MITSUBISHI ELECTRIC

Mitsubishi Industrial Robot

MELFA

Robot Seminar Textbook <Force Sensor Application>

MELFA

BFP-A3614

MELFA Robot Seminar Curriculum <Force Sensor Application>

Day 1		Day 2	
Item	Time	Item	Time
Opening greetings Orientation Features of the force sensor 1) Specifications and configuration of the force sensor Force sensor specifications Selecting the force sensor set 2) Installing the force sensor (actual machine operation) Attaching and installing the sensor attachment adapter and force sensor Installing the tool	90 min	7) Force sense function (teaching) Practice (actual machine operation)	75 min
Break	15 min	Break	15 min
3) Device connection and wiring 4) Parameter setting (actual machine operation) Force sensor parameter setting Connection and setting check Details of force sensor parameter	60 min	8) Force sense function (interrupt processing) Practice (actual machine operation) 9) Force sense Practice (actual machine operation)	75 min
Lunch		Lunch	
5) Force sense function (programming) Details of control mode and control characteristics (actual machine operation) Force control Stiffness control Control characteristics change Gravity offset cancel	110 min	10) Application example Application practice 1 (actual machine operation)	90 min
Break	20 min	Break	20 min
6) Force log Force log parameters Force log data acquisition (actual machine operation) End	110 min	11) Application example Application practice 2 (actual machine operation) End	90 min

⚠ Safety Precautions

Always read the following precautions and the separate "Safety Manual" before starting use of the robot to learn the required measures to be taken.

⚠CAUTION All teaching work must be carried out by an operator who has received special training.
(This also applies to maintenance work with the power source turned ON.)
→Enforcement of safety training

⚠CAUTION For teaching work, prepare a work plan related to the methods and procedures of operating the robot, and to the measures to be taken when an error occurs or when restarting. Carry out work following this plan.
(This also applies to maintenance work with the power source turned ON.)
→Preparation of work plan

⚠WARNING Prepare a device that allows operation to be stopped immediately during teaching work.
(This also applies to maintenance work with the power source turned ON.)
→Setting of emergency stop switch

⚠CAUTION During teaching work, place a sign indicating that teaching work is in progress on the start switch, etc.
(This also applies to maintenance work with the power source turned ON.)
→Indication of teaching work in progress

⚠DANGER Provide a fence or enclosure during operation to prevent contact of the operator and robot.
→Installation of safety fence

⚠CAUTION Establish a set signaling method to the related operators for starting work, and follow this method.
→Signaling of operation start

⚠CAUTION As a principle turn the power OFF during maintenance work. Place a sign indicating that maintenance work is in progress on the start switch, etc.
→Indication of maintenance work in progress

⚠CAUTION Before starting work, inspect the robot, emergency stop switch and other related devices, etc., and confirm that there are no errors.
→Inspection before starting work

The points of the precautions given in the separate "Safety Manual" are given below.
Refer to the actual "Safety Manual" for details.

⚠DANGER When automatic operation of the robot is performed using multiple control devices (GOT, programmable controller, push-button switch), the interlocking of operation rights of the devices, etc. must be designed by the customer.

⚠CAUTION Use the robot within the environment given in the specifications. Failure to do so could lead to faults or a drop of reliability.
(Temperature, humidity, atmosphere, noise environment, etc.)

⚠CAUTION Transport the robot with the designated transportation posture. Transporting the robot in a non-designated posture could lead to personal injuries or faults from dropping.

⚠CAUTION Always use the robot installed on a secure table. Use in an instable posture could lead to positional deviation and vibration.

⚠CAUTION Wire the cable as far away from noise sources as possible. If placed near a noise source, positional deviation or malfunction could occur.

⚠CAUTION Do not apply excessive force on the connector or excessively bend the cable. Failure to observe this could lead to contact defects or wire breakage.

⚠CAUTION Make sure that the workpiece weight, including the hand, does not exceed the rated load or tolerable torque. Exceeding these values could lead to alarms or faults.

⚠WARNING Securely install the hand and tool, and securely grasp the workpiece. Failure to observe this could lead to personal injuries or damage if the object comes off or flies off during operation.

