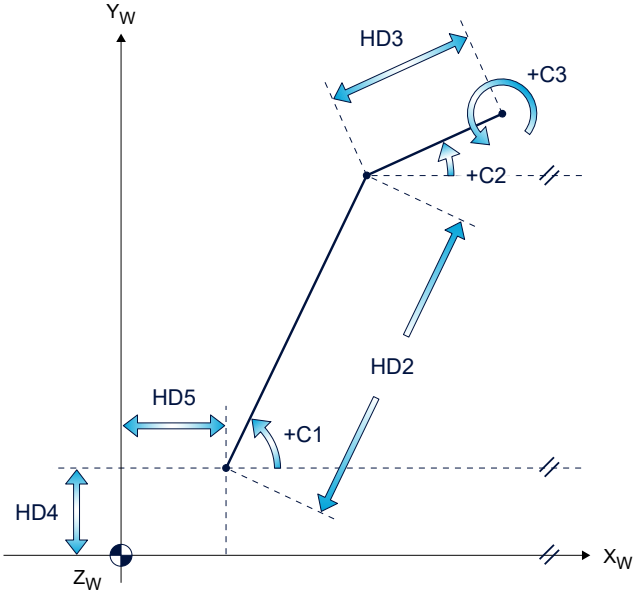
Fig. 126: SCARA kinematics in zero position (C1=0, C2=0, C3=0, HD8=0)

SCARA works as a left-handed or right-handed robot depending on the angular position of robot joint 2 (C2). The machine axis position before selecting the transformation therefore decides whether SCARA is positioned as a left-handed or right-handed robot. A change can be made from left-handed to right-handed robot when the kinematic transformation is inactive.

HD7 can be used to define the reference of the robot joint (C2).

In the default case of HD7 = 0 C2 refers to the angle between the extension of the first arm and the second arm. In the case of HD7 = 1 C2 refers to the angle between the X axis and the second arm.

HD8 is a rotary offset of C2. This permits the description of a zero position of the kinematics where the SCARA is not completely stretched out but is angled in the second joint. HD8=0 is the default.

HD7 = 0 (default)	HD7 = 1
Right-handed robot	Right-handed robot
	
Left-handed robot	Left-handed robot
	

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool length offset in Z direction	1.0 E-4 mm
HD2	1	Length offset from joint 1 to joint 2	1.0 E-4 mm
HD3	2	Length offset joint 2 to rotary axis C3	1.0 E-4 mm
HD4	3	X offset origin C1 axis	1.0 E-4 mm
HD5	4	Y offset origin C1 axis	1.0 E-4 mm
HD6	5	Rotary offset C1 axis	1.0 E-4°
HD7	6	Calculate reference of the robot joint for C2 0 = C2 as an offset of C1 (default) Calculate 1 = C2 as an angle to the X axis	[-]
HD8	7	Rotary offset C2 axis	1.0 E-4°

3.2 KIN_TYP_37 – Delta robot kinematics

The strut kinematics referred to as delta robot consists of 3 rotary axes arranged at an offset of 120 degrees guiding 2 parallel struts via connecting levers. In turn, these struts guide the tool platform. Tool orientation is constant.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z (J1, J2, J3)	
Axis index	0, 1, 2	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z	-

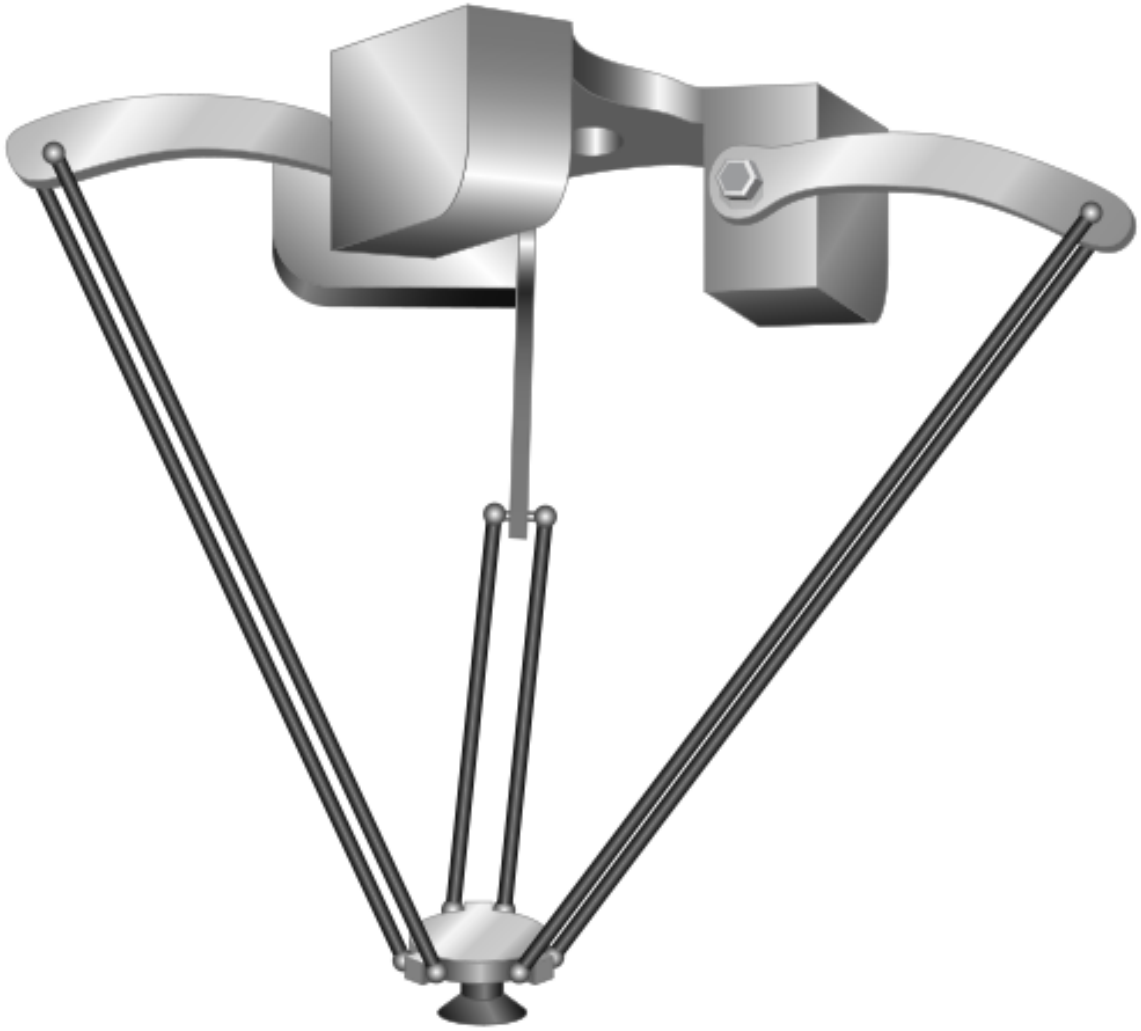


Fig. 127: Overhead delta robot kinematics

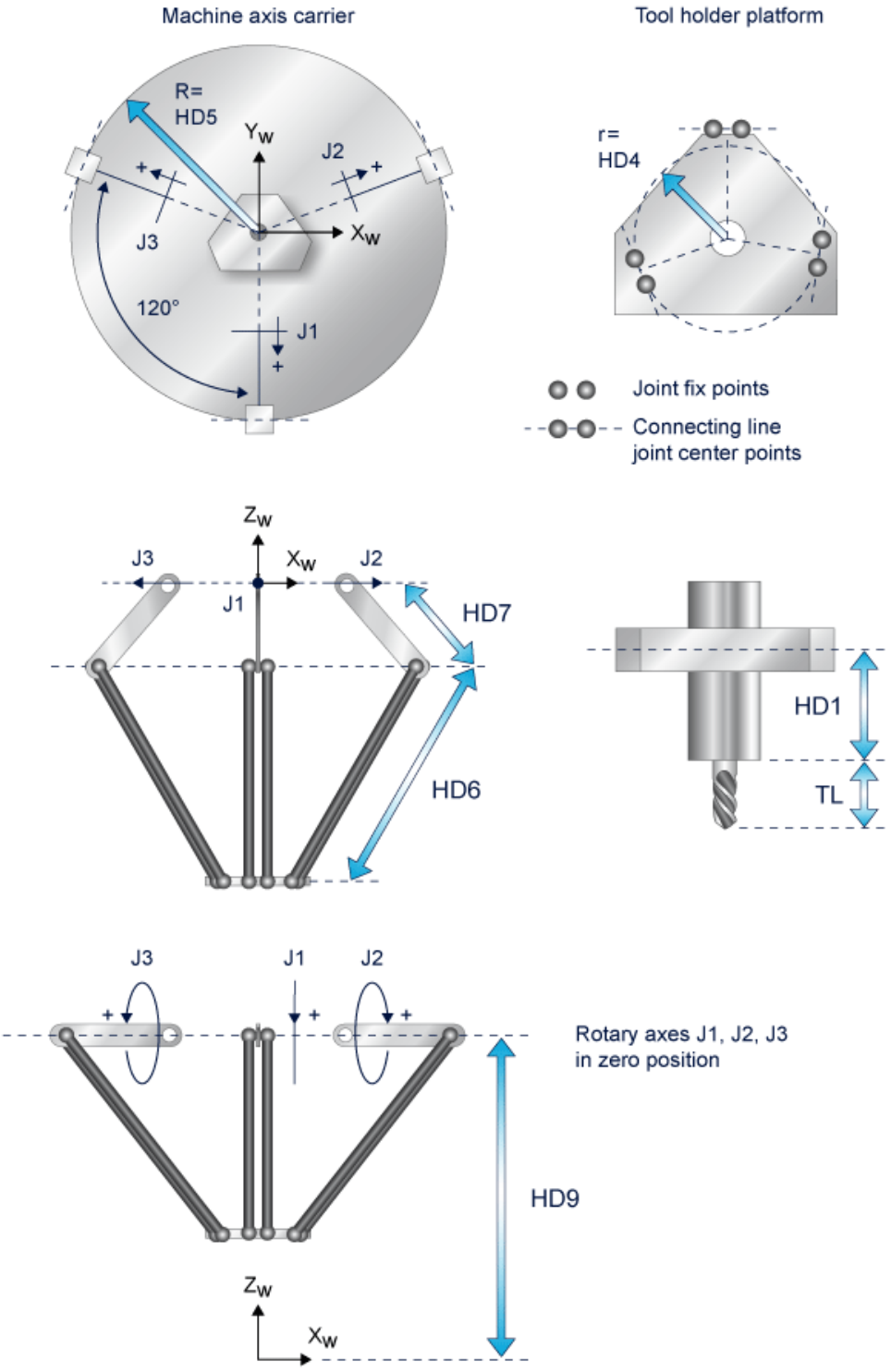


Fig. 128: Offsets of delta robot kinematics

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool offset Z	1.0 E-4 mm
HD2	1	n.a.	[-]
HD3	2	n.a.	[-]
HD4	3	Radius of connecting line of bottom joint fixed points	1.0 E-4 mm
HD5	4	Radius of connecting line of top joint fixed points	1.0 E-4 mm
HD6	5	Bottom strut/arm length	1.0 E-4 mm
HD7	6	Top strut/arm length (connecting lever)	1.0 E-4 mm
HD8	7	Angular offset zero position J1 (ideal zero position of top arm horizontal)	1.0 E-4°
HD9	8	Angular offset zero position J2 (ideal zero position of top arm horizontal)	1.0 E-4°
HD10	9	Angular offset zero position J3 (ideal zero position of top arm horizontal)	1.0 E-4°
HD11	10	Limit of minimum joint angle J1 to J3	1.0 E-4°
HD12	11	Limit of maximum joint angle J1 to J3	1.0 E-4°
HD13	12	Z zero offset Cart. Workpiece coordinate system	1.0 E-4 mm

The Cartesian coordinate system lies in the origin of the motor mount. The parameter HD11 can shift the system origin so that it is located below the motor mount and the tool holder platform.

By default, the strut connecting levers must be horizontal in the drive zero position. If this is not the case, the angle zero position can be corrected for the internal kinematic model by the parameters HD8, HD9 and HD10. When all rotary axes move in positive rotation, the TCP moves in negative Z direction.

Example: Connecting lever in horizontal position, drive position: 900000 [1.0 E-4°]

HD8, HD9, HD10: 900000 [1.0 E-4°]

Notice

This kinematic transformation was developed in collaboration with Esslingen University (www.hs-esslingen.de).

