4.5 Coordinate system description of the robot

4.5.1 About the robot's coordinate system

The robot's coordinate system has following four.

① World coordinate system: Origin is *1
The coordinate system as the standard for displaying the current position of robot. note 1)

② Base coordinate system: Origin is *2 (J1 axis rotation center on the bottom of the robot.)
A coordinate system established with reference to the robot mounting face. It is set by specifying parameter MEXBS with data on a center position for robot installation (base conversion data) as viewed from the world coordinate system or by executing a base command.
By default, because the base conversion data is set to zero (0), the world coordinate system is in agreement with the base coordinate system.

③ Mechanical interface coordinate system: Origin is *3 (J6 axis rotation center on the tool installation surface.)
A coordinate system established with reference to the robot's mechanical interface.

④ Tool coordinate system: Origin is *4
A coordinate system established with reference to the robot's mechanical interface. Its relation to the interface coordinate system is determined by the tool data (i.e., by specified settings for parameter MEXTL or by the execution of a tool command.)

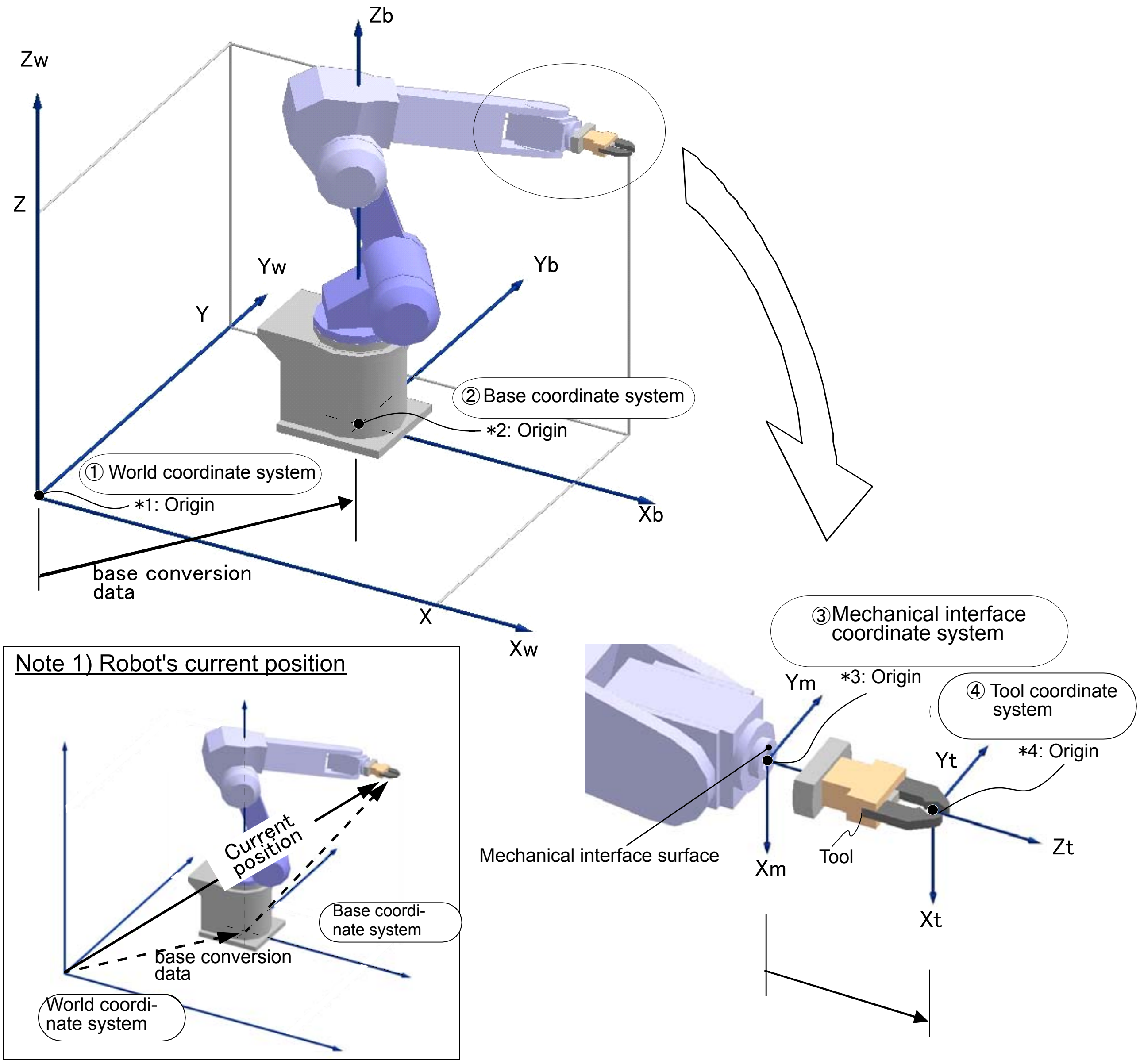


Fig.4-3:Robot's coordinate system

4.5.2 About base conversion

The base conversion permits the world coordinate system to be moved, when required, to the reference position of the work table or the work.
Under the control of this function, the robot's current position is treated as the one relative to the work table or the work. Therefore, where there are a plurality of work groups involved on which the robot shares an identical motional/positional relation, the robot can perform the same operations (sequence of motions) just with a change being made to the world coordinate system, i.e., without the need to be taught the operations (sequence of motions) for each work group. Change to the world coordinate system stated here are called base conversion, which is accomplished by specifying parameter MEXBS with base conversion data (coordinate values) or by executing a Base command.

Base conversion data to be specified should be data on the position of the origin point of the base coordinate system as viewed from a world coordinate system which is newly established. Thus, when you specify the data by using the robot's current position (using a Fram function, etc.), do so by inversely converting the position data [for example, Base Inv(P1)].
When you specify work coordinate system parameters WK1CRD - WK3CRD by executing a Base command, however, you do not have to make the inverse conversion yourself as it is done in internal processing.