⚠WARNING Securely ground the robot and controller. Failure to observe this could lead to malfunctioning by noise or to electric shock accidents.

⚠CAUTION Indicate the operation state during robot operation. Failure to indicate the state could lead to operators approaching the robot or to incorrect operation.

⚠WARNING When carrying out teaching work in the robot's movement range, always secure the priority right for the robot control. Failure to observe this could lead to personal injuries or damage if the robot is started with external commands.

⚠CAUTION Keep the jog speed as low as possible, and always watch the robot. Failure to do so could lead to interference with the workpiece or peripheral devices.

⚠CAUTION After editing the program, always confirm the operation with step operation before starting automatic operation. Failure to do so could lead to interference with peripheral devices because of programming mistakes, etc.

⚠CAUTION Make sure that if the safety fence entrance door is opened during automatic operation, the door is locked or that the robot will automatically stop. Failure to do so could lead to personal injuries.

⚠CAUTION Never carry out modifications based on personal judgments, non-designated maintenance parts. Failure to observe this could lead to faults or failures.

⚠WARNING When the robot arm has to be moved by hand from an external area, do not place hands or fingers in the openings. Failure to observe this could lead to hands or fingers catching depending on the posture.

⚠CAUTION Do not stop the robot or apply emergency stop by turning the robot controller's main power OFF. If the robot controller main power is turned OFF during automatic operation, the robot accuracy could be adversely affected. Also a dropped or coasted robot arm could collide with peripheral devices.

⚠CAUTION Do not turn OFF the robot controller's main power while rewriting the robot controller's internal information, such as a program and parameter. Turning OFF the robot controller's main power during automatic operation or program/parameter writing could break the internal information of the robot controller.

⚠DANGER Do not connect the Handy GOT when using the GOT direct connection function of this product. Failure to observe this may result in property damage or bodily injury because the Handy GOT can automatically operate the robot regardless of whether the operation rights are enabled or not.

⚠DANGER Do not connect the Handy GOT to a programmable controller when using an iQ Platform compatible product with the CR800-R controller. Failure to observe this may result in property damage or bodily injury because the Handy GOT can automatically operate the robot regardless of whether the operation rights are enabled or not.

⚠DANGER Do not remove the SSCNET III cable while power is supplied to the multiple CPU system or the servo amplifier. Do not look directly at light emitted from the tip of SSCNET III connectors or SSCNET III cables of the Motion CPU or the servo amplifier. Eye discomfort may be felt if exposed to the light.
(Reference: SSCNET III employs a Class 1 or equivalent light source as specified in JIS C 6802 and IEC60825-1 (domestic standards in Japan).)

⚠DANGER Do not remove the SSCNET III cable while power is supplied to the controller. Do not look directly at light emitted from the tip of SSCNET III connectors or SSCNET III cables. Eye discomfort may be felt if exposed to the light.
(Reference: SSCNET III employs a Class 1 or equivalent light source as specified in JIS C 6802 and IEC60825-1 (domestic standards in Japan).)

⚠DANGER Attach the cap to the SSCNET III connector after disconnecting the SSCNET III cable. If the cap is not attached, dirt or dust may adhere to the connector pins, resulting in deterioration connector properties, and leading to malfunction.

⚠CAUTION Make sure there are no mistakes in the wiring. Connecting differently to the way specified in the manual can result in errors, such as the emergency stop not being released. In order to prevent errors occurring, please be sure to check that all functions (such as the teaching box emergency stop, customer emergency stop, and door switch) are working properly after the wiring setup is completed.

⚠CAUTION Use the network equipments (personal computer, USB hub, LAN hub, etc) confirmed by manufacturer. The thing unsuitable for the FA environment (related with conformity, temperature or noise) exists in the equipments connected to USB.
When using network equipment, measures against the noise, such as measures against EMI and the addition of the ferrite core, may be necessary. Please fully confirm the operation by customer. Guarantee and maintenance of the equipment on the market (usual office automation equipment) cannot be performed.

■Revision History

Print Date	Instruction Manual No.	Revision content
2018-07-31	BFP-A3614	·First print

■ Introduction

1. What is the Force Sense Function?

The force sense function uses force sensor information with 6 degrees of freedom to provide the robot with a sense of its own force.