3.3 KIN_TYP_45 – 6-axis articulated robot kinematics

Kinematic structure

Articulated robot with 6 machine axes. All articulated axes of the robot except for the manual axes A1 and A2 are linear axes. The axes A1 and A2 are modulo axes with ranges of 0 to 180, 0 to -180 degrees. The joint axis C1 can also be configured as a modulo axis if no trailing cable must be considered.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B, C (C1, B1, B2, A1, B3, A2)	
Axis index	0, 1, 2, 3, 4, 5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, B, C	-

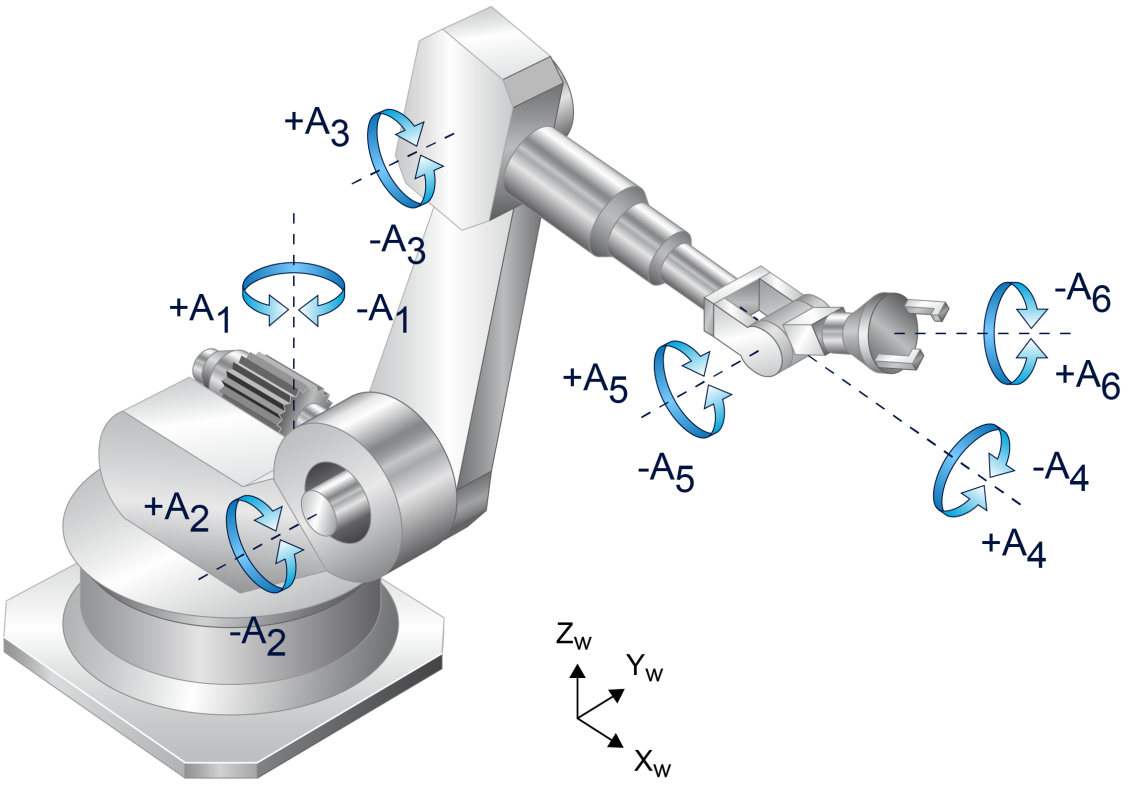


Fig. 129: 6-axis articulated robot

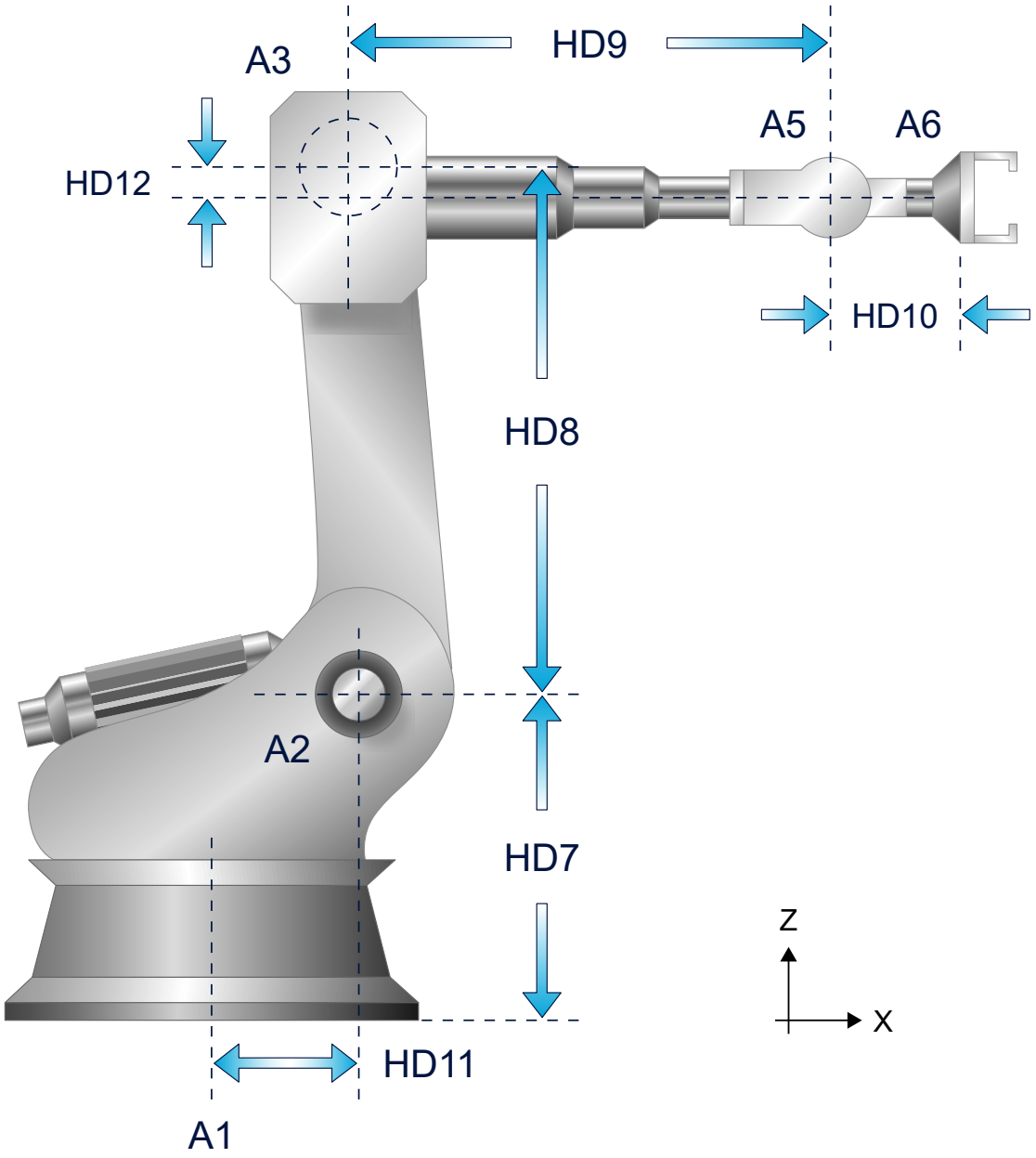


Fig. 130: HD offset data in side view

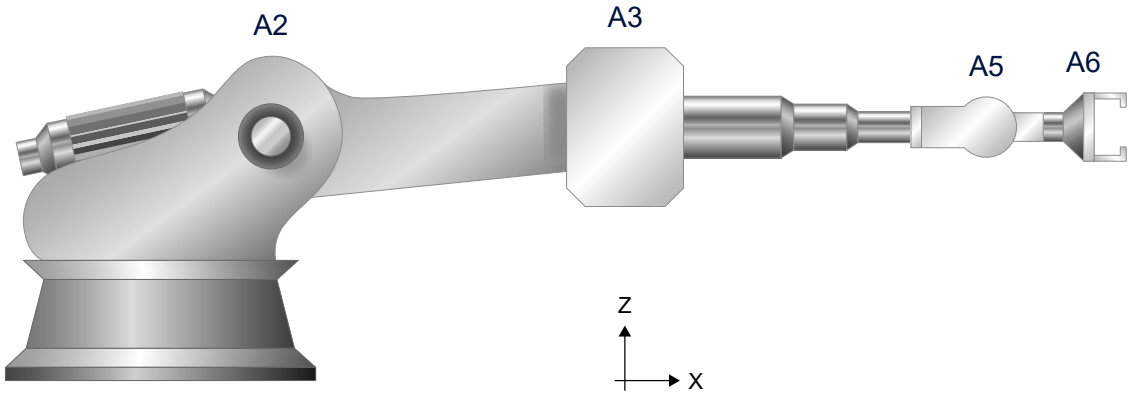


Fig. 131: Zero position for HD145 and HD15

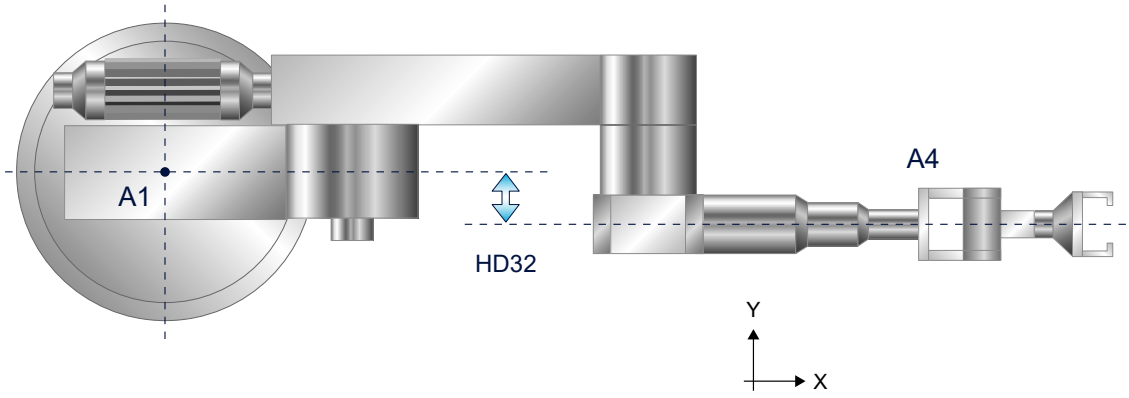


Fig. 132: Articulated robot, top view

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool Z offset in the Flange Coordinate System [▶ 184] (variant 1)	1.0 E-4 mm
HD2	1	Tool X offset in the Flange Coordinate System [▶ 184] (variant 1)	1.0 E-4 mm
HD3	2	Tool Y offset in the Flange Coordinate System [▶ 184] (variant 1)	1.0 E-4 mm
HD4	3	Angle of tool rotation about the X'' axis	1.0 E-4°
HD5	4	Angle of tool rotation about the Y'' axis	1.0 E-4°
HD6	5	Angle of tool rotation about the Z axis	1.0 E-4°
HD7	6	Z offset from origin of Cartesian spatial coordinate system to rotation point of joint axis 2	1.0 E-4 mm
HD8	7	Z offset from rotary axis joint 2 to rotary axis joint 3	1.0 E-4 mm
HD9	8	X offset from rotary axis joint 3 to rotary axis joint 5	1.0 E-4 mm
HD10	9	X offset from manual axis joint 5 to flange surface on joint 6	1.0 E-4 mm
HD11	10	X offset from origin of Cartesian spatial coordinate system to rotation point of joint axis 2	1.0 E-4 mm
HD12	11	Z offset from rotary axis joint 5 to rotary axis joint 3. Please refer to note under the table.	1.0 E-4 mm
HD14	13	Rotary offset for zero position of robot joint axis 2 (see Angle offset)	1.0 E-4°
HD15	14	Rotary offset for zero position of robot joint axis 3 (see Angle offset)	1.0 E-4°
HD21	20	Rotation direction of joint axis 1: 0 (positive), 1 (negative)	[-]
HD22	21	Rotation direction of joint axis 2: 0 (positive), 1 (negative)	[-]
HD23	22	Rotation direction of joint axis 3: 0 (positive), 1 (negative)	[-]
HD24	23	Rotation direction of joint axis 4: 0 (positive), 1 (negative)	[-]
HD25	24	Rotation direction of joint axis 5: 0 (positive), 1 (negative)	[-]
HD26	25	Rotation direction of joint axis 6: 0 (positive), 1 (negative)	[-]
HD31	30	Flange Coordinate System [▶ 184]: 0 (variant 1) 1 (variant 2)	[-]
HD32	31	Y offset from rotary axis joint 4 to rotary axis joint 1. Please refer to note under the table.	1.0 E-4 mm

HD33	32	Control flag for machining type 0: Default 1: Moved workpiece Once you set the parameter HD33, the machining mode switches to the mode of the moved workpiece. We therefore advise you to set this parameter first by selecting the fixed tool and positioning the robot in readiness or to set this parameter in the tool management system.	[-]
HD34	33	Tool length compensation direction 0: none (default) 1: -Z 2: -X 3: -Y 4: Z 5: X 6: Y By default, the entered tool length is not included when you select a tool with Kinematic 45 enabled. If this parameter is unequal to 0, the tool length is included in the set direction.	[-]
HD35	34	Rotation sequence of tool orientation HD4-6 0: Z Y' X" (default) 1: X Y' Z"	[-]
HD36	35	Rotary offset for zero position of robot joint axis 1	1.0 E-4°
HD37	36	Rotary offset for zero position of robot joint axis 4	1.0 E-4°
HD38	37	Rotary offset for zero position of robot joint axis 5	1.0 E-4°
HD39	38	Rotary offset for zero position of robot joint axis 6	1.0 E-4°

Notice

Set the correct sign for parameters HD12 and HD32.

HD12: Positive sign; the rotary axis of joint 3 is located in the positive Z direction **above** the rotary axis of joint 5

HD32: Positive sign; the rotary axis of joint 1 is located in the positive Y direction **above** the rotary axis of joint 4

Robot poses can also be specified as an alternative to axis-specific positioning, see [PROG// Status & Turn (IS, IT) [▶ 184]].

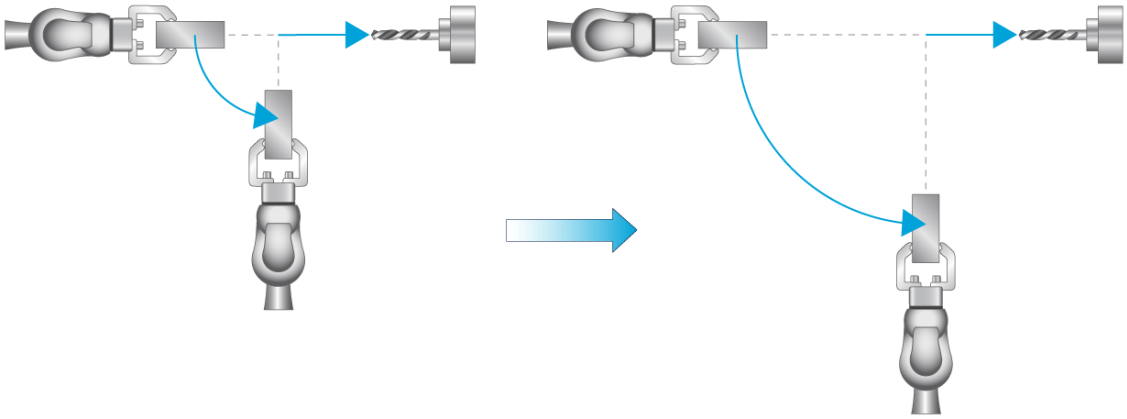
For more information on kinematic offset data, see [CMS-A2].