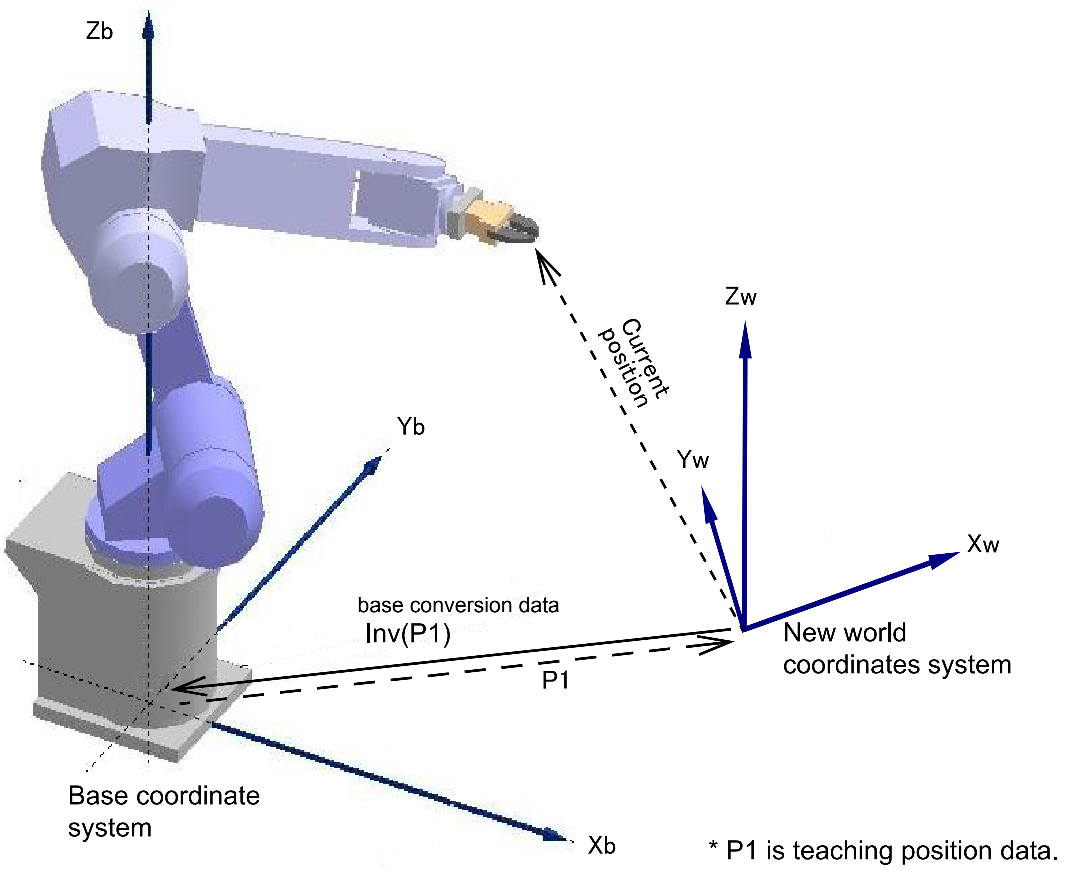


Fig.4-4:Base conversion

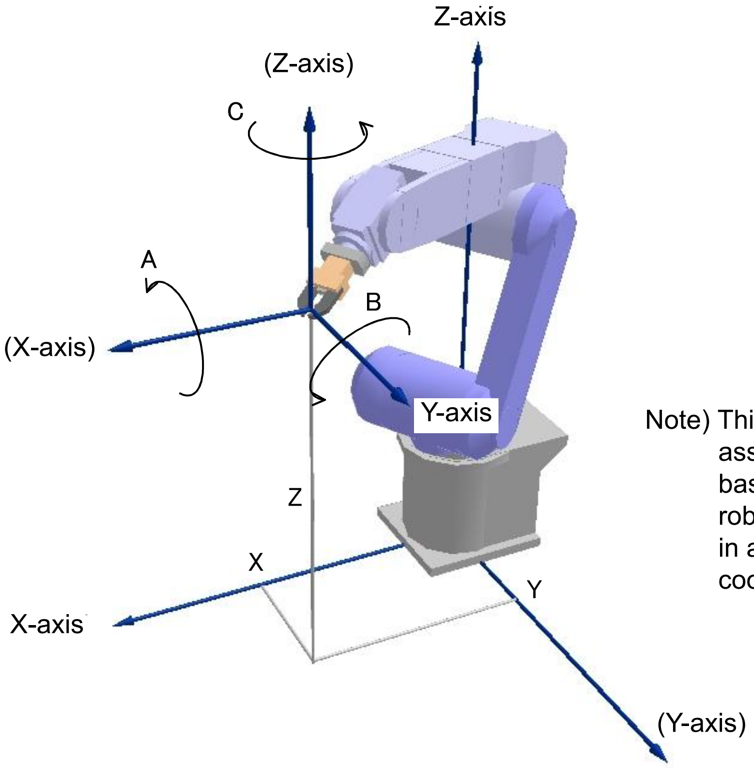
⚠CAUTION

Since the performance of the base conversion causes the reference for the robot's current position to change, data taught till then becomes unusable as it is. If the robot is inadvertently allowed to move to a position taught before the performance of the base conversion, it can stray to an unexpected position, possibly resulting in property damage or personal injury.
When using the base conversion function, be sure to maintain positive control over relation between the base coordinate system subject to conversion and the position which the robot is taught to take so that a proper robot operation and an effective use of the base conversion function are insured.

4.5.3 About position data

Positional data for the robot is comprised of six elements which indicate the position of the hand's leading end (mechanical interface center where no tool setting is made) (X, Y, and Z) and the robot's posture (A, B, and C), plus a structure flag.
Each element constitutes reference data for the robot's world coordinate system.

[Meaning] X, Y, Z: Coordinate data. Position of the robot hand's leading end (in mm).
A, B, C: Posture data. Angle that defines the robot's posture (in degrees)
A → Angle of rotation on X axis
B → Angle of rotation on Y axis
C → Angle of rotation on Z axis



Note) This diagram is produced by assuming a situation in which no base data setting is made, i.e., the robot's world coordinate system is in agreement with its base coordinate system.

Fig.4-5:Reference for posture angles

A, B, and C represent the robot's posture in the coordinate system of its hand's leading end (or flange center where no tool setting is made), each indicating a angle of rotation on the X axis, Y axis, and Z axis of the world coordinate system. Rotation corresponding to the direction of a right-handed screw when you look at the + side of each coordinate axis is "+" rotation. Also, rotation is set to take place in a predetermined sequence, and the amount of rotation is calculated (controlled) first for a rotation on the Z axis, followed by one on the Y axis and one on the Z axis in the order shown.