Using dedicated commands and status variables compatible with the robot program language (MELFA-BASIC) facilitates work requiring micro force adjustments and power detection.

The force sense function acquires the position information and force information to verify and manage the data.

Force sensor

2. Features of the force sense function

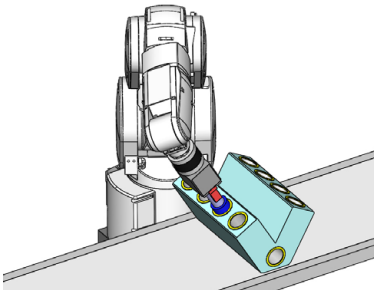
(1) Robots can be controlled with flexibility and operated while following the target workpieces.
(2) Robots can be operated while pushing in the desired direction with a fixed amount of force.
(3) Robot flexibility and contact detection conditions can be changed during movement.
(4) Contact status can be detected and interrupt processing performed.
(5) Position information and force information at the time of contact can be performed.
(6) Force data synchronized with position data can be saved as log data.
(7) Log data can be displayed in a graph using RT ToolBox3.
(8) Log data files can be transferred to an FTP server.

3. Main applications

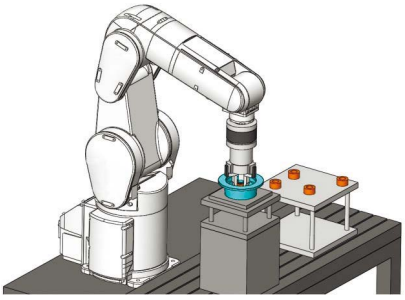
· Assembling and fitting with a fixed amount of force to a desired direction

· Inspection by the detection of force variation during and after assembly

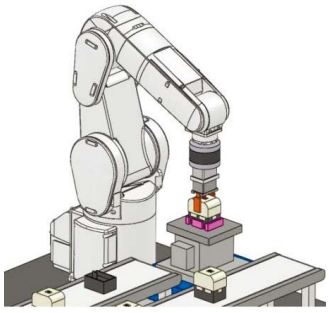
· Transporting and others



Assembly and fitting



Fitting and inspection



Force inspection and assembly

4. Procedure from selection to automatic operation

Step	Description	Reference
1	Select the Force Sensor	Chapter 1 Force Sensor Specifications and Configuration 1.3 Selecting the Force Sensor Set
2	Attach the force sensor attachment adapter	Chapter 2 Installing the Force Sensor 2.1 Attaching the Sensor Attachment Adapter
3	Install the force sensor	Chapter 2 Installing the Force Sensor 2.2 Install the Force Sensor
4	Securing the force sensor cable	Chapter 2 Installing the Force Sensor 2.3 Fixing the force sensor cable
5	Install the tool (hand)	Chapter 2 Installing the Force Sensor 2.5 Tool installation
6	Connect the force sense interface unit and robot controller	Chapter 3 Device Connection and Wiring 3.1 Force Sense Interface Unit ⇔ Robot Controller
7	Connect the force sense interface unit and force sensor	Chapter 3 Device Connection and Wiring 3.2 Force Sense Interface Unit ⇔ Force Sensor
8	Turn ON the force sense interface unit Turn ON the robot controller	Chapter 3 Device Connection and Wiring 3.3 Power ON/OFF
9	Set the force sensor parameter Restart the controller	Chapter 4 Parameter Setting 4.1 Force Sensor Parameter Setting
10	Set the tool (hand) information	Chapter 4 Parameter Setting 4.2 Hand Parameter Setting
11	Check the force sensor connection and setting	Chapter 4 Parameter Setting 4.3 Connection and Setting Check
12	Programming	Chapter 5 Force Sense Function (Programming)
13	Teaching	Chapter 7 Teaching Operation (Teaching)
14	Debug	
15	Automatic operation	

Chapter 1 Force Sensor Specifications and Configuration

1.1 Force Sensor Specifications

There are two types (rated load: 200 N and 1000 N) of force sensors.