3.3.1 Moved workpiece

The moved workpiece is a subfunction of kinematic 45. It allows the control of an industrial robot where the workpiece is attached to the flange by a standard processing program, whereas the (milling) tool has a fixed position in space.

Notice

The further the robot is away from the fixed tool, the greater the movement of the robot when changing the orientation ABC.



This function is activated by the kinematic parameter HD33 of kinematic 45.

Tool set-up

The tool parameters for kinematic 45 can be directly entered in the parameters HD1-6 or they can be activated by a suitable tool by means of tool-head offsets when the tool is selected.

Tool-head offsets are added to the kinematic parameters (no concatenation takes place). If this function is used, it is recommended to set the parameters HD1-6 in the channel parameter list to “0”.

Parameterisation example of HD1-3 for a fixed tool:

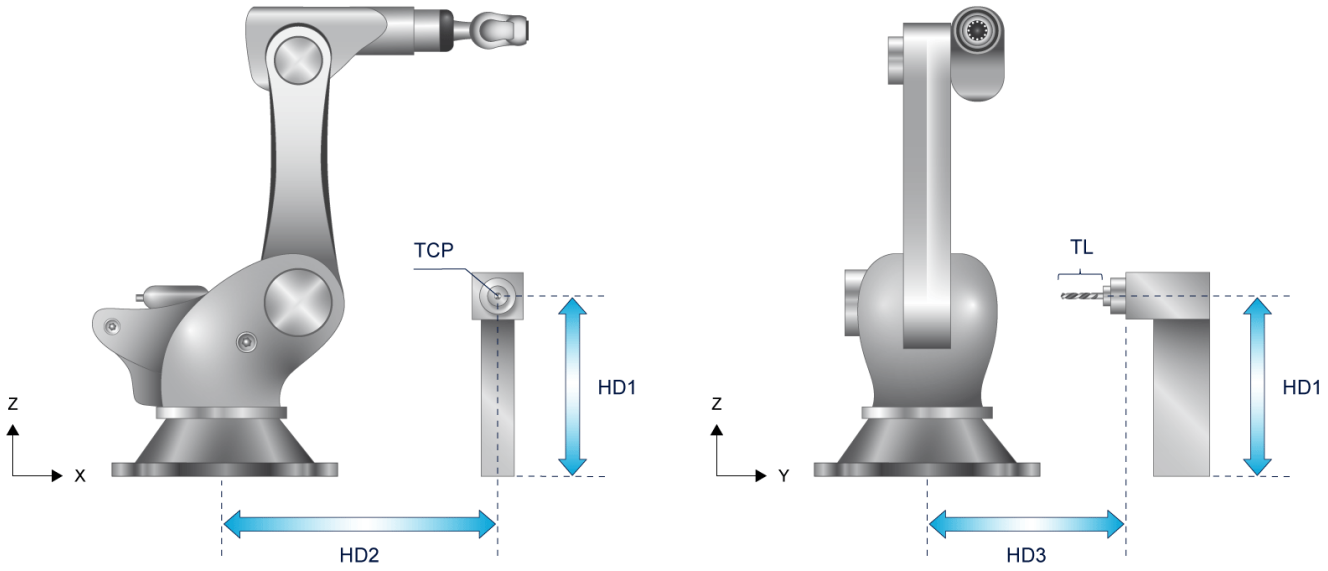


Fig. 133: Tool offsets of the fixed position tool.

Example: Parameterisation of HD4-6 for a fixed tool:

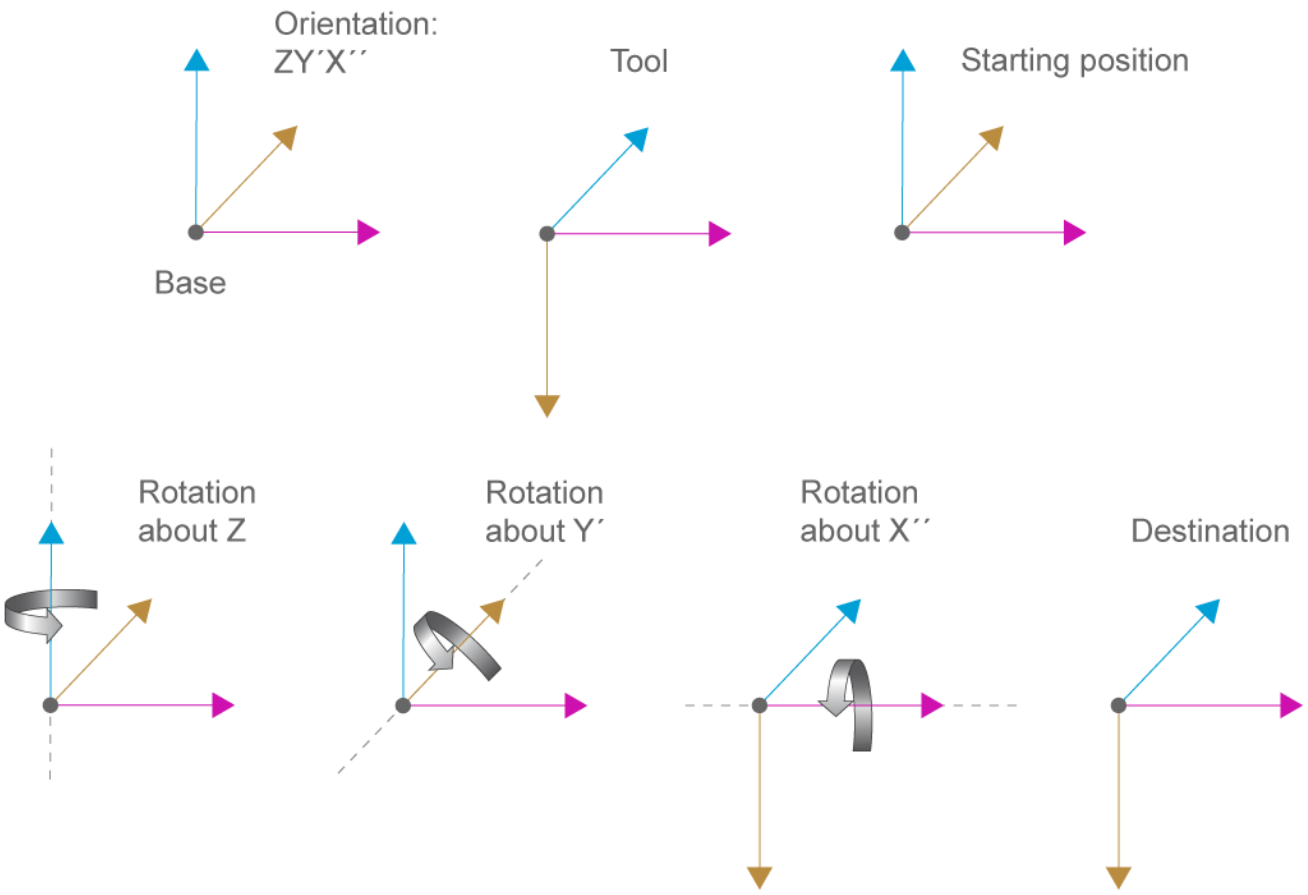


Fig. 134: Procedure for defining the orientation with rotation sequence Z Y‘ X“

Tool set-up

Offsets of the coordinate system into the workpiece now have the robot flange system as the lowest reference point for the moved workpiece.

Every further offset/rotation haves as usual.

Only one tool can be active at any one time. This is the machining tool of the moved workpiece. A gripper on the flange can be defined by an offset (e.g. #CS).

The parameterisation example below refers to the standard flange orientation (HD 31 = 0).

Flange system

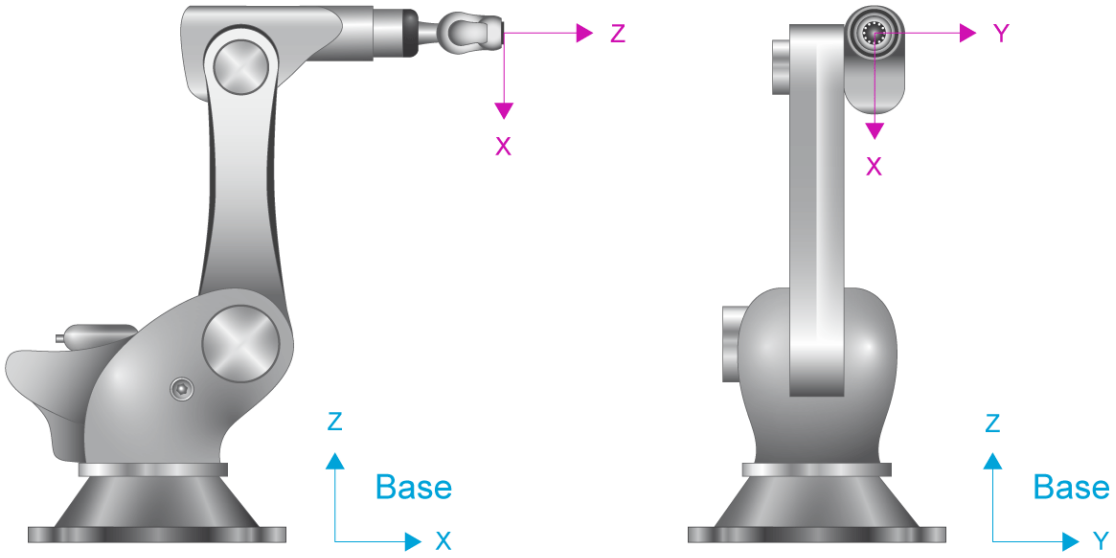


Fig. 135: The orientation of the robot flange and the world

Flange system offset

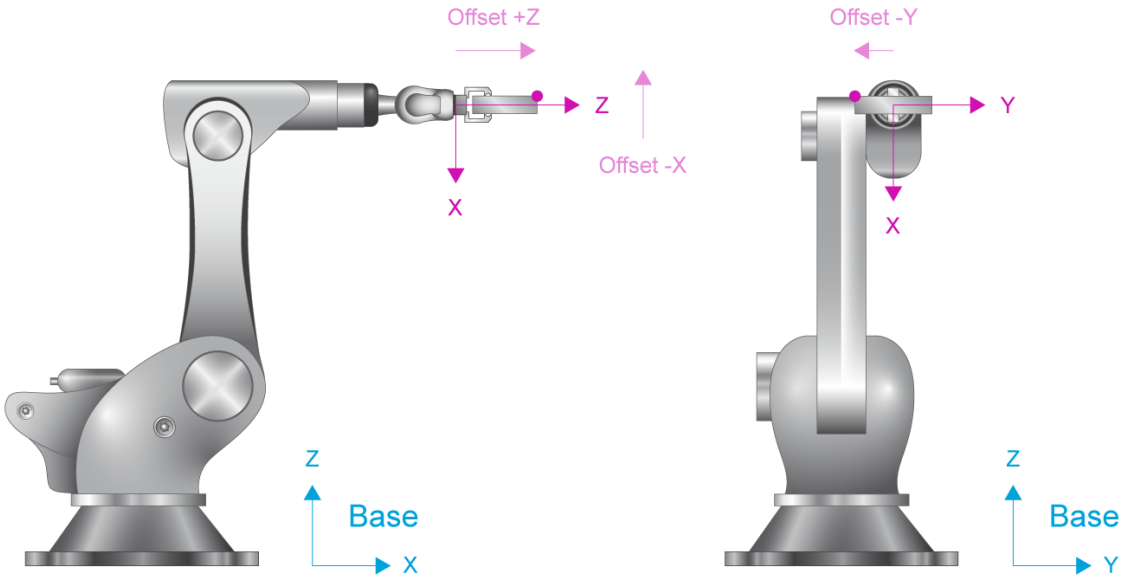
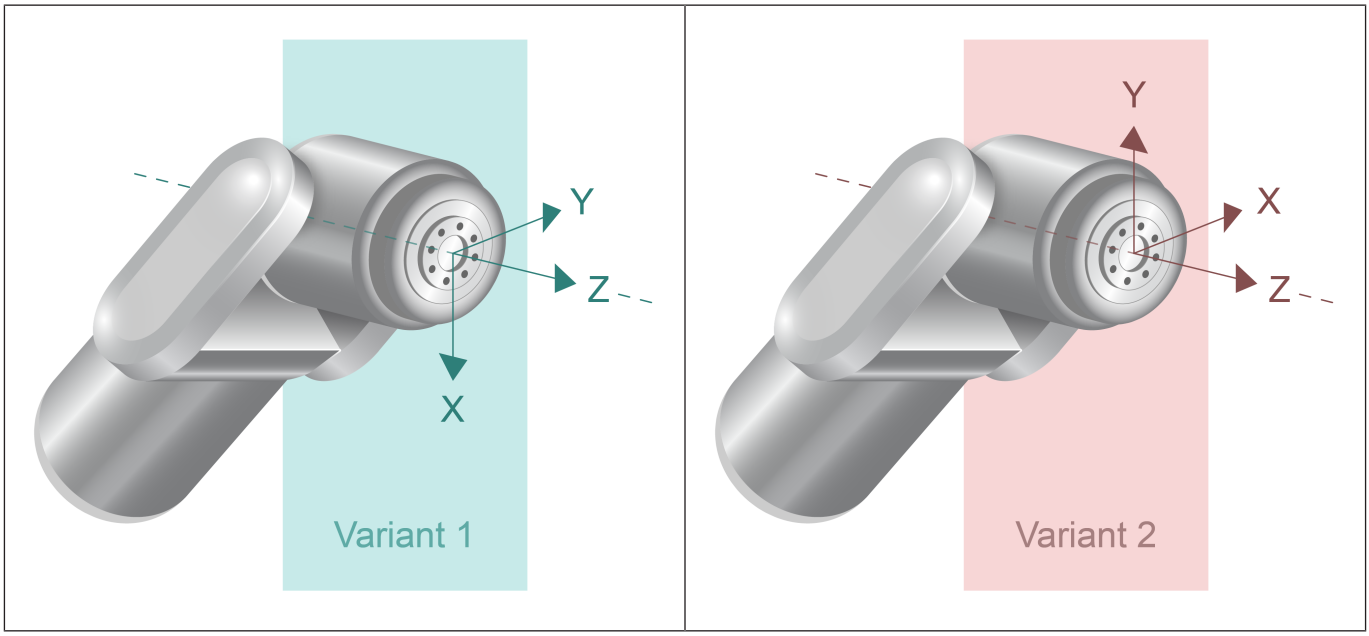


Fig. 136: Offset from the flange to the black dot in the workpiece.