4.5.4 About tool coordinate system (mechanical interface coordinate system)

To set the robot's control point at the leading end of the hand attached thereto, it is necessary to make tool data settings. Tool data defines the position of the tool's leading end with reference to a mechanical interface coordinate system that is established for the flange. Therefore, our explanation deals with the mechanical interface coordinate system in the first place.

In helping you to understand the tool coordinate system, explanation here uses a vertical 6-axis robot by way of example. For details about other models (vertical 5-axis robot, horizontal articulated arm robot, and others), refer to Page 433, "5.6 Standard Tool Coordinates".

(1) Mechanical interface coordinate system

As shown in Fig. 4-6 , a coordinate system having its origin point chosen at the center of the flange is called a mechanical interface coordinate system. X axis, Y axis and Z axis of the mechanical interface coordinate system are denoted as Xm, Ym and Zm, respectively.

Zm is an axis which passes through the flange center and is perpendicular to the flange face. The direction which goes outside from the flange face is + (plus). Xm and Ym are coplanar with the flange face. A line joining the flange center with the positioning pin hole is represented by Xm axis. "+" direction of the Xm axis is opposite to the pin hole as seen from the center.

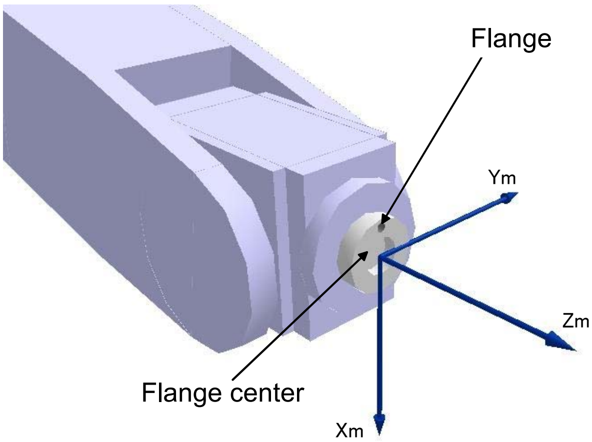


Fig.4-6:Mechanical interface coordinate system

When the flange rotates, the mechanical interface coordinate system rotates, as well. (Fig. 4-7)

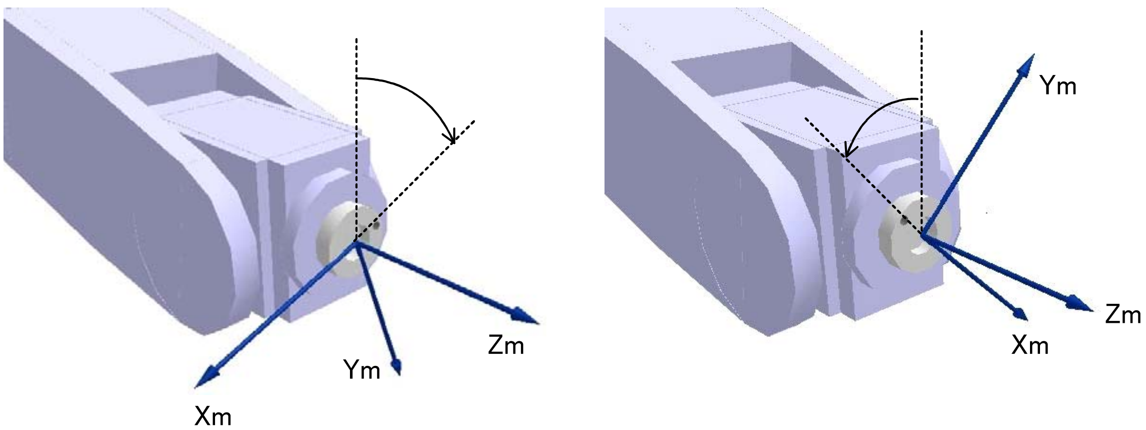


Fig.4-7:Rotation of flange and mechanical interface coordinate system

(2) Tool coordinate system

A tool coordinate system is one that is defined for the leading end of the robot hand (control point for the robot hand).

It is obtained by shifting the origin point of a mechanical interface coordinate system to the leading end of the robot hand (control point hand) and adding given rotational elements.

X axis, Y axis and Z axis of the tool coordinate system are denoted as Xt, Yt and Zt, respectively.

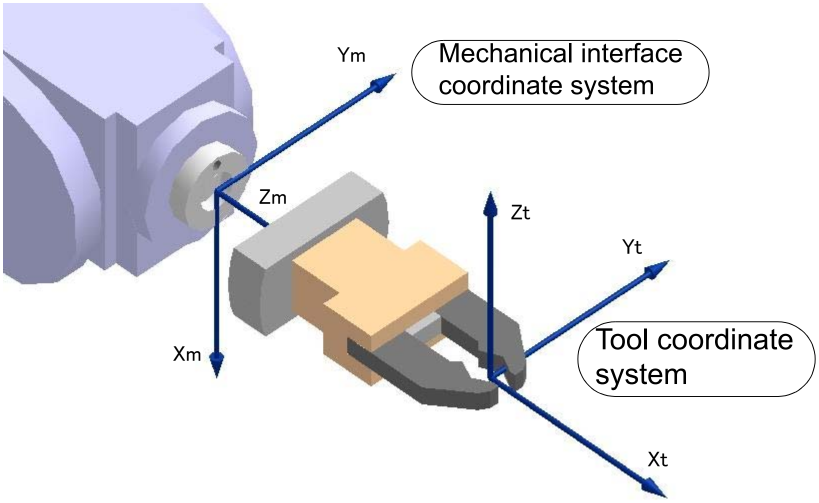


Fig.4-8:Mechanical interface coordinate system and tool coordinate system

Tool data consists of the same elements as position data.

X, Y, Z: Amount of shift. Amount by which the origin point of the mechanical interface coordinate system is shifted to agree with that of the tool coordinate system (in mm).