(1) Specifications of the force sensor

Item		Unit	Specification Value		Remarks
Model		-	1F-FS001-W200	1F-FS001-W1000	
Rated load (*1)	Fx, Fy, Fz	N	200	1000	Be sure to set the value within the rated load to the FSLMTMX (force sensor permissible value) parameter.
	Mx, My, Mz	Nm	4	30	
Resolution (Minimum control force)	Fx, Fy, Fz	N	Approx. 0.03	Approx. 0.15	
	Mx, My, Mz	Nm	Approx. 0.0006	Approx. 0.0046	
Minimum control force (*2)	Fx, Fy, Fz	N	0.3		This value can be changed by the FSMINCTL (force sensor minimum control force) parameter.
	Mx, My, Mz	Nm	0.03		
Consumption current		mA	200		
Output form		-	RS422		
Weight (sensor unit)		g	360	580	
External dimensions		mm	φ80×32.5	φ90×40	
Protective structure		-	IP30		

*1: When 1F-FS001-W200 is used with RV-7/13/20FR, RV-7/13/20F robot, the moment beyond the moment rated load of the force sensor is applied if the tool/workpiece of the robot's maximum load mass is grasped and its hand posture is set vertically to the installation surface (the robot set on the floor).
Use the force sensor with the hand posture at which the moment does not exceed the moment rated load (for example, with the hand posture facing downward).

*2: Minimum value of force or moment for force sense control.

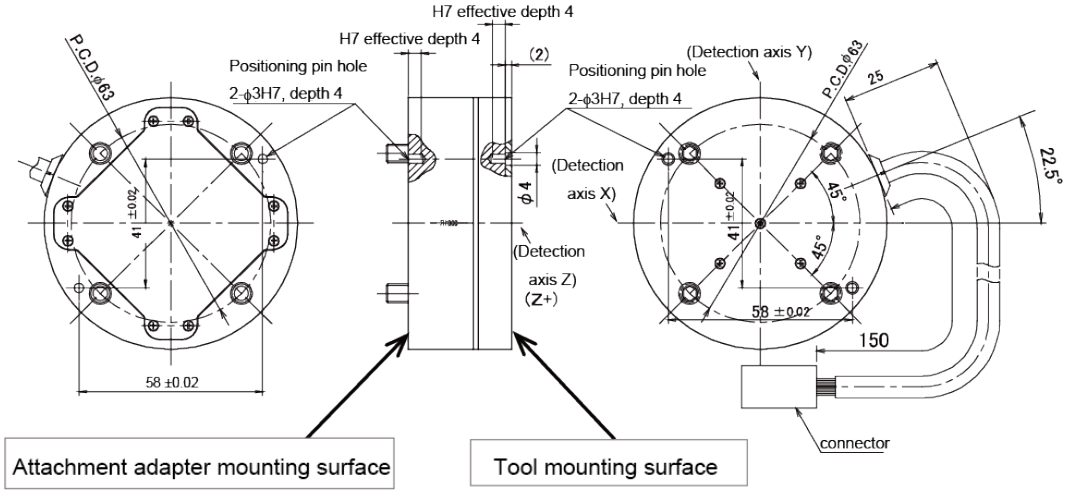
⚠Caution

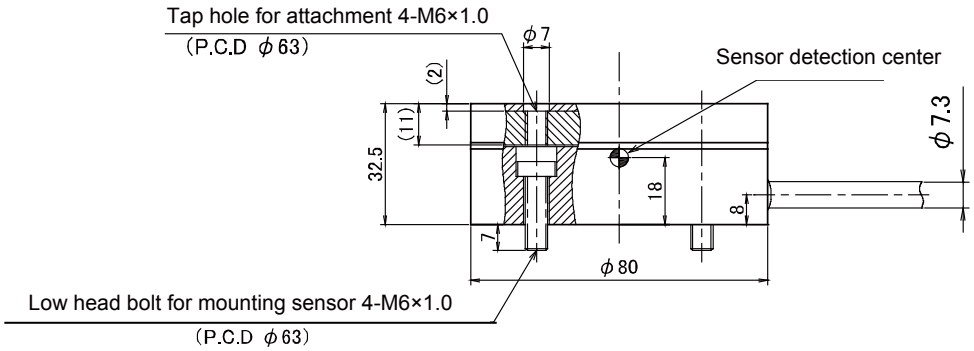
When a load beyond the rated load is applied repeatedly, distortion occurs gradually inside the sensor. Therefore, the force cannot be detected precisely. Use the force sensor with a load within the rated range.