3.3.2 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



3.3.3 Status & Turn (IS, IT)

An option exists to specify the robot pose for the corresponding Cartesian position as an alternative to axis-specific positioning and to obtain a more precise specified position of a #PTP movement for industrial robots.

The robot pose is therefore described using Status (IS).

In addition, the signs of the axis positions are described using Turn (ÍT)

It is not permitted to program Turn without Status.

Notice

Robot positioning with Status & Turn is currently only available for kinematic type 45 [▶ 176].

Status bit

An overview of robot poses is contained in Kinematic poses of six-axis articulated robot [▶ 189].

The robot pose is divided into 3 criteria. If a criterion applies, a corresponding numerical value is added to the status.

1. criterion If the wrist is behind axis A1, decimal 1 or binary 1 is added (yellow area in the figure on the left).

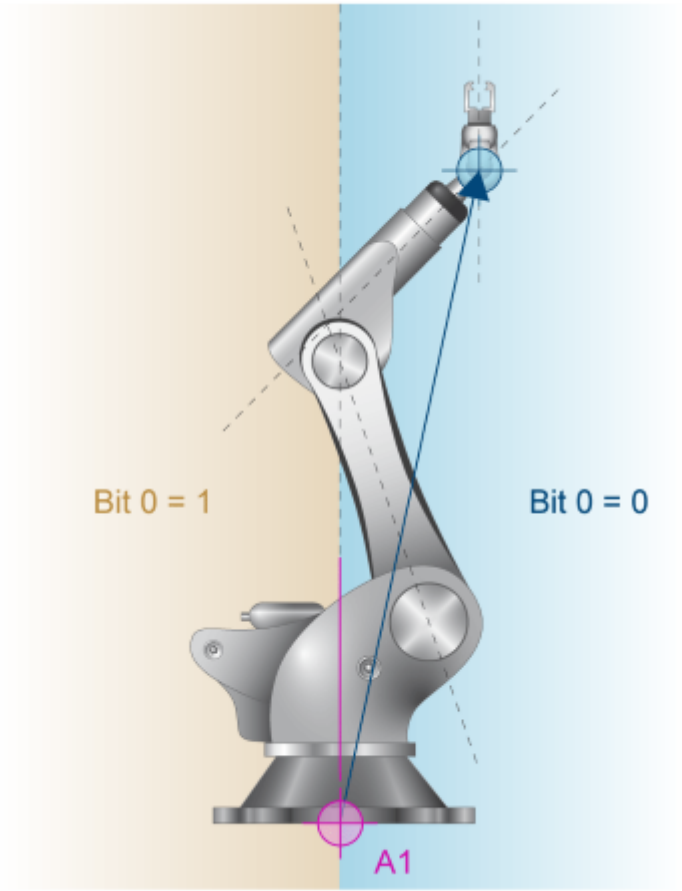


Fig. 137: The intersection of the hand axes (arrowhead) is in the (blue) base area.

2nd criterion If the wrist is in front of the straight line through axes A2 and A3, decimal 2 or binary 10 is added (centre and right image).

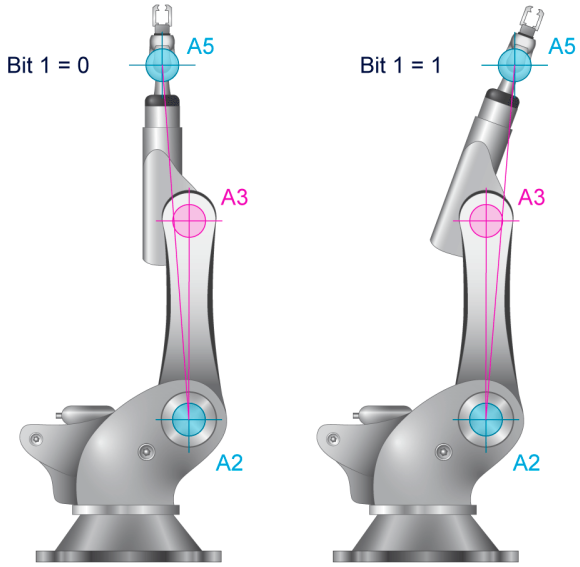


Fig. 138: Status bit 1 for robots with an offset between axis A3 and axis A5

3rd criterion Indicates the position of axis A5. If A5 > 0, decimal 4 or binary 100 is added.

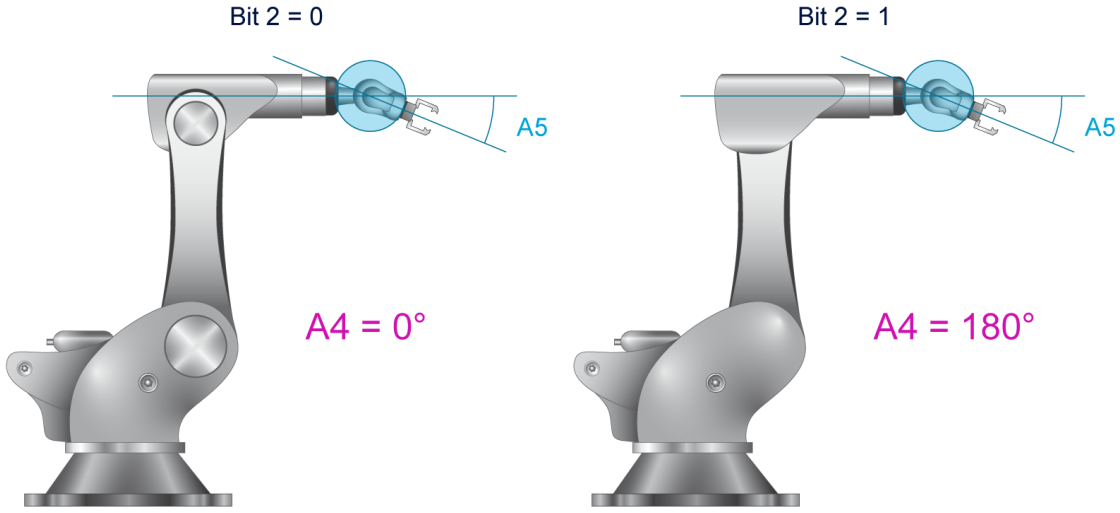


Fig. 139: Status bit 2 for axis angle position A4=0° and A4=180°.

Turn bit (optional)

The optional turn value lists the negative signs of the axis angles.

When the turn value is considered in a binary representation, the sign of each axis angle is assigned to a bit. These are then added to a number, i.e. the turn.

If the axis angle of an axis is < 0°, the value is 1.

	A6 < 0°	A5 < 0°	A4 < 0°	A3 < 0°	A2 < 0°	A1 < 0°
Binary	100000	010000	001000	000100	000010	000001
Decimal	32	16	8	4	2	1

If all 6 axis angles are in the negative range, this results in a turn value of decimal 63 or binary 111111; accordingly, this results in decimal 0 and binary 000000 for 6 positive axis angles.

Notice

The turn value must be consistent with the status value.

For example, a 1 in status bit 2 describes a negative A5 angle. In addition, if the A4 turn bit is set to 0 (positive A5 angle), the status and turn values are in contradiction. In this case, an error message is output.

Description

The additional parameters Status & Turn are available for unambiguous programming of the robot poses (Kin_Typ_45 [▶ 176]) with Cartesian target coordinates of a PTP movement.

```
Syntax of Programming Status & Turn with the prefixes "IS" and "IT" (optional):
#PTP ON
G.. X.. Y.. … IS.. IT..
#PTP OFF
```

Binary numbers can be programmed with the following syntax:

'B<0…1>', or '2#<0…1>', or '02#<0…1>'.

When binary numbers are used, the syntax is as follows:

Status: **IS**'Bxxx'

Turn: **IT**'Bxxxxxx'

When decimal numbers are used, the syntax is as follows:

Status: **IS**<*expr*>

Turn: **IT**<*expr*>

Display values

The following CNC objects are provided for this function:

- mc_st_valid_r: Validity of the status & turn value
  (Task COM index group 0x12010<C_{ID}> Index offset 0xB1)
- mc_st_status_r: Status value of kinematic 45
  (Task COM index group 0x12010<C_{ID}> Index offset 0xB2)
- mc_st_turn_r: Turn value of kinematic 45
  (Task COM index group 0x12010<C_{ID}> Index offset 0xB3)

Notice

If Status & Turn are not programmed, the target point is determined on the axis angle level using the shortest way strategy.

Programing Example

Status & Turn programmed with binary numbers

```
N010 #PTP ON
N020 G01 X1100 Y0 Z1400 A0 B90 C0 IS'B010' IT'B000010' F5000
N030 G01 X1200 ;target point is determined by shortest way
N040 #PTP OFF
```

Programing Example

Status & Turn programmed with decimal numbers

```
N010 #PTP ON
N020 G01 X1000 Y0 Z1400 A0 B90 C0 IS2 IT2 F5000
N030 #PTP OFF
N040 G01 X1500
N050 G01 Y1000
N060 G01 X-1000
N070 #PTP ON
N080 G01 X-1000 Y-1000 ;target point is determined by shortest way
N090 #PTP OFF
```

3.3.4 Singularities with a six-axis articulated robot kinematic

A distinction is made between three types of singularity:

1. Wrist singularity
2. Elbow singularity
3. Shoulder singularity

Wrist singularity

This occurs when angle A5 (axis B3) is equal to zero.

Elbow singularity

An elbow singularity occurs when the wrist lo located on a straight line running through the axes B1 and B2. When HD12 = 0, this corresponds to an angle A3 (axis B2) equal to zero.

Fig. 140: Elbow singularity

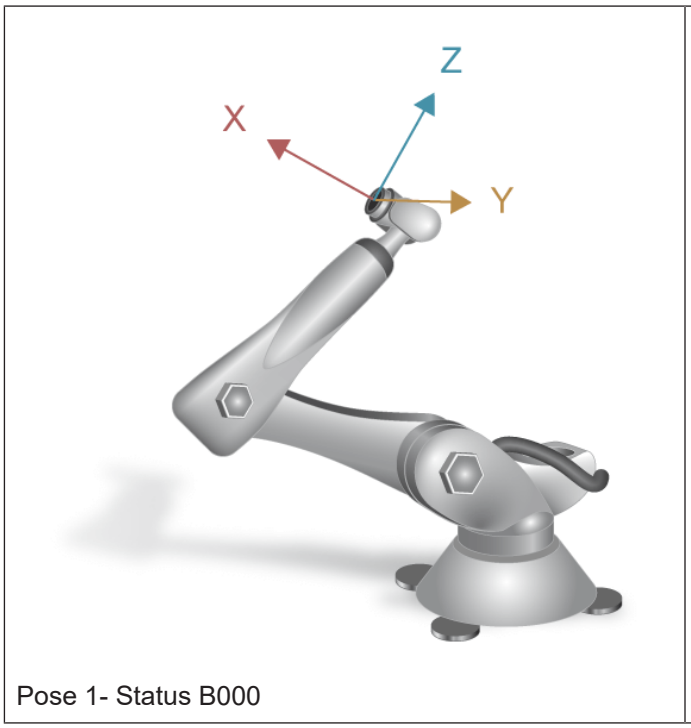
Shoulder singularity

A shoulder singularity occurs when HD32 = 0 if the wrist is located on the extended C1 axis.

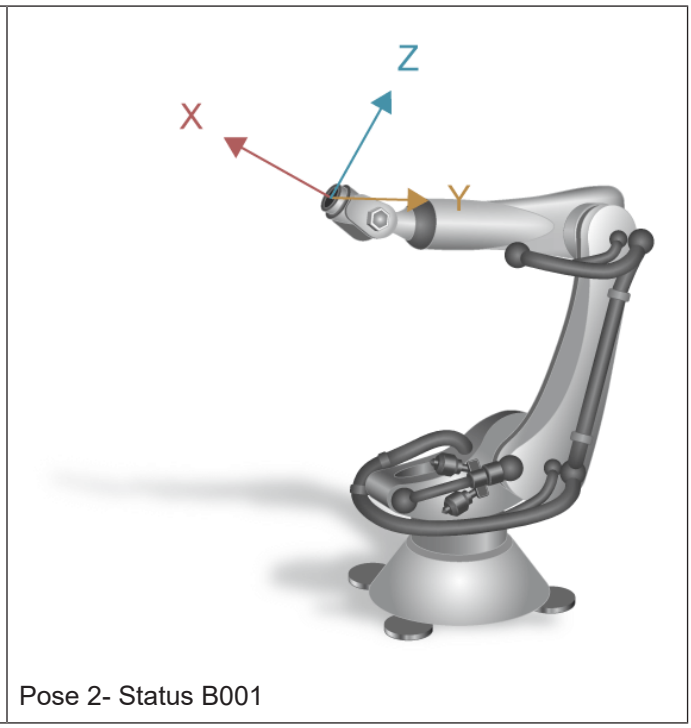
When HD32 ≠ 0, the shoulder singularity occurs if the wrist is located on the cylindrical sleeve of radius HD32 about the C1 axis.