A, B, C: Angle of rotation of each coordinate axis (in degrees)

- A → Angle of rotation on X axis
- B → Angle of rotation on Y axis
- C → Angle of rotation on Z axis

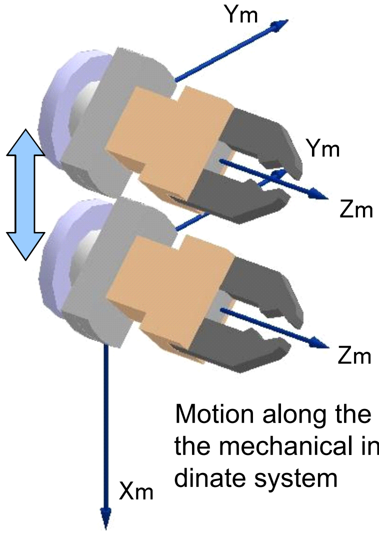
(3) Effects of use of tool coordinate system

1) Jogging and teaching operations

When placing the robot into tool-jog mode, you can let it operate in the direction of the face of the robot hand. This makes it easier to adjust the posture of the robot hand toward the work concerned or the posture of the work being held by the robot hand.

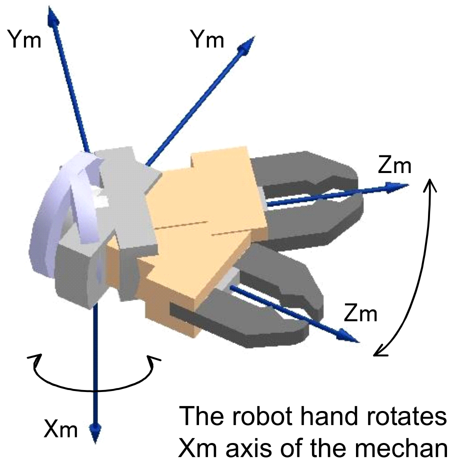
In the case of tool data setting being not made

Travel in the direction of X axis



Motion along the Xm axis of the mechanical interface coordinate system

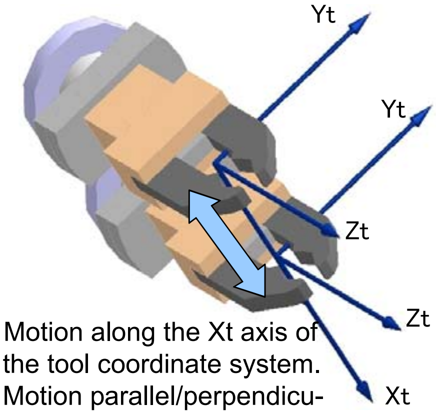
Travel in the direction of A axis



The robot hand rotates on the Xm axis of the mechanical interface coordinate system, thus having a wide range of motion at its leading end.

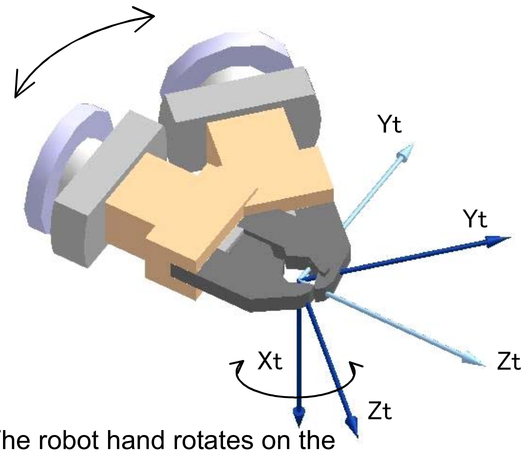
In the case of tool data setting being made

Travel in the direction of X axis



Motion along the Xt axis of the tool coordinate system. Motion parallel/perpendicular to the face of the robot hand assures a register with the orientation of the work.

Travel in the direction of A axis



The robot hand rotates on the Xt axis of the tool coordinate system. Rotational motion on the leading end of the robot hand permits a change of posture without the need to displace the work from its original position.

Fig.4-9:Tool jogging operation with/without tool data

2) Automatic operation

Travel command permits you to set robot motion during the removal or transfer of processed work by specifying approach/pullout distance settings. Approach or pullout takes place in the direction of the Z axis of the robot's tool coordinate system.

To move the robot hand to a point 50mm over the work transfer position as shown in Fig. 4-10, the following indication is used:

```
Mov  P1,50
```

This means that the robot hand should move +50mm in the direction of the Z axis at P1 (tool coordinate system).

Setting the direction of the Z axis of the tool coordinate system to suit the orientation of work being process and/or the operating condition of the robot leads to an improved workability.

In the example shown in Fig. 4-10, because the robot hand is oriented laterally to insert or remove the work, the direction of the Z axis of the tool coordinate system is chosen to agree with the orientation of the work.