(2) Force Sensor External Dimensions

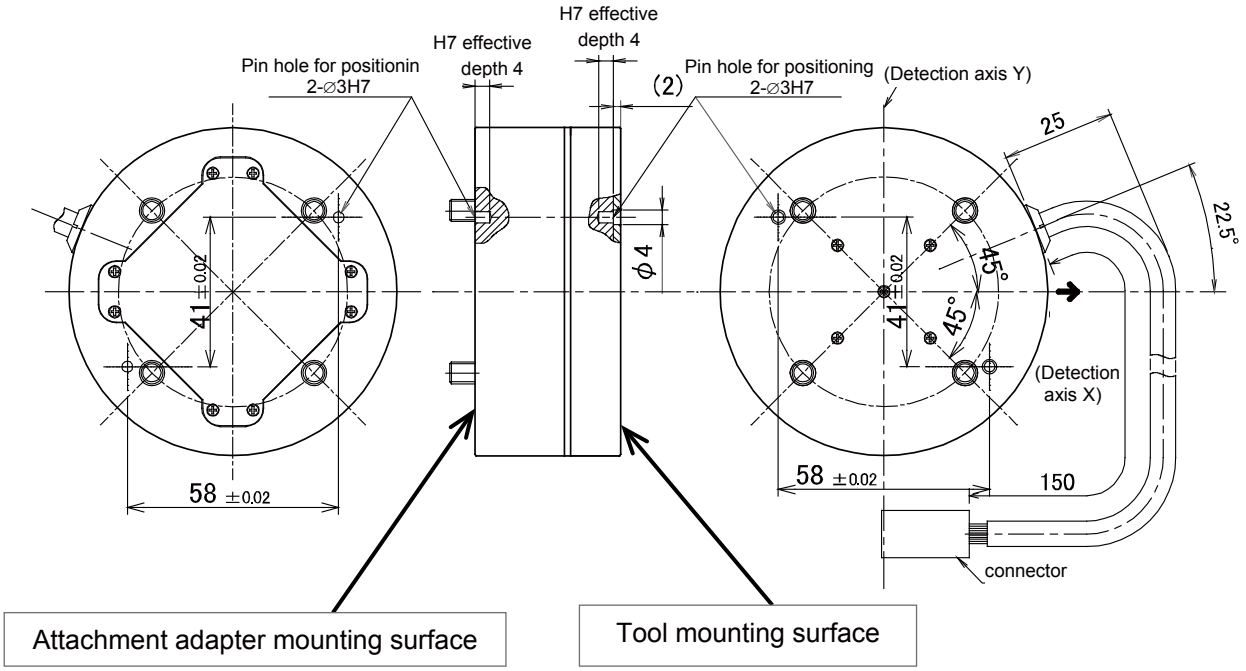
Outline drawings of the force sensor are shown below.