3.3.5 Kinematic poses of six-axis articulated robot

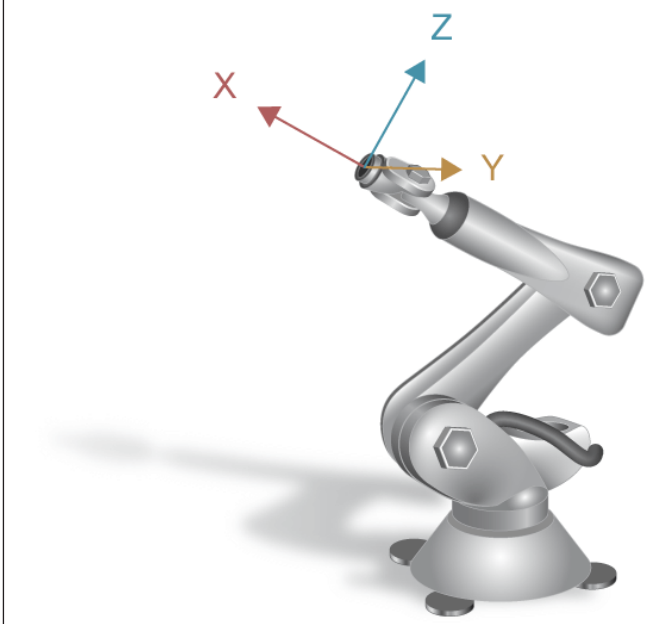
Pose denotes the position and orientation of the TCP, The six-axis articulated robot kinematic described here (KIN_TYP_45) can achieve a pose with up to eight different joint configurations.



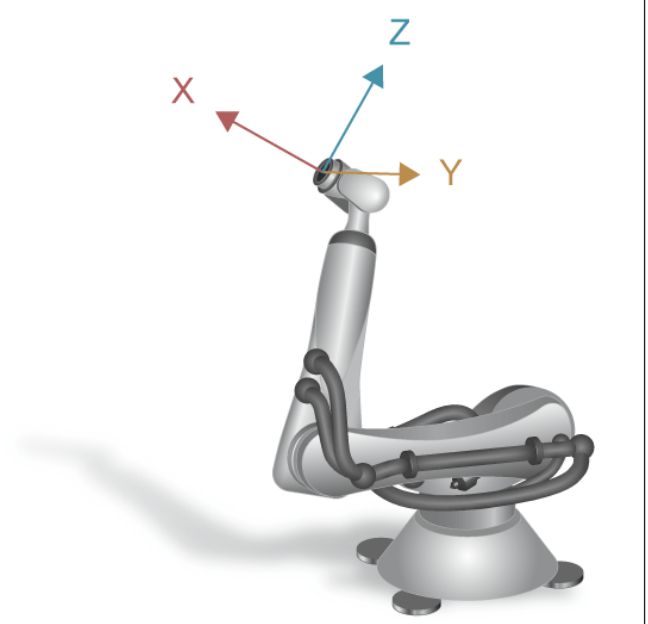
Pose 1- Status B000



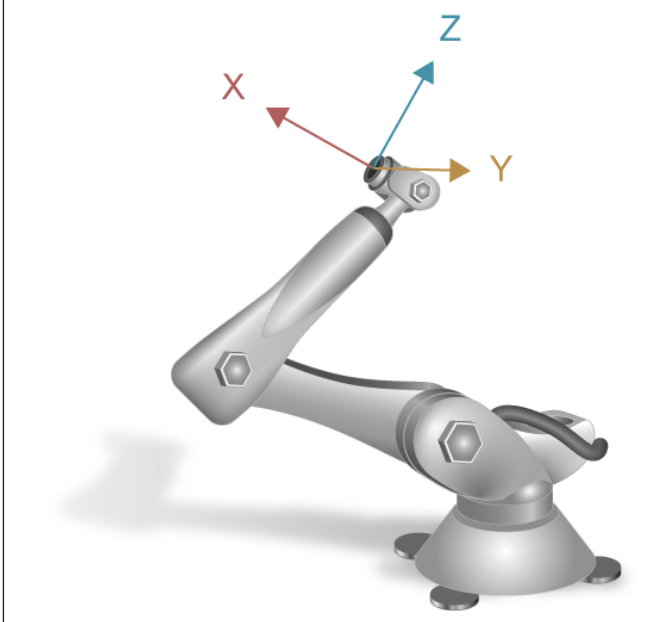
Pose 2- Status B001



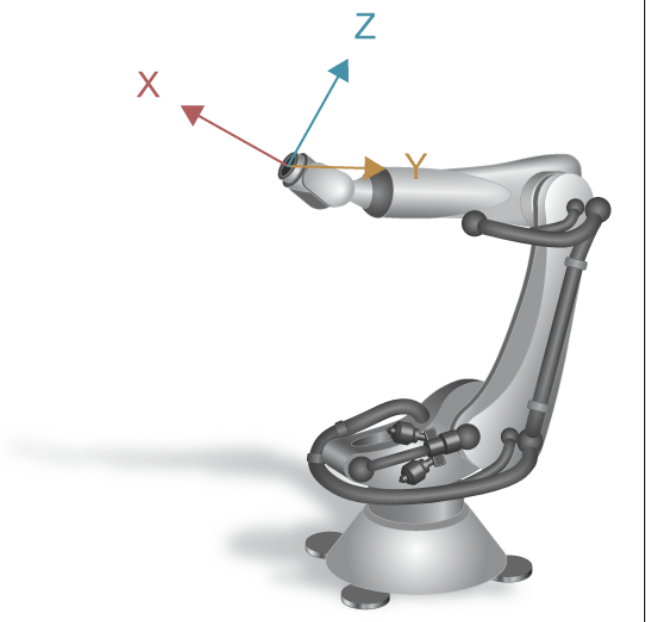
Pose 3- Status B010



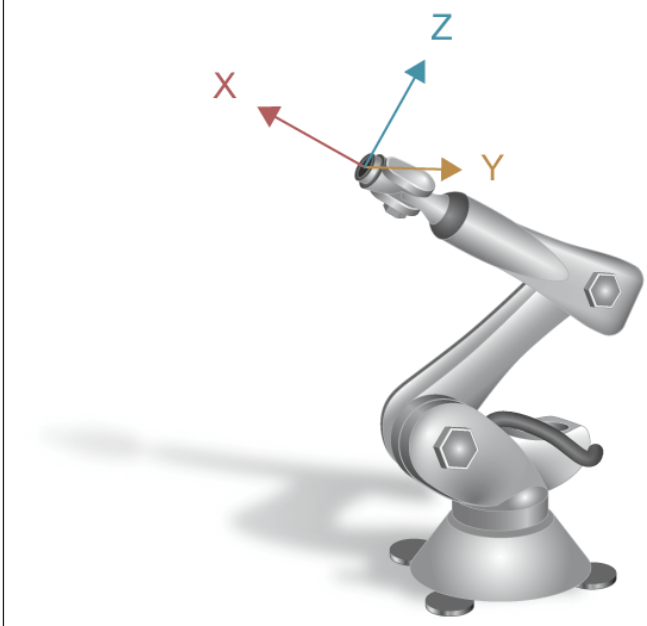
Pose 4- Status B011



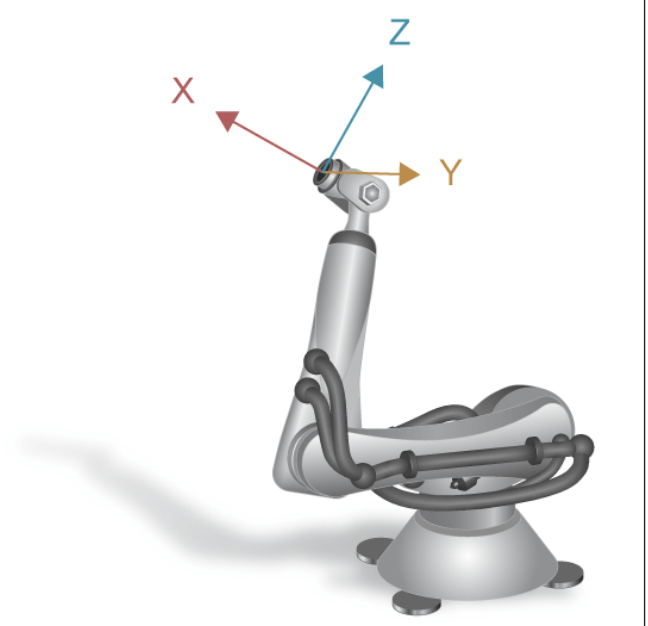
Pose 5- Status B100



Pose 6- Status B101



Pose 7- Status B110



Pose 8- Status B111

The possible joint configurations are identified by the pose status.

Notice

When a transformation is active, the robot cannot change its pose status.

KIN_TYP_96 - Palletising kinematic

Kinematic structure

The articulated axes are numbered from 1 to 4. Axis 1 rotates about the z axis of the Cartesian coordinate system. The robot is represented with all articulated axes in zero position.

Rotation in positive direction corresponds to the mathematically positive direction of rotation in the Cartesian coordinate system. Articulated axes G1, G2, G3 must be configured as linear axes (with limited motion range). Articulated axis G4 must be configured as a modulo axis with a range of -180° to +180°.

The transformation may only be used when software limit switches are correctly set. In particular, the movements of axis 2 are dependent on the limit switch of axis 3. NB: Without limit switches, this transformation can damage the robot.

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

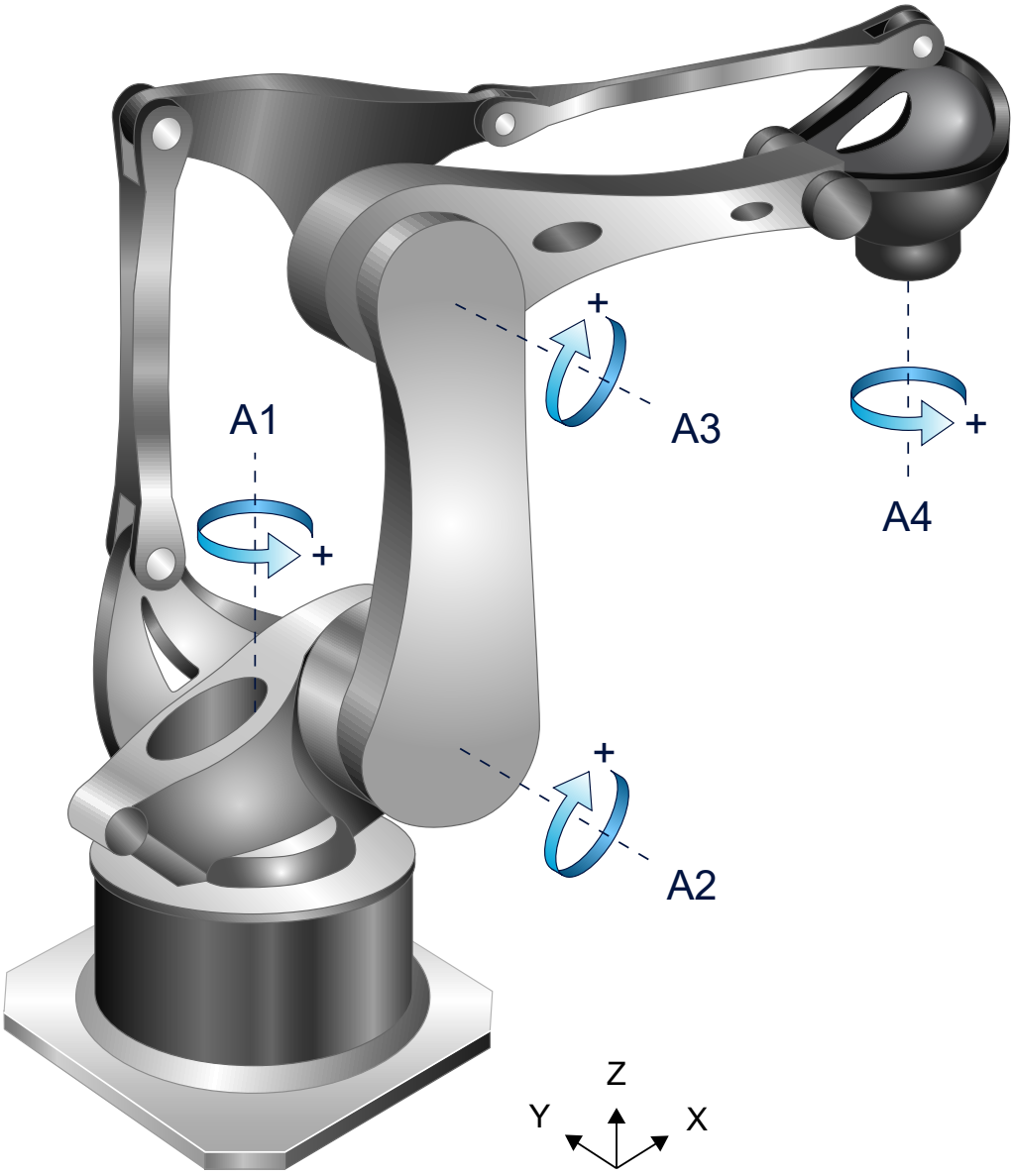


Fig. 141: 4-axis palletising robot

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	X offset articulated axis G2	1.0 E-4 mm
HD2	1	Z offset articulated axis G2	1.0 E-4 mm
HD3	2	Length of the first arm (distance between G3 and G2)	1.0 E-4 mm
HD4	3	Y offset between G2 and G1.	1.0 E-4 mm
HD5	4	Length of second arm (distance between the right-hand joint of the second arm and G3)	1.0 E-4 mm
HD6	5	Length of head (distance between G4 and the right-hand joint of the second arm)	1.0 E-4 mm
HD7	6	Y offset of tool to G4	1.0 E-4 mm
HD8	7	X offset of tool to G4	1.0 E-4 mm
HD9	8	Z offset of tool to G4	1.0 E-4 mm
HD10	9	Z offset between G4 and G3	1.0 E-4 mm