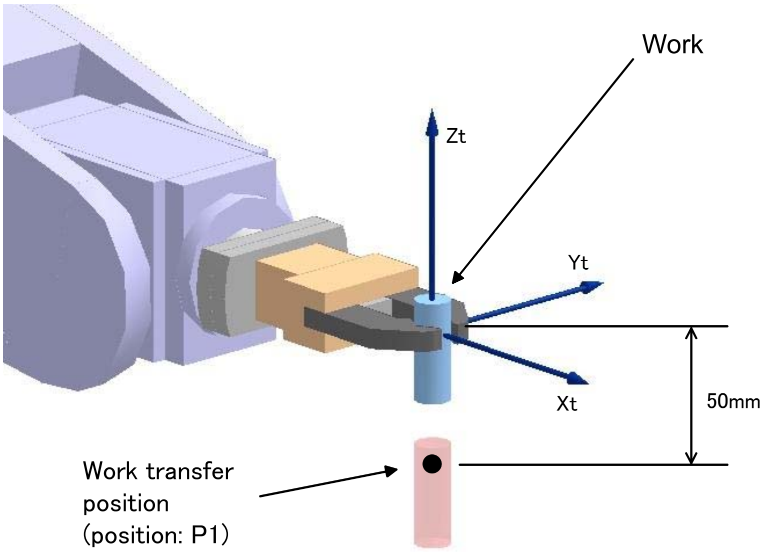


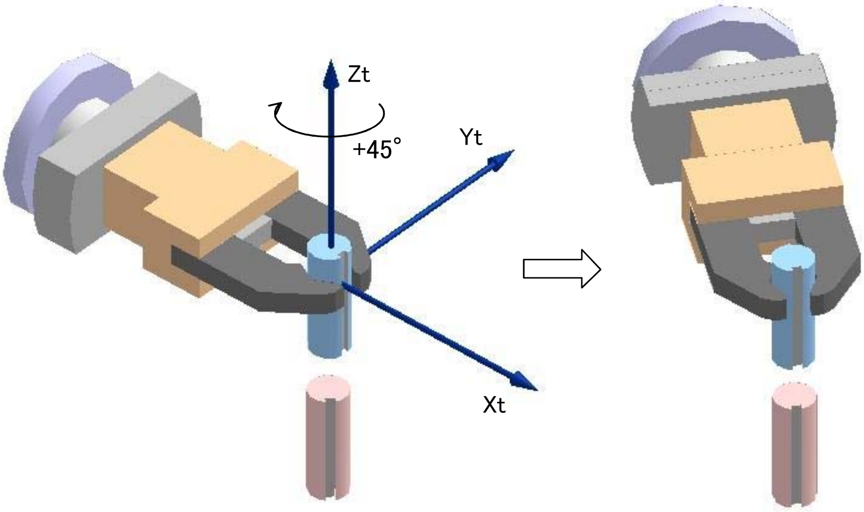
Fig.4-10:Approach/pullout motion

Making tool data settings will come in useful when you have to make changes to the posture of your work as in work phasing, as well.

To achieve work phasing by turning the work on its center axis as shown in Fig. 4-11, the following indication is used:

```
Mov  P1*(0,0,0,0,0,45)
```

"*(0, 0, 0, 0, 0, 45)" means that a position calculation should be carried out at "*" and that C out of (X, Y, Z, A, B, C) should be rotated 45 degree. As C represents a rotation on the Z axis, the robot comes to rotate 45 degree on the Z axis (Zt axis of tool coordinate system) at P1.



(a) Position of P1

(b) Position of Mov P1* (0, 0, 0, 0, 0, 45)

Fig.4-11:Rotational motion in tool coordinate system

7.2 Configuration flag

The configuration flag indicates the robot posture.

For the 6-axis type robot, the robot hand end is saved with the position data configured of X, Y, Z, A, B and C. However, even with the same position data, there are several postures that the robot can change to. The posture is expressed by this configuration flag, and the posture is saved with FL1 in the position constant (X, Y, Z, A, B, C) (FL1, FL2).

The types of configuration flags are shown below.

*For vertical multi-joint type robot

(1) Right/Left

R is center of flange in comparison with the plane through the J1 axis vertical to the ground. (5-axis type robot)

P is center of J5 axis rotation in comparison with the plane through the J1 axis vertical to the ground. (6-axis type robot)

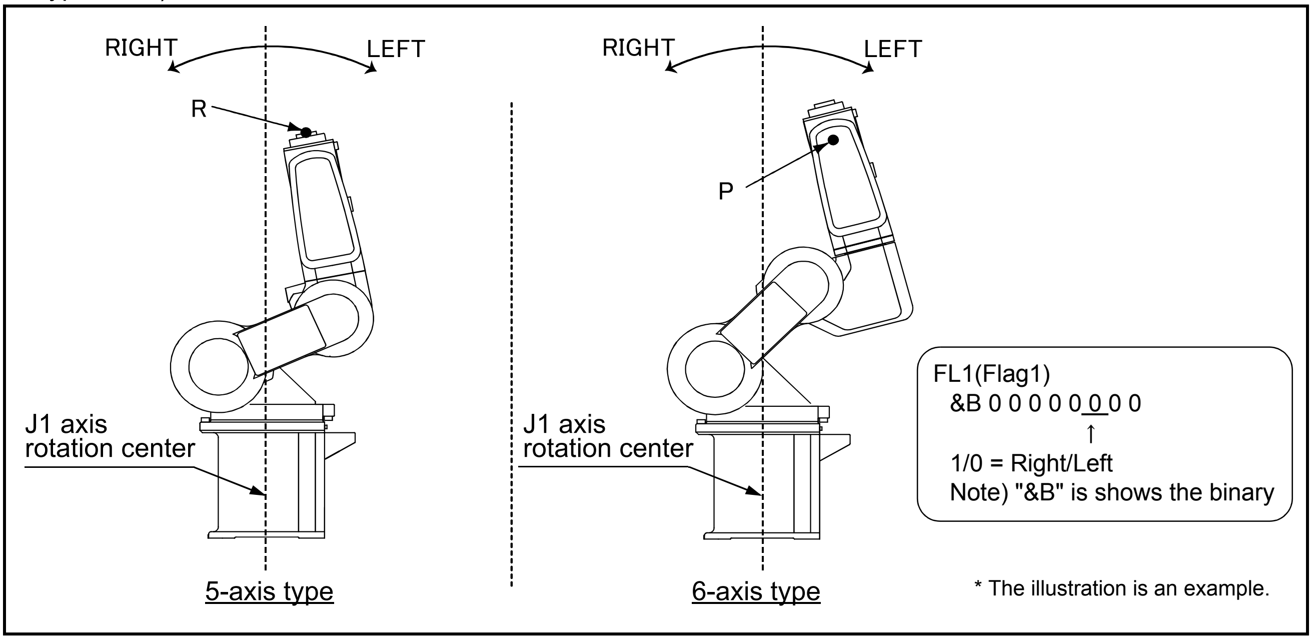


Fig.7-1:Configuration flag (Right/Left)

(2) ABOVE/BELOW

P is center of J5 axis rotation in comparison with the plane through both the J3 and the J2 axis.