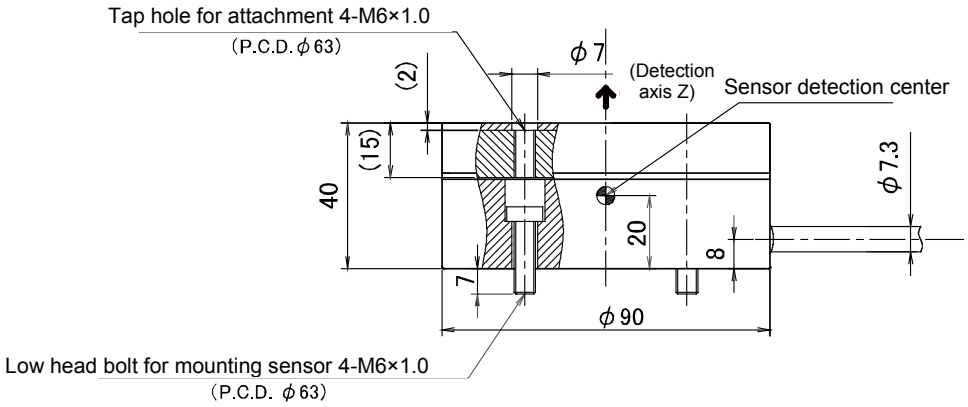
a) 1F-FS001-W200





b) 1F-FS001-W1000

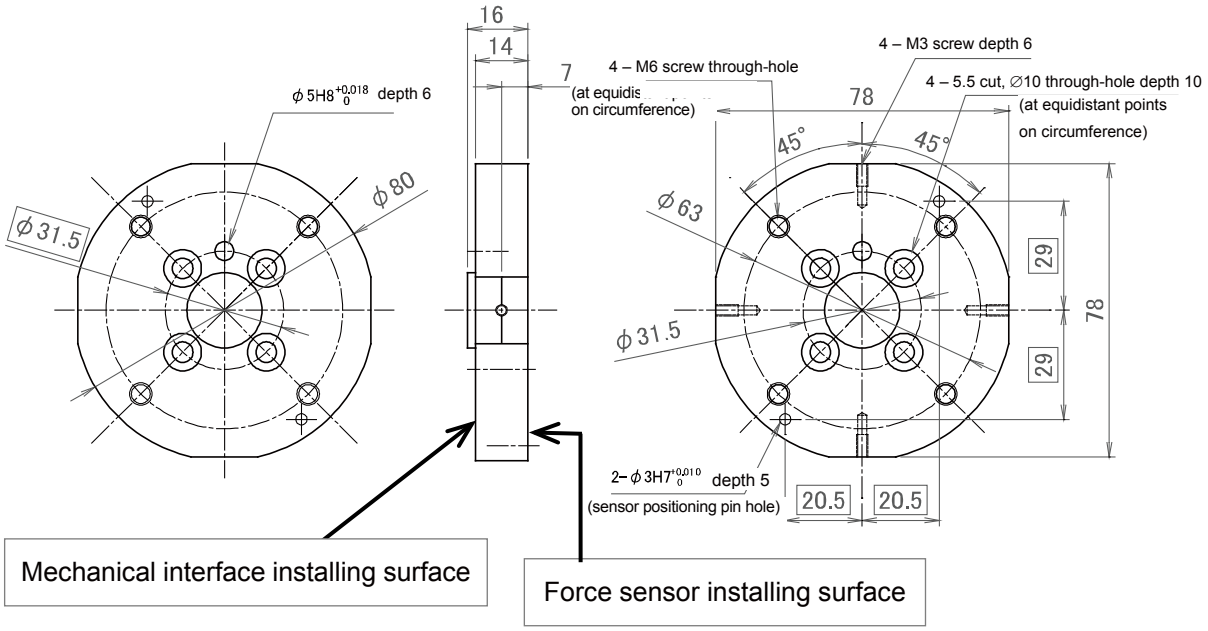




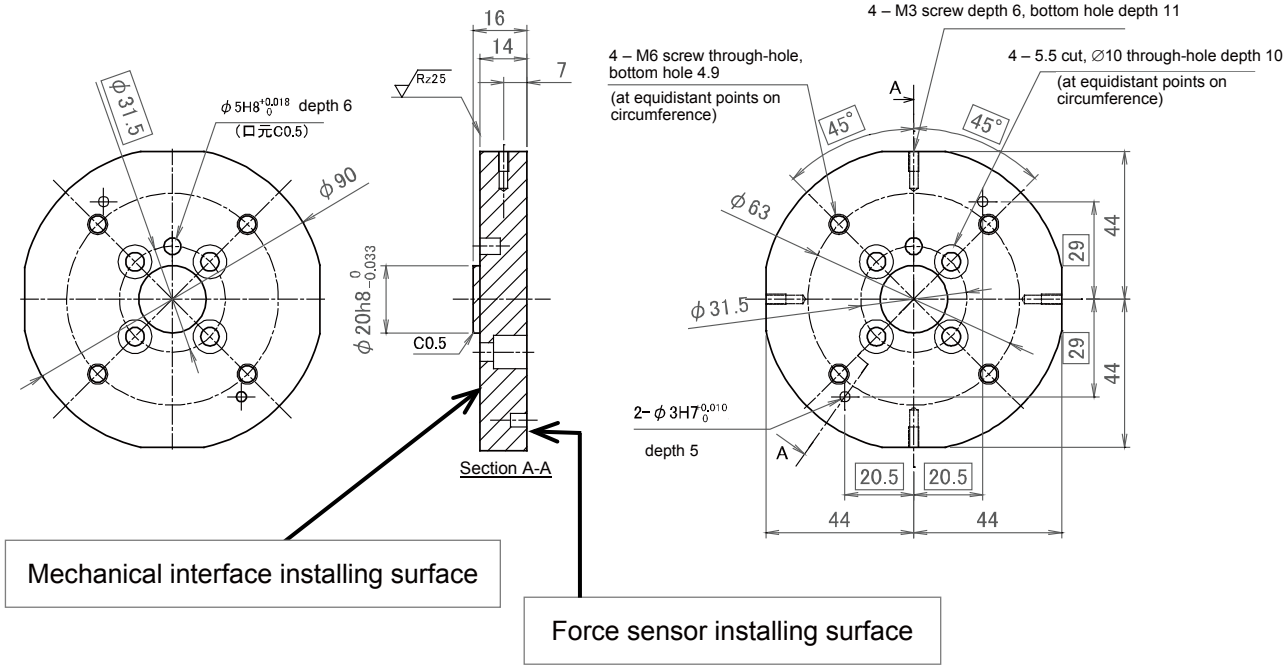