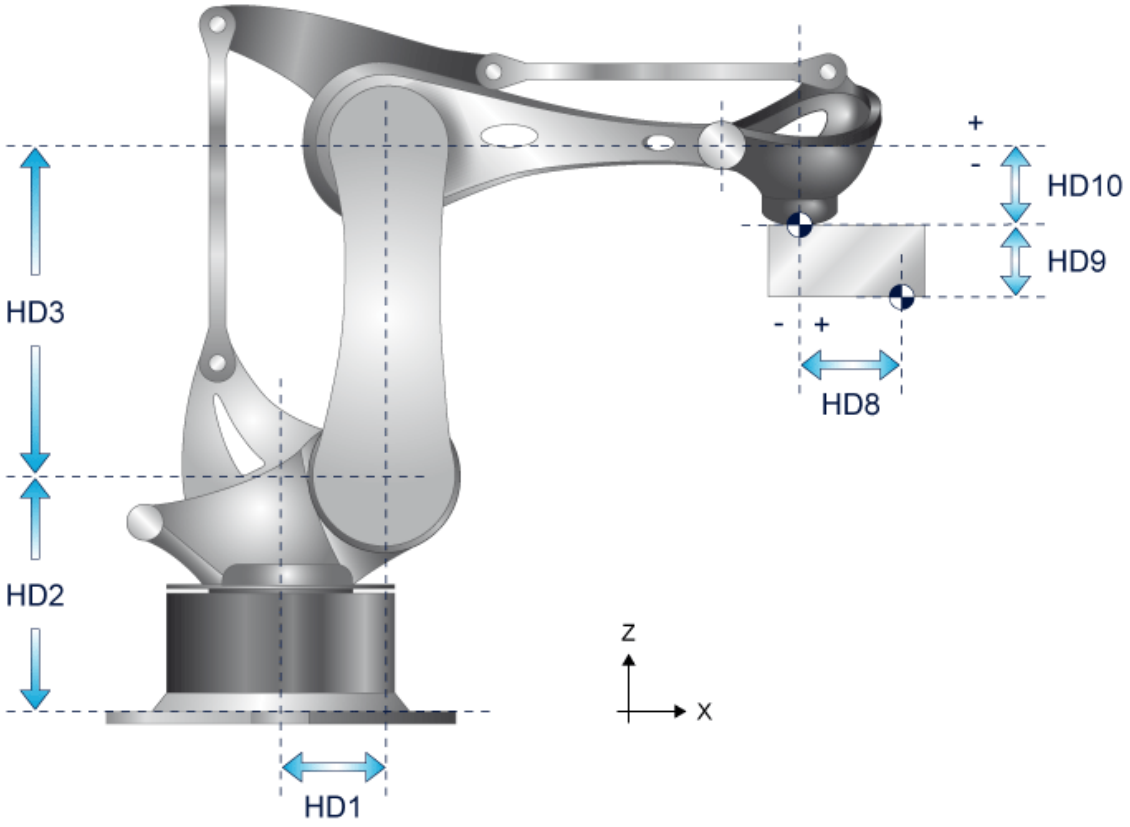


Fig. 142: Side view of HD offset data - palletising robot

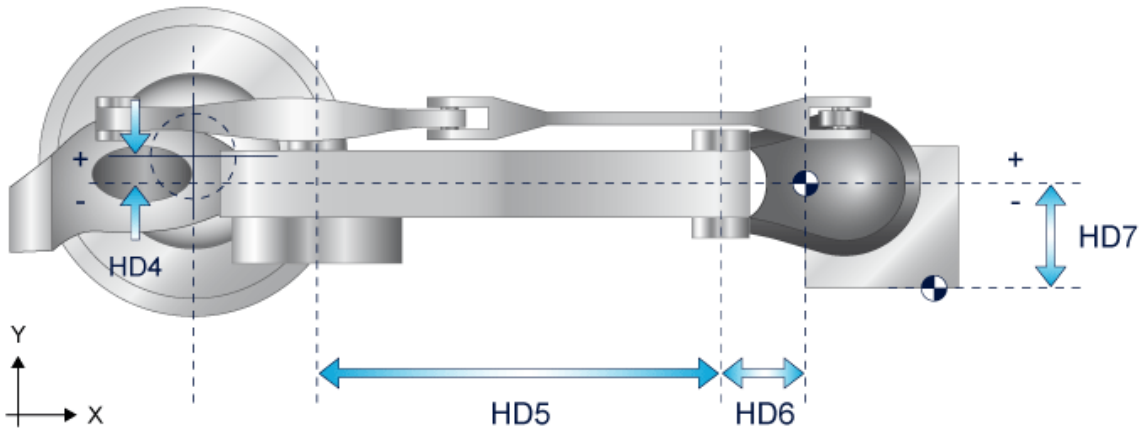


Fig. 143: Top view of HD offset data - palletising robot

3.4 KIN_TYP_206 – 5-axis robot on linear unit

Kinematic structure

The Kinematic Structure consists of a linear unit that carries a five-axis robot.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, A, B, C (A1, A2, A3, A4, A5, A6)	
Axis index	0, 1, 2, 3, 4, 5	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, A, B, C	-

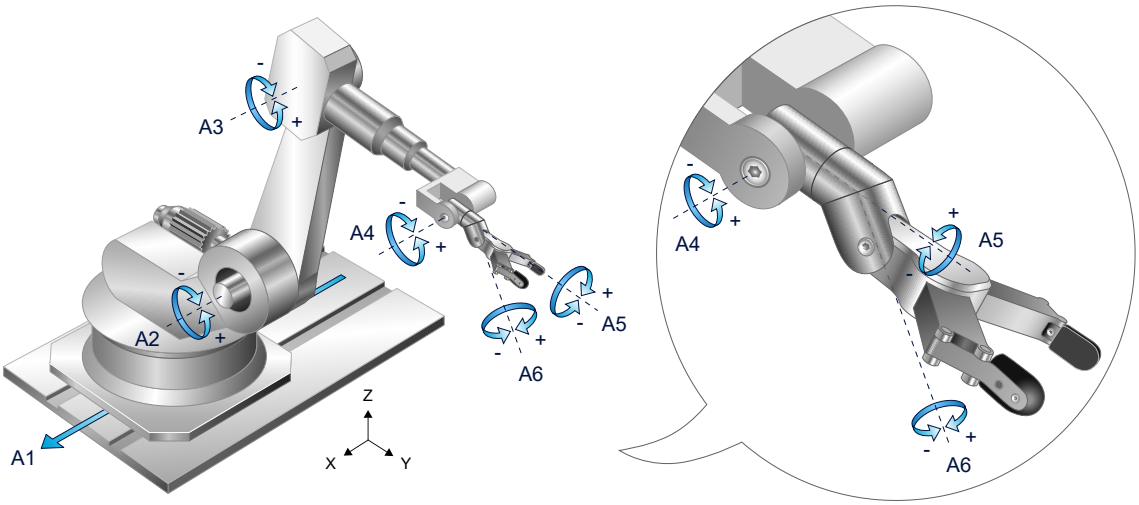


Fig. 144: 5-axis robot on linear unit

Axis configuration

The axis configuration below is recommended.

Axis name	Axis type (P-AXIS-00018)	Axis mode (P-AXIS-00015)
A1	Linear	Linear
A2	Rotation	Linear
A3	Rotation	Linear
A4	Rotation	Modulo, 0° to 360° or Linear
A5	Rotation	Modulo, 0° to 360°
A6	Rotation	Modulo, 0° to 360°

Notice

Software limit switches can be configured for axes with linear axis mode to reduce the risk of collisions,

The position of the axes in space is described in the zero position of the machine. A mount point is specified in the Machine Coordinate System for each rotary axis.

There is a length and angle offset for each axis.

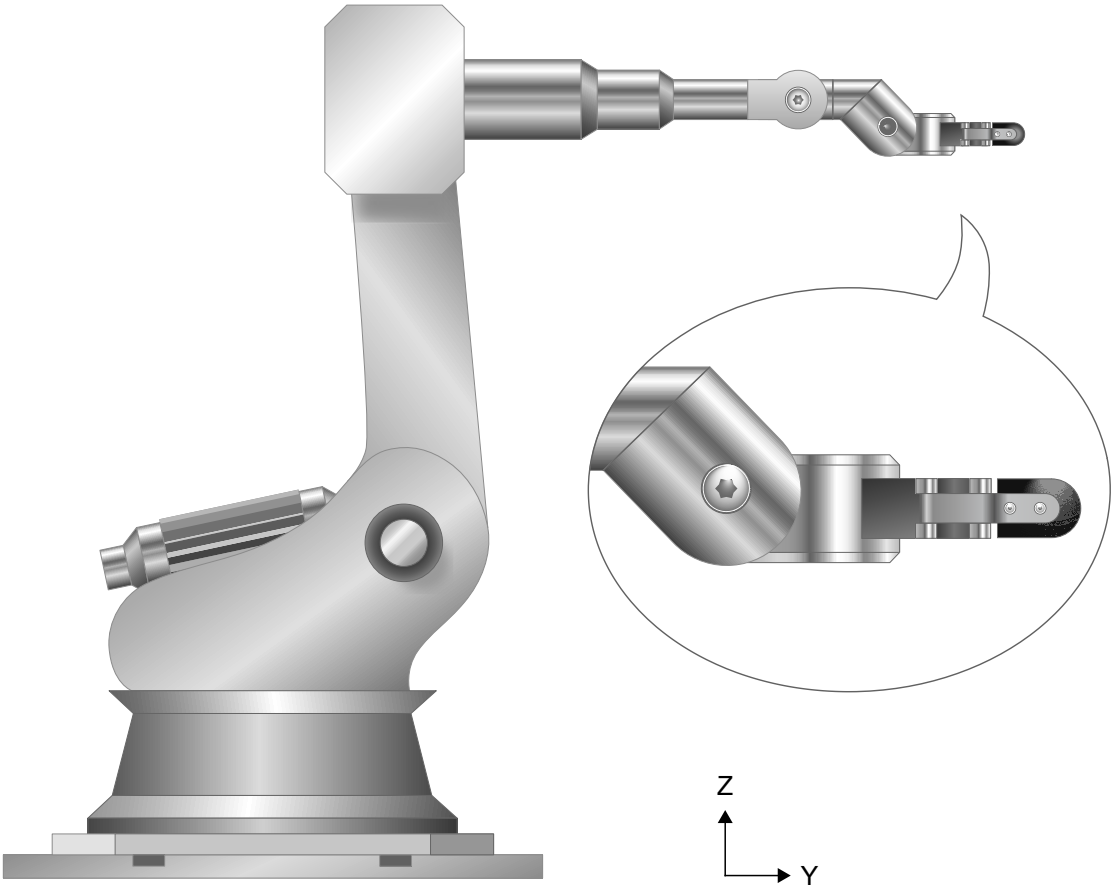


Fig. 145: Example of a zero position

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool offset in X direction	1.0 E-4 mm
HD2	1	Tool offset in Y direction	1.0 E-4 mm
HD3	2	Tool offset in Z direction	1.0 E-4 mm
HD4	3	Tool rotation about the Z' axis	1.0 E-4°
HD5	4	Tool rotation about the Y' axis	1.0 E-4°
HD6	5	Tool rotation about the X' axis	1.0 E-4°
HD7-HD9	6-8	-	
HD10	9	Deviation of A1 in XZ plane	1.0 E-4°
HD11	10	Deviation of A1 in XY plane	1.0 E-4°
HD12	11	Length offset for A1	1.0 E-4 mm
HD13	12	X coordinate of mount point of A2	1.0 E-4 mm
HD14	13	Y coordinate of reference point of A2	1.0 E-4 mm
HD15	14	Z coordinate of reference point of A2	1.0 E-4 mm
HD16	15	Deviation of A2 in XZ plane	1.0 E-4°
HD17	16	Deviation of A2 in XY plane	1.0 E-4°
HD18	17	Angle offset for A2	1.0 E-4°
HD19	18	X coordinate of mount point of A3	1.0 E-4 mm
HD20	19	Y coordinate of reference point of A3	1.0 E-4 mm
HD21	20	Z coordinate of reference point of A3	1.0 E-4 mm
HD22	21	Deviation of A3 in XZ plane	1.0 E-4°
HD23	22	Deviation of A3 in XY plane	1.0 E-4°
HD24	23	Angle offset for A3	1.0 E-4°
HD25	24	X coordinate of mount point of A4	1.0 E-4 mm
HD26	25	Y coordinate of reference point of A4	1.0 E-4 mm
HD27	26	Z coordinate of reference point of A4	1.0 E-4 mm
HD28	27	Deviation of A4 in XZ plane	1.0 E-4°
HD29	28	Deviation of A4 in XY plane	1.0 E-4°
HD30	29	Angle offset for A4	1.0 E-4°

HD31	30	X coordinate of mount point of A5	1.0 E-4 mm
HD32	31	Y coordinate of mount point of A5	1.0 E-4 mm
HD33	32	Z coordinate of mount point of A5	1.0 E-4 mm
HD34	33	Deviation of A5 in YZ plane	1.0 E-4°
HD35	34	Deviation of A5 in XY plane	1.0 E-4°
HD36	35	Angle offset for A5	1.0 E-4°
HD37	36	X coordinate of mount point of A6	1.0 E-4 mm
HD38	37	Y coordinate of mount point of A6	1.0 E-4 mm
HD39	38	Z coordinate of mount point of A6	1.0 E-4 mm
HD40	39	Deviation of A6 in XZ plane	1.0 E-4°
HD41	40	Deviation of A6 in XY plane	1.0 E-4°
HD42	41	Angle offset for A6	1.0 E-4°
HD43	42	Cardanic angle alpha of A6 axis	1.0 E-4°

Tool offset data of the kinematic

The parameters HD1 to HD6 are available for a tool flanged onto axis A6.