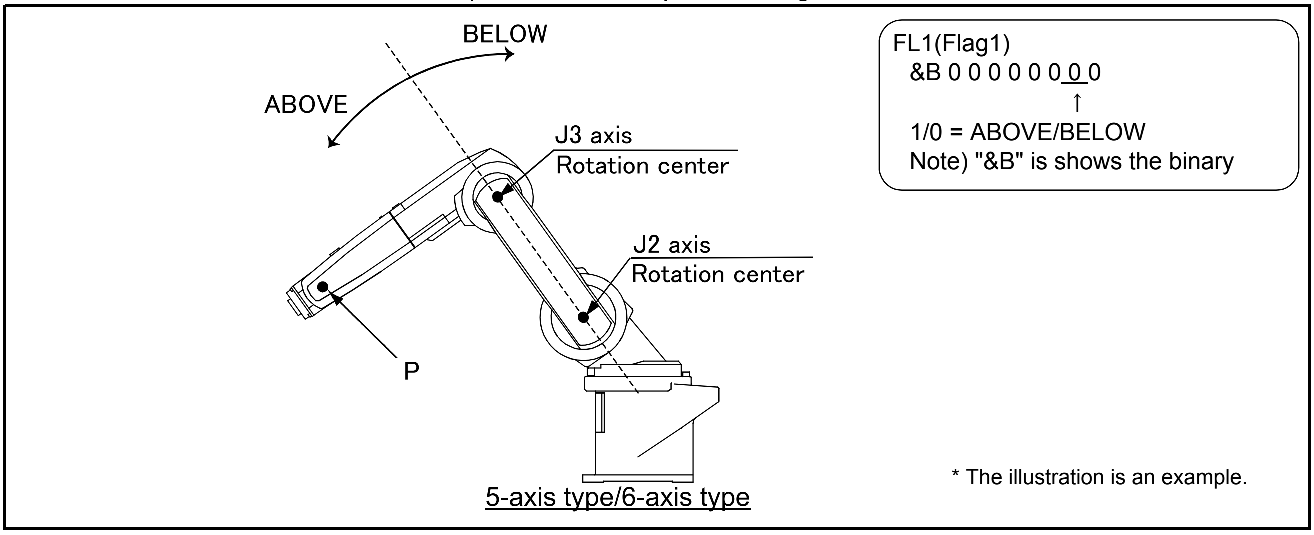


Fig.7-2:Configuration flag (ABOVE/BELOW)

(3) NONFLIP/FLIP (6-axis type robot only.)

This means in which side the J6 axis is in comparison with the plane through both the J4 and the J5 axis.

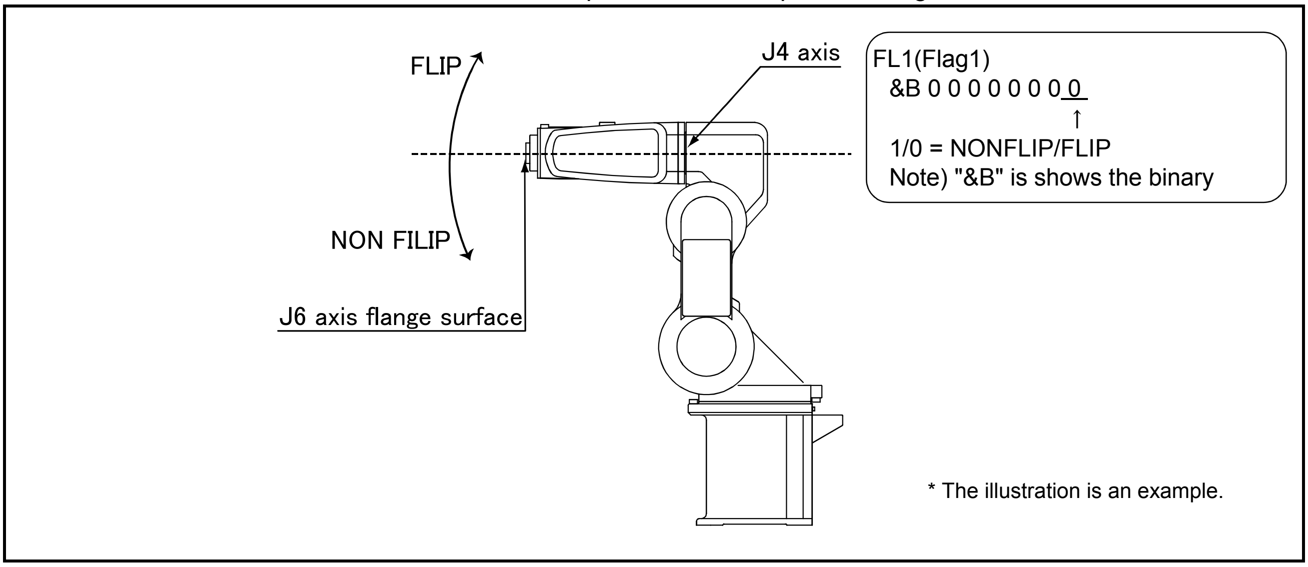


Fig.7-3 : Configuration flag (NONFLIP/FLIP)

5.20 About singular point passage function

(1) Overview of the function

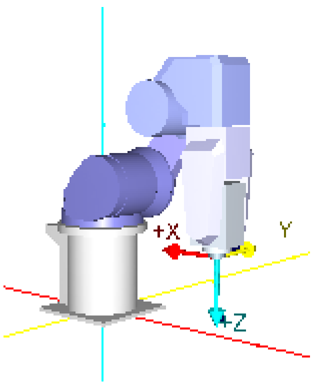
Mitsubishi's robots calculate linear interpolation movement and store teaching positions as position data in the XYZ coordinates system. In the case of a vertical 6-axis robot, for example, the position data is expressed using coordinate values of the robot's X, Y, Z, A, B and C axes, but the robot can be in several different postures even if the position data is the same. For this reason, the robot's position can be selected among the possible options using the coordinate values and the structure flag (a flag indicating the posture). However, there can be an infinite number of combinations of angles that a particular joint axis can take. Even if the structure flag is used, at the positions where this flag is switched, it may not be possible to operate the robot with the desired position and posture (for example, in the case of a vertical 6-axis robot, axes J4 and J6 are not uniquely determined when axis J5 is 0 degree). Such positions are called singular points, and they cannot be reached through XYZ jog and linear interpolation-based operation. To avoid this problem in the past, the operation layout had to be designed such that no singular points would exist in the working area, or the robot had to be operated using joint interpolation if it could not avoid passing a singular point.

The singular point passage function allows a robot to pass singular points through XYZ jog and linear interpolation, which helps increasing the degree of freedom for the layout design by enlarging the working area by linear interpolation.

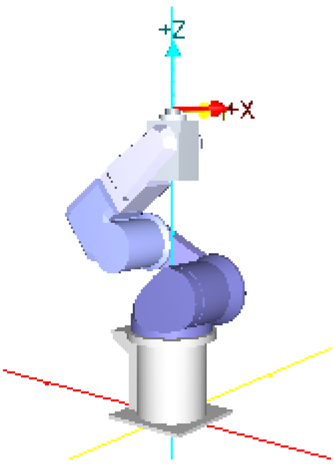
*Positions of singular points that can be passed

The positions of singular points that the singular point passage function allows the robot to pass are as follows.