(3) Sensor Attachment Adapter External Dimensions

Outline drawings of the sensor attachment adapter are shown below.

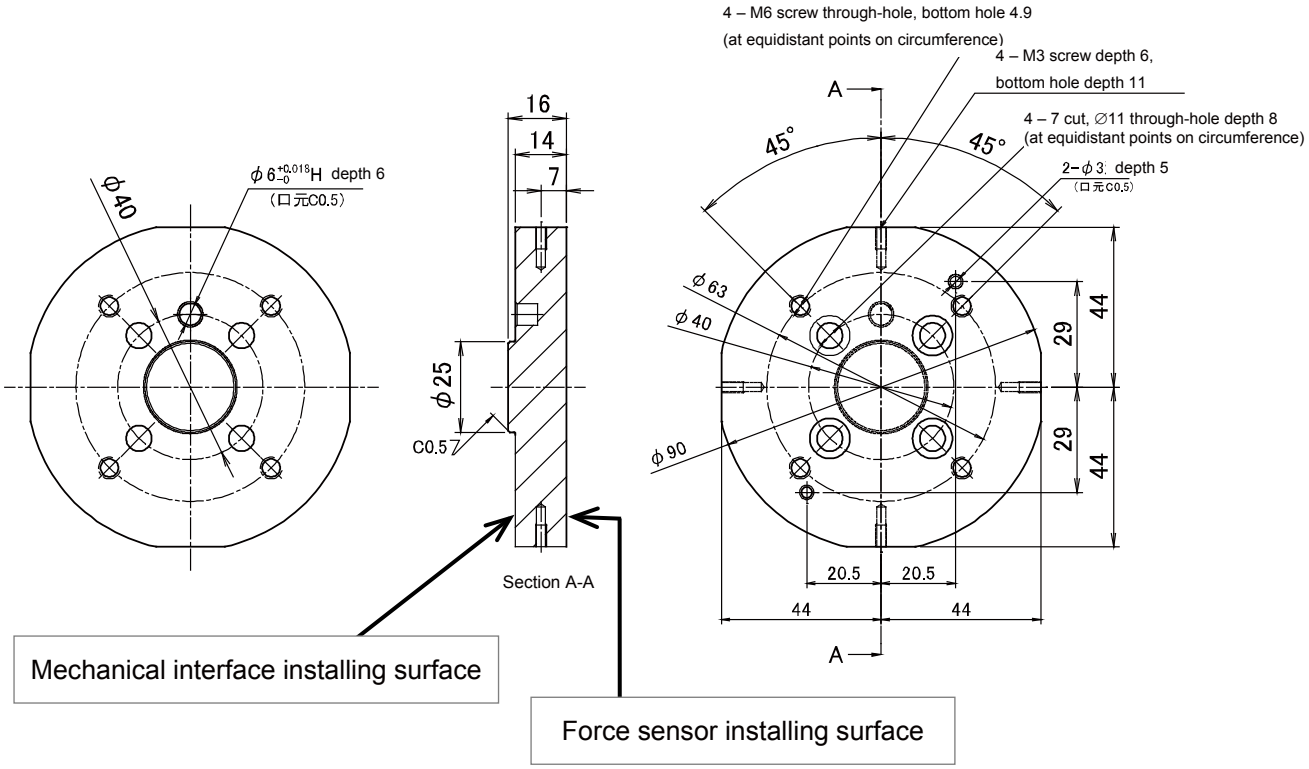
a) For 1F-FS001-W200 (RV-2/4/7FR and RV-2/4/7F)