Notice

If a tool length is active (`V.G.WZ_AKT.L`.), it is added to `HD2`.

3.5 KIN_TYP_208 – 4-axis robot on linear unit

Kinematic structure

The Kinematic Structure consists of a linear unit that carries a four-axis robot.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, C, A, (A1, A2, A3, A4, A5)	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, C, A	-

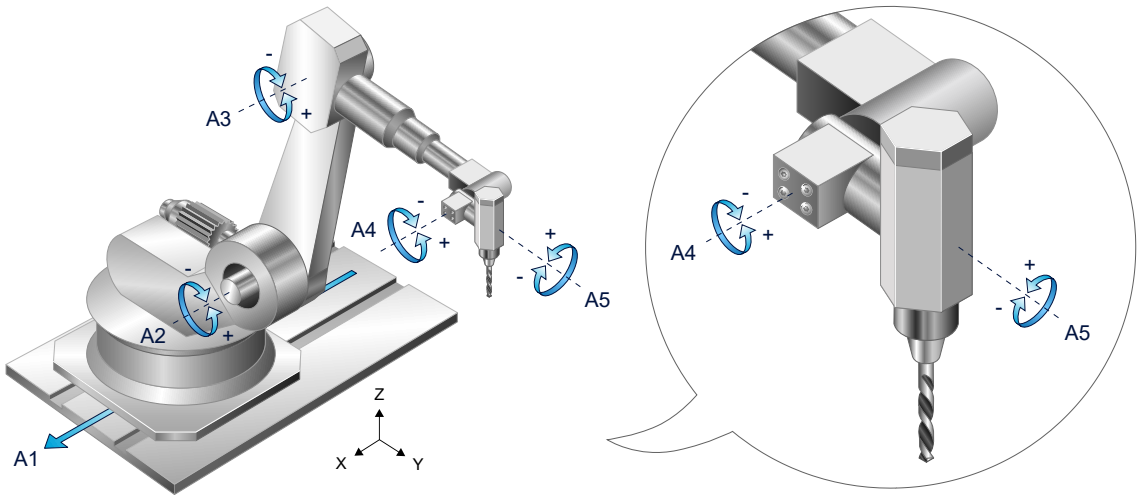


Fig. 146: 4-axis robot on linear unit

Axis configuration

The axis configuration below is recommended.

Axis name	Axis type (P-AXIS-00018)	Axis mode (P-AXIS-00015)
A1	Linear	Linear
A2	Rotation	Linear
A3	Rotation	Linear
A4	Rotation	Linear, modulo range -180° to 180°
A5	Rotation	Linear, modulo range -180° to 180°

Notice

Software limit switches can be configured for axes with linear axis mode to reduce the risk of collisions,

The position of the axes in space is described in the zero position of the machine. A mount point is specified in the Machine Coordinate System for each rotary axis.

There is a length and angle offset for each axis.

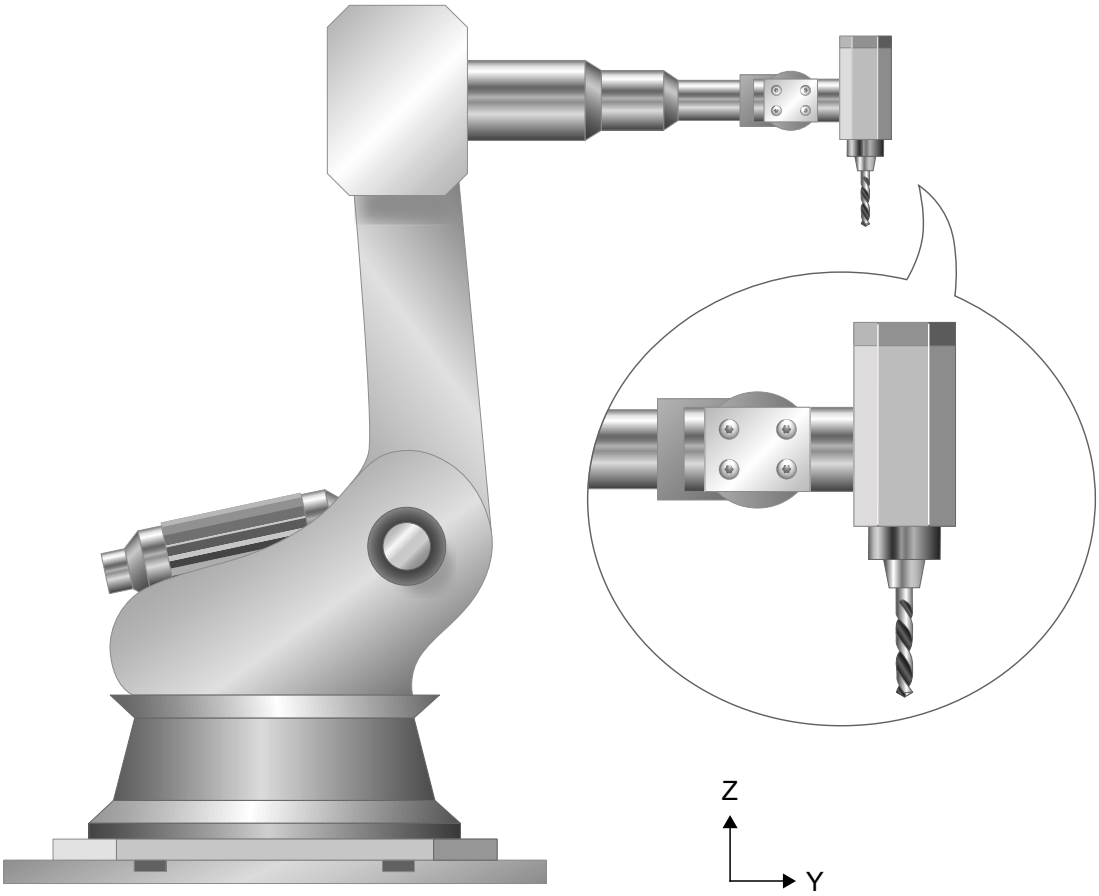


Fig. 147: Example of a zero position

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool offset in X direction	1.0 E-4 mm
HD2	1	Tool offset in Y direction	1.0 E-4 mm
HD3	2	Tool offset in Z direction	1.0 E-4 mm
HD4	3	Tool rotation about the Z' axis	1.0 E-4°
HD5	4	Tool rotation about the Y' axis	1.0 E-4°
HD6	5	Tool rotation about the X' axis	1.0 E-4°
HD7-HD9	6-8	-	
HD10	9	Deviation of A1 in XZ plane	1.0 E-4°
HD11	10	Deviation of A1 in XY plane	1.0 E-4°
HD12	11	Length offset for A1	1.0 E-4 mm
HD13	12	X coordinate of mount point of A2	1.0 E-4 mm
HD14	13	Y coordinate of mount point of A2	1.0 E-4 mm
HD15	14	Z coordinate of mount point of A2	1.0 E-4 mm
HD16	15	Deviation of A2 in XZ plane	1.0 E-4°
HD17	16	Deviation of A2 in XY plane	1.0 E-4°
HD18	17	Angle offset for A2	1.0 E-4°
HD19	18	X coordinate of mount point of A3	1.0 E-4 mm
HD20	19	Y coordinate of mount point of A3	1.0 E-4 mm
HD21	20	Z coordinate of mount point of A3	1.0 E-4 mm
HD22	21	Deviation of A3 in XZ plane	1.0 E-4°
HD23	22	Deviation of A3 in XY plane	1.0 E-4°
HD24	23	Angle offset for A3	1.0 E-4°
HD25	24	X coordinate of mount point of A4	1.0 E-4 mm
HD26	25	Y coordinate of mount point of A4	1.0 E-4 mm
HD27	26	Z coordinate of mount point of A4	1.0 E-4 mm
HD28	27	Deviation of A4 in XZ plane	1.0 E-4°
HD29	28	Deviation of A4 in XY plane	1.0 E-4°
HD30	29	Angle offset for A4	1.0 E-4°

HD31	30	X coordinate of mount point of A5	1.0 E-4 mm
HD32	31	Y coordinate of mount point of A5	1.0 E-4 mm
HD33	32	Z coordinate of mount point of A5	1.0 E-4 mm
HD34	33	Deviation of A5 in YZ plane	1.0 E-4°
HD35	34	Deviation of A5 in XY plane	1.0 E-4°
HD36	35	Angle offset for A5	1.0 E-4°

Tool offset data of the kinematic

The parameters HD1 to HD6 are available for a tool flanged onto axis A5.

Notice

If a tool length is active (`V.G.WZ_AKT.L`.), it is added to `HD3`.

Use of coordinate systems (#CS command)

If a coordinate system (#CS command) is used, the channel parameter P-CHAN-00247 must be set to 1.

If P-CHAN-00247 is not set, the #CS command has no effect.

3.6 KIN_TYP_213- Five-axis palletising robot

The articulated axes are 1,2,3,4,5. Axis 1 rotates about the z axis of the Cartesian coordinate system. The robot is represented in Figure 2 with all articulated axes in zero position.

Release Note

Functionality available as of CNC Build V3.1.3081 or V3.1.3108.

Rotation in positive direction corresponds to the mathematically positive direction of rotation in the Cartesian coordinate system. Articulated axes G2, G3, G4 must be configured as linear axes (with a limited range of motion).
Articulated axis G5 must be configured as a modulo axis within the range of -180° to +180°. Optionally, articulated axis G1 can be configured as a linear or a modulo axis, provided no limitations need to be considered, e.g. trailing cables.

Notice

When programming in Cartesian coordinates, the flange must first be aligned parallel to the X/Y plane of the base coordinate system (B=0). Only then will programming the C angle result in the expected alignment of the flange/tool.

However, if the robot is operated with B ≠ 0, the resulting motion may not correspond to the expected orientation.

Notice

In this kinematic model, the programmed tool orientation normally relates to the Cartesian base coordinate system of the machine.
If coordinate systems (#CS) are used, it may be necessary to configure channel parameter P-CHAN-00247 accordingly, depending on the required response.

Axis configuration in the NC channel		
Axis identifier	X, Y, Z, B, C (G1, G2, G3, G4, G5)	
Axis index	0, 1, 2, 3, 4	
Kinematic structure		
	Tool axes	**Workpiece axes**
NC axes	X, Y, Z, B, C	-