In the case of vertical 6-axis robots

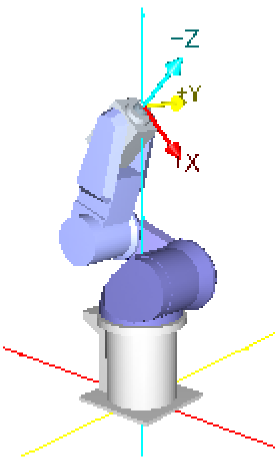


<1> Positions where axis J5 = 0 degree
In these positions, the structure flag switches between NonFlip and Flip.



<2> Positions where the center of axis J5 coincides with the rotation axis of axis J1
In these positions, the structure flag switches between Right and Left.

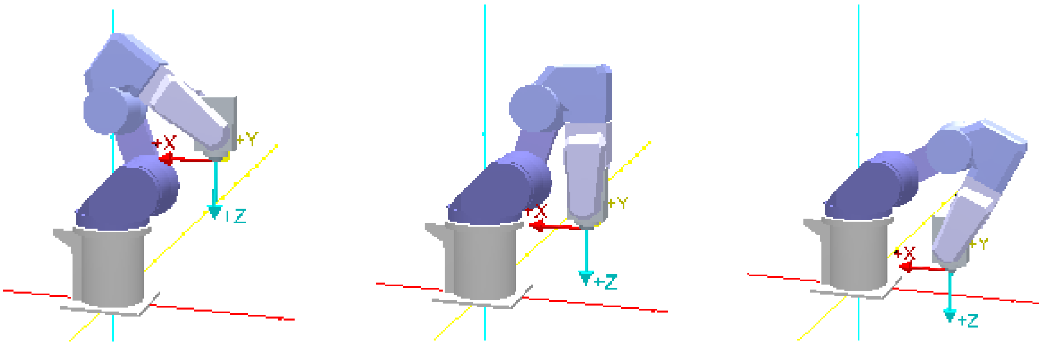
In the case of vertical 5-axis robots



<1> Positions where the center of mechanical interface coincides with the rotation axis of axis J1
In these positions, the structure flag switches between Right and Left.

*Operation when the singular point passage function is valid
When the singular point passage function is made valid, the robot can move from position A to position C via position B (the position of a singular point) and vice versa through XYZ jog and linear interpolation operation. In this case, the value of the structure flag switches before and after passing position B.
If the singular point passage function is invalid (or not supported), the robot stops before moving from position A to position B, as an error occurs. The robot stops immediately before position B in the case of XYZ jog operation.

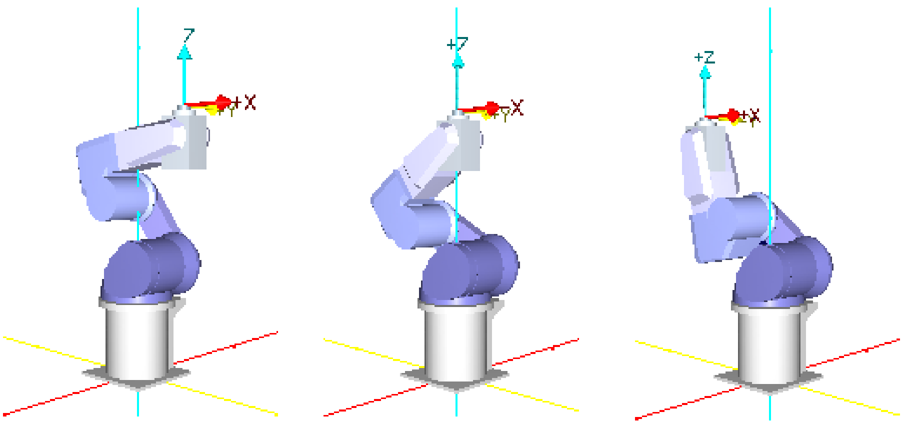
Position A Position B Position C



The robot can pass a singular point when the robot's motion path passes through the singular point. If the motion path does not go through the singular point (passes near the singular point), the robot continues operation without switching the value of the structure flag.

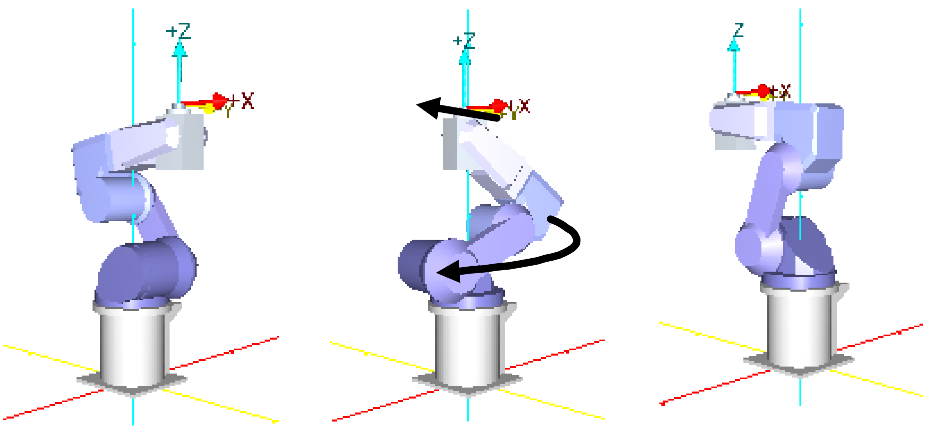
•Positions D -> E -> F: The robot's motion path passes through a singular point (the structure flag switches before and after position E).

Position D Position E Position F



•Positions G -> H -> I: The robot's motion path passes near a singular point (the structure flag is not switched).

Position G Position H Position I



⚠CAUTION When passing near a singular point, the robot may rotate in a wide circle as in the case of position H in the figure above. Be sure to keep an eye on the robot and avoid getting in the way when working near the robot, such as when teaching positions.

*How to use the singular point passage function
In order to use the singular point passage function in jog operation, specify 1 (valid) for parameter FSP-JOGMD and turn the power supply to the controller off and on again. To use the function in automatic operation, specify 2 for constant 2 in the TYPE specification of the interpolation instruction.

* Available robot models
Following models are available for the singular point passage function.

Available robot models
RV-2F, RV-4F series, RV-4FJL, RV-7F series, RV-7FLL, RV-13F series, RV-20F

When the singular point passage function is enabled for the models other than the target models, normal operation (in which the posture is maintained and the structure flags are not switched) is performed for jog operation and an error occurs in automatic operation.

*Limitations
There are the following limitations to the use of the singular point passage function.

(1) The singular point passage function cannot be used if additional axes are used for multiple mechanisms.
(2) The singular point passage function cannot be used if synchronization control is used for additional axes of a robot.
(3) The singular point passage function cannot be used if the compliance mode is valid.
(4) The singular point passage function cannot be used if the collision detection function is valid.
(5) The information collection level of the maintenance forecast function must be set to level 1 (factory setting).

(2) Singular point passage function in jog operation
In case of jog operation, the singular point passage function is specified to be valid (1) or invalid (0) by parameter FSPJOGMD.

FSPJOGMD	XYZ jog	Tool jog	Work jog	3-axis XYZ jog	CYLINDER jog	JOINT jog
0 (Factory setting)	Normal XYZ jog operation	Normal Tool jog operation	Normal Work jog operation	The setting value does not affect. (For the X, Y, and Z axes, the posture is maintained and the structure flags are not switched.)	The setting value does not affect. (The posture is maintained and the structure flags are not switched.)	The setting value does not affect.
1	Singular point passage XYZ jog	Singular point passage Tool jog	Singular point passage Work jog			

1) The normal XYZ/TOOL/WORK jog operation refers to the operation in which the posture is maintained and the structure flags are not switched.
2) For robots that cannot use the singular point passage function, changing the setting value of parameter FSPJOGMD has no effect; robots perform the normal operation (The posture is maintained and the structure flags are not switched.)
The models supporting the singular point passage function are RV-F series robots. (Refer to Available robot models in details.)
3) It is not possible to specify multiple axes to perform jog operation at the same time when passing a singular point. If it is attempted to operate an axis while another axis is operating, the operation is ignored.
4) A singular point adjacent alarm is generated if the robot comes near a singular point when performing jog operation using a T/B. See Page 470, "5.20 About singular point passage function".
5) The specification of parameter FSPJOGMD is reflected in jog operation via dedicated input signals as well.

(3) Singular point passage function in position data confirmation (position jump)
The specification of parameter FSPJOGMD is also reflected in position data confirmation (position jump).

FSPJOGMD	MO position movement	MS position movement
0 (Factory setting)	The setting value does not affect. The position moves in the joint mode.	Normal position movement (The posture is maintained and the structure flags are not switched.)
1		Singular point passage position movement

⚠CAUTION If an interpolation instruction (e.g., Mvs P1) is executed directly from T/B when parameter FSPJOGMD is set to 1 (valid), the robot operates with the singular point passage function enabled even if the function is not made valid by the TYPE specification.

(4) Singular point passage function in automatic operation
In order to use the singular point passage function in automatic operation, make the function valid in the TYPE specification for each target interpolation instruction.

TYPE (Type)

[Function]
Specify the singular point passage function in the TYPE specification of an interpolation instruction. The interpolation instructions that support this function are linear interpolation (Mvs), circular interpolation (Mvr, Mvr2 and Mvr3).

[Format]

```
TYPE[]<Constant 1>, <Constant 2>
```

[Terminology]

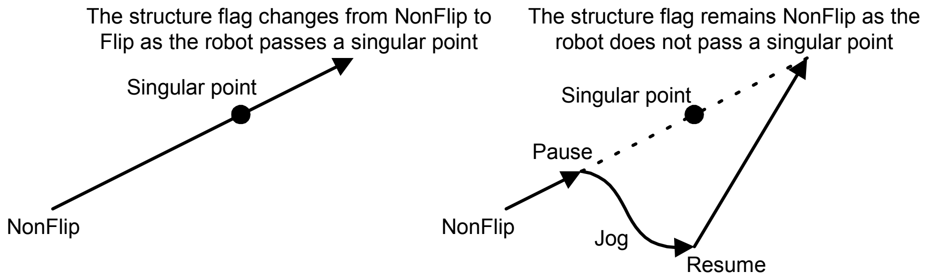
<Constant 1>	0/1	: Short cut/detour
<Constant 2>	0/1/2	: Equivalent rotation/3-axis XYZ/singular point passage

[Reference Program]

1 Mvs P1 TYPE 0,2	' Perform linear interpolation from the current position to P1 with the singular point passage function enabled.
2 Mvr P1,P2,P3 TYPE 0,2	' Perform circular interpolation from P1 to P3 with the singular point passage function enabled.

[Explanation]
(1) A runtime error occurs if 2 is specified for constant 2 for robots that do not support the singular point passage function.
(2) The structure flag is not checked between the starting point and the end point if the singular point passage function is specified. Moreover, since the structure flag of the target position cannot be identified, the movement range is not checked for the target position and intermediate positions before the start of operation.
(3) If a speed is specified with the Spd instruction, the specified speed is set as the upper limit and the robot automatically lowers the speed down to the level where a speed error does not occur near a singular point.
(4) The optimal acceleration/deceleration is not applied for interpolation instructions for which the singular point passage function is specified; the robot operates with a fixed acceleration/deceleration. At this point, if the acceleration time and the deceleration time are different due to the specification of the Accel instruction, the longer time is used for both acceleration and deceleration.
(5) The specification of the Cnt instruction is not applied to interpolation instructions for which the singular point passage function is specified; the robot operates with acceleration/deceleration enabled.
(6) If the current position and the starting point position are different when a circular interpolation instruction is set to be executed, the robot continues to operate until the starting point using 3-axis XYZ linear interpolation, even if the singular point passage function is specified in the TYPE specification.

(7) If an interpolation for which the singular point passage function is specified is paused and the operation is resumed after jog movement, the robot moves to the position at which the operation was paused according to parameter RETPATH. If parameter RETPATH is set to 0 (invalid: do not return to the paused position), the structure flag is not switched unless the motion path after resuming the operation does not pass a singular point as in the figure below. Thus, the posture of the robot at the completion of interpolation may be different from the case where the operation is not paused.



(8) If the singular point passage function is specified, the operation speed may be lowered compared to normal linear interpolation, etc. Moreover, the singular point passage function may affect the execution speed of programs as the function involves complicated processing. Specify the singular point passage function only for interpolation instructions where the function is required.