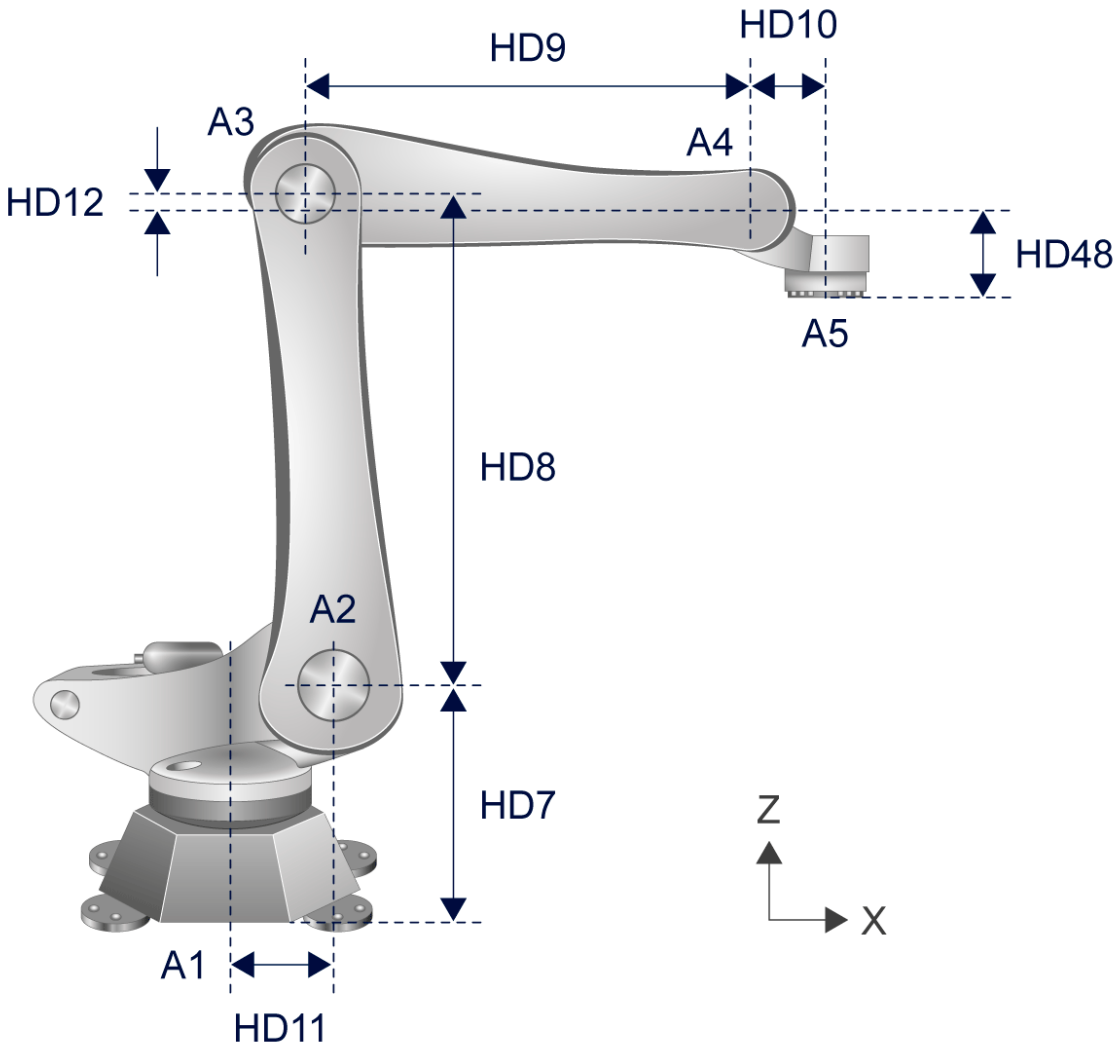


Fig. 148: Side view

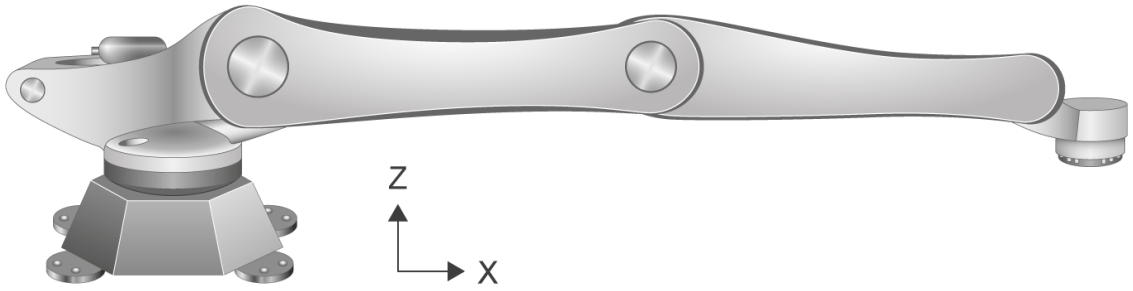


Fig. 149: Zero position without rotary offsets

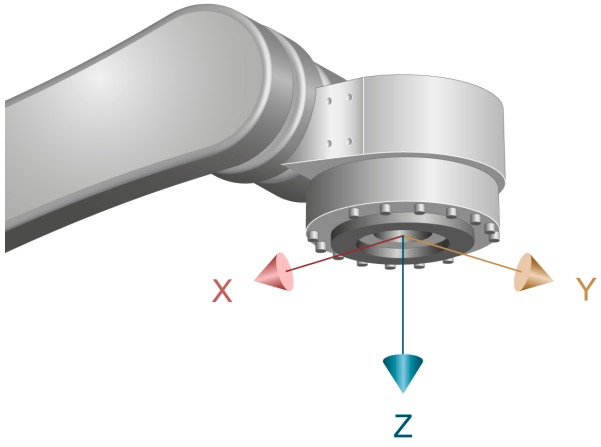


Fig. 150: Flange coordinate system

Offset data of kinematics

HD offset	param[i]	Description	Unit
HD1	0	Tool Z offset in flange coordinate system	1.0 E-4 mm
HD2	1	Tool X offset in flange coordinate system	1.0 E-4 mm
HD3	2	Tool Y offset in flange coordinate system	1.0 E-4 mm
HD6	5	Angle of tool rotation about the Z axis	1.0 E-4°
HD7	6	Z offset base to G2	1.0 E-4 mm
HD8	7	Offset G2 to G3	1.0 E-4 mm
HD9	8	X offset G3 to G4	1.0 E-4 mm
HD10	9	X offset G4 to G5	1.0 E-4 mm
HD11	10	X offset base to G2	1.0 E-4 mm
HD12	11	Z offset G4 to G3 **Note**: Positive sign; the rotary axis of joint 3 is located in the positive Z direction above the rotary axis of joint 4.	1.0 E-4 mm
HD14	13	Rotary offset for zero position of robot joint axis 2	1.0 E-4°
HD15	14	Rotary offset for zero position of robot joint axis 3	1.0 E-4°
HD21	20	Rotation direction of joint axis 1: 0 (positive), 1 (negative)	[-]
HD22	21	Rotation direction of joint axis 2: 0 (positive), 1 (negative)	[-]
HD23	22	Rotation direction of joint axis 3: 0 (positive), 1 (negative)	[-]
HD24	23	Rotation direction of joint axis 4: 0 (positive), 1 (negative)	[-]
HD25	24	Rotation direction of joint axis 5: 0 (positive), 1 (negative)	[-]
HD36	35	Rotary offset for zero position of robot joint axis 1	1.0 E-4°
HD37	36	Rotary offset for zero position of robot joint axis 4	1.0 E-4°
HD38	37	Rotary offset for zero position of robot joint axis 5	1.0 E-4°
HD48	47	Z offset G4 to G5. **Note**: Positive sign: Flange is in positive Z direction below G4	1.0 E-4 mm

Programing Example

Five-axis palletising robot

```
N010 #KIN ID[213]

; move robot to arbitrary position
N020 A1=23 A2=[-90] A3=90 A4=[-11] A5=47

N030 #TRAFO ON
; first move flange parallel to "floor"
N040 G00 B0
; then i.e. do some pick and place
; -> flange stays parallel to "floor" if B does NOT get explicitly pro-
grammed
N050 F2000
N060 G01 X1000 Y1300 Z700 C0
N070 G01 Z500
N080 G01 X1500 Y1300 Z700 C90
N090 #TRAFO OFF
N100 M30
```

4 Classification of transformations

Depending on their characteristics the transformations in the first two chapters can be classified in the following way:

4.1 Transformation type

Transform-ation type	Type	Number of axes	Number of workpiece axes	Special features
1 [▶ 20]	RTCP	5		
2 [▶ 23]	RTCP	5		
3 [▶ 25]	RTCP	4		
4 [▶ 27]	RTCP	4		
5 [▶ 29]	RTCP	4		
6 [▶ 33]	RTCP	4		
7 [▶ 35]	RTCP	5		
8 [▶ 38]	RTCP	5		
9 [▶ 41]	RTCP	5		
10 [▶ 44]	RTCP	5		
11 [▶ 47]	RTCP	5		
12 [▶ 50]	Complete	3		3-axis parallel kinematics with constant orientation
13/14 [▶ 55]	RTCP	3		Face machining (#FACE)
16 [▶ 58]	RTCP	5		
17 [▶ 61]	RTCP	5		3 machine axes, 2 auxiliary axes
18 [▶ 64]	RTCP	5		3 machine axes, 2 auxiliary axes
19 [▶ 67]	Complete	5		3-column parallel kinematics, 5 machine axes
21 [▶ 70]	Complete	4		LAMBDA shear kinematics with compensation of rot. C axis, constant orientation, 4 machine axes
22 [▶ 73]	RTCP	5	2	2 axes in workpiece, 3 machine axes
23 [▶ 75]	RTCP	5		
25 [▶ 78]	RTCP	5		
28 [▶ 82]	RTCP	5		
30 [▶ 85]	RTCP	4		
33 [▶ 87]	RTCP	5		
34 [▶ 90]	RTCP	4		
36 [▶ 168]	RTCP	4		SCARA

Transformation type	Type	Number of axes	Number of workpiece axes	Special features
37 [▶ 173]	Complete	3		Delta robot
45 [▶ 176]	Complete	6		6-axis articulated robot
52 [▶ 92]	RTCP	5		
57 [▶ 94]	RTCP	5		Rotary/swivel table
58 [▶ 98]	RTCP	5		Rotary/swivel table
59 [▶ 102]	RTCP	5		Cardanic head
60 [▶ 112]	RTCP	5		Cardanic head
61 [▶ 116]	RTCP	5		
63 [▶ 120]	RTCP	5		
64 [▶ 124]	RTCP	6		
70 [▶ 128]	RTCP	5		
76 [▶ 132]	Complete	5		Mechanical TCP
80 [▶ 135]	RTCP	5		
81 [▶ 139]	RTCP	5		
82 [▶ 143]	RTCP	6		
85 [▶ 146]	RTCP	2		
96 [▶ 192]	Complete	4		4-axis palletising robot
206 [▶ 196]	Complete	5		5-axis robot on linear unit
207 [▶ 157]	RTCP	5		
208 [▶ 200]	Complete	4		4-axis robot on linear unit
209 [▶ 160]	RTCP	5		Tripod with rotary/swivel table
213 [▶ 204]	Complete	5		Five-axis palletising robot

4.2 Kinematic type

Transformation ID	With rotary table	Robot kinematics	Parallel kinematics	Shear kinematics	With manual axis
1 [▶ 20]	1				
2 [▶ 23]					
3 [▶ 25]					
4 [▶ 27]					
5 [▶ 29]					
6 [▶ 33]					
7 [▶ 35]					1
8 [▶ 38]					1
9 [▶ 41]					
10 [▶ 44]					
11 [▶ 47]	1				
12 [▶ 50]			1		
13/14 [▶ 55]					
16 [▶ 58]					
17 [▶ 61]					1
18 [▶ 64]					1
19 [▶ 67]			1		
21 [▶ 70]				1	
22 [▶ 73]					
23 [▶ 75]	1				
25 [▶ 78]					
28 [▶ 82]					
30 [▶ 85]					
33 [▶ 87]					
34 [▶ 90]	1				
36 [▶ 168]		1			
37 [▶ 173]			1		
45 [▶ 176]		1			
52 [▶ 92]	1				
57 [▶ 94]	1				
58 [▶ 98]	1				
59 [▶ 102]					

Transformation ID	With rotary table	Robot kinematics	Parallel kinematics	Shear kinematics	With manual axis
60 [▶ 112]					
61 [▶ 116]	1				
63 [▶ 120]	1				
64 [▶ 124]	1				
70 [▶ 128]					
76 [▶ 132]					
80 [▶ 135]	1				
81 [▶ 139]	1				
82 [▶ 143]	1				
85 [▶ 146]		1			
96 [▶ 192]		1			
206 [▶ 196]		1			
207 [▶ 157]					1
208 [▶ 200]		1			
209 [▶ 160]	1				
213 [▶ 204]		1			

4.3 Application

Transformation ID	5-axis machining	Milling	Drilling	Sawing	Plasma cutting	Laser cutting
1 [▶ 20]	1	1	1			
2 [▶ 23]	1	1	1			
3 [▶ 25]		1	1			
4 [▶ 27]		1	1			
5 [▶ 29]		1	1			
6 [▶ 33]		1	1			
7 [▶ 35]		1	1			
8 [▶ 38]				1		
9 [▶ 41]	1	1	1			
10 [▶ 44]				1		
11 [▶ 47]	1	1				
12 [▶ 50]		1	1			
16 [▶ 58]	1	1	1			
17 [▶ 61]		1	1			
18 [▶ 64]				1		
19 [▶ 67]		1	1			
21 [▶ 70]		1				
22 [▶ 73]	1	1	1			1
23 [▶ 75]	1	1	1			
25 [▶ 78]	1	1	1		1	1
28 [▶ 82]	1	1	1			
30 [▶ 85]		1	1			
33 [▶ 87]	1	1				
34 [▶ 90]		1	1			
36 [▶ 168]		1	1			
37 [▶ 173]		1	1			
45 [▶ 176]	1	1	1			
52 [▶ 92]	1	1	1			
57 [▶ 94]	1	1	1			
58 [▶ 98]	1	1	1			
59 [▶ 102]	1	1	1			

Transformation ID	5-axis machining	Milling	Drilling	Sawing	Plasma cutting	Laser cutting
60 [▶ 112]	1	1	1			
61 [▶ 116]	1	1	1			
63 [▶ 120]	1	1	1			
64 [▶ 124]	1	1	1			
70 [▶ 128]	1	1	1			
76 [▶ 132]	1					
80 [▶ 135]	1	1	1			
81 [▶ 139]	1	1	1			
82 [▶ 143]	1	1	1			
85 [▶ 146]						
96 [▶ 192]						
98 [▶ 148]						1
206 [▶ 196]	1	1	1			
207 [▶ 157]	1	1	1			
208 [▶ 200]	1	1	1			
209 [▶ 160]	1	1	1			
213 [▶ 204]						

4.4 Tube machining transformations

Transformation ID	Description
15	Round tube, lateral surface (3/4-axis)
78	Round tube, projection (3/4-axis)
79	Polygonal tube, profiled tube (3/4-axis)
90	Round tube, lateral surface (5/6-axis)
93	Polygonal tube, profiled tube (5/6-axis)

For more information on tube machining, go to the section
TF5290 | TC3 CNC Cutting Plus on our product page https://www.beckhoff.de/tf5290

You will find function descriptions on these transformations in the Beckhoff Information System

TwinCAT 3 > TFxxxx | TC3 Functions > TF5xxx - Motion > TF52xx - TC3 CNC > **Tube machining**

https://infosys.beckhoff.de/content/1031/tf5290_tube_processing/index.html

5 Definition of terms

General:

ID	Identifier; general identifier
Type	Kinematic structure with specific features
RT	Backward transformation
TCP	Tool centre point; centre point of milling cutter
VT	Forward transformation
MCS	Machine coordinate system
TCS	Workpiece coordinate system
MNP	Machine zero point
SBP	Slide reference point (tool slide reference point)

Other abbreviations:

HD	Kinematic offset value (head distance)

6 Appendix

6.1 Suggestions, corrections and the latest documentation

Did you find any errors? Do you have any suggestions or constructive criticism? Then please contact us at documentation@isg-stuttgart.de. The latest documentation is posted in our Online Help (DE/EN):

QR code link: https://www.isg-stuttgart.de/documentation-kernel/

The link above forwards you to:

https://www.isg-stuttgart.de/fileadmin/kernel/kernel-html/index.html

Notice

Change options for favourite links in your browser;

Technical changes to the website layout concerning folder paths or a change in the HTML framework and therefore the link structure cannot be excluded.

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Keyword index

K

ISG Industrielle Steuerungstechnik GmbH
STEP, Gropiusplatz 10
D-70563 Stuttgart

www.isg-stuttgart.de
support@isg-stuttgart.de