b) For 1F-FS001-W1000 (RV-2/4/7FR and RV-2/4/7F)



c) For 1F-FS001-W1000 (RV-13/20FR and RV-13/20F)



(4) Configuration of the force sensor set

·The force sensor set for the FR series and F series (for 200 N and 1000 N each) are available.

·The force sense interface units of the force sensor set for the FR series and F series are different. (Refer to the right table.)

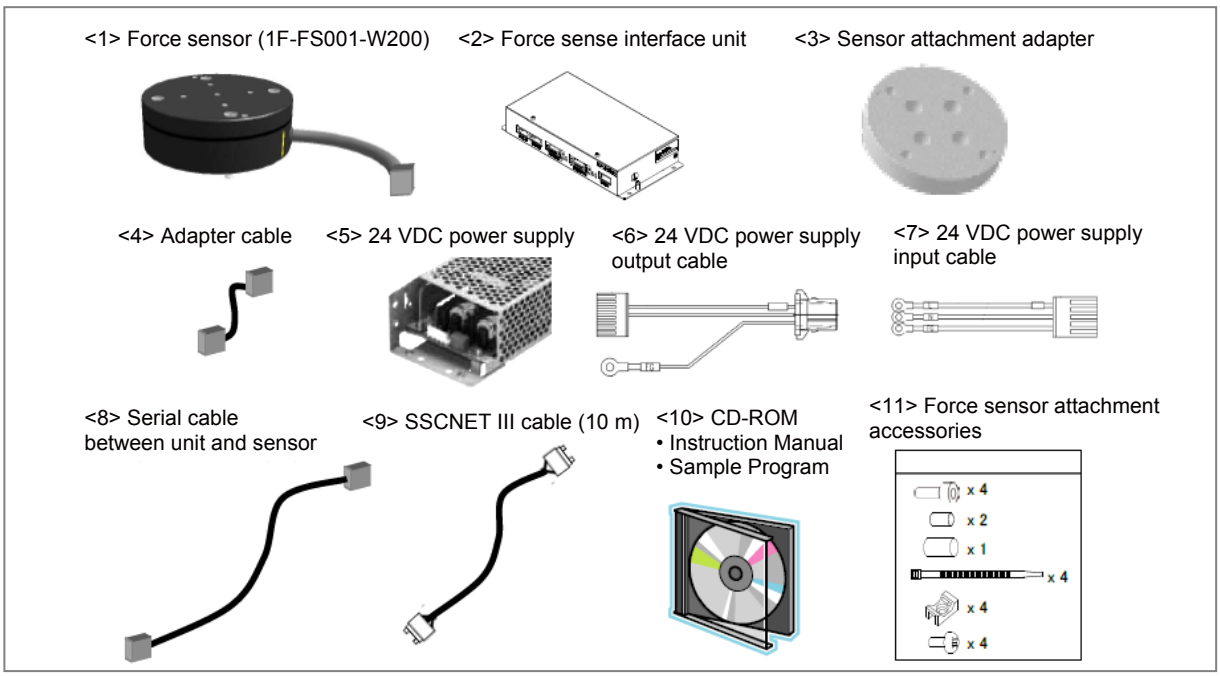
[Note] The force sensor set for the F series cannot be used for the FR series.

Force sensor set	Force sense interface unit model
For FR series	2F-DQ561
For F series	2F-TZ561

Force sense interface unit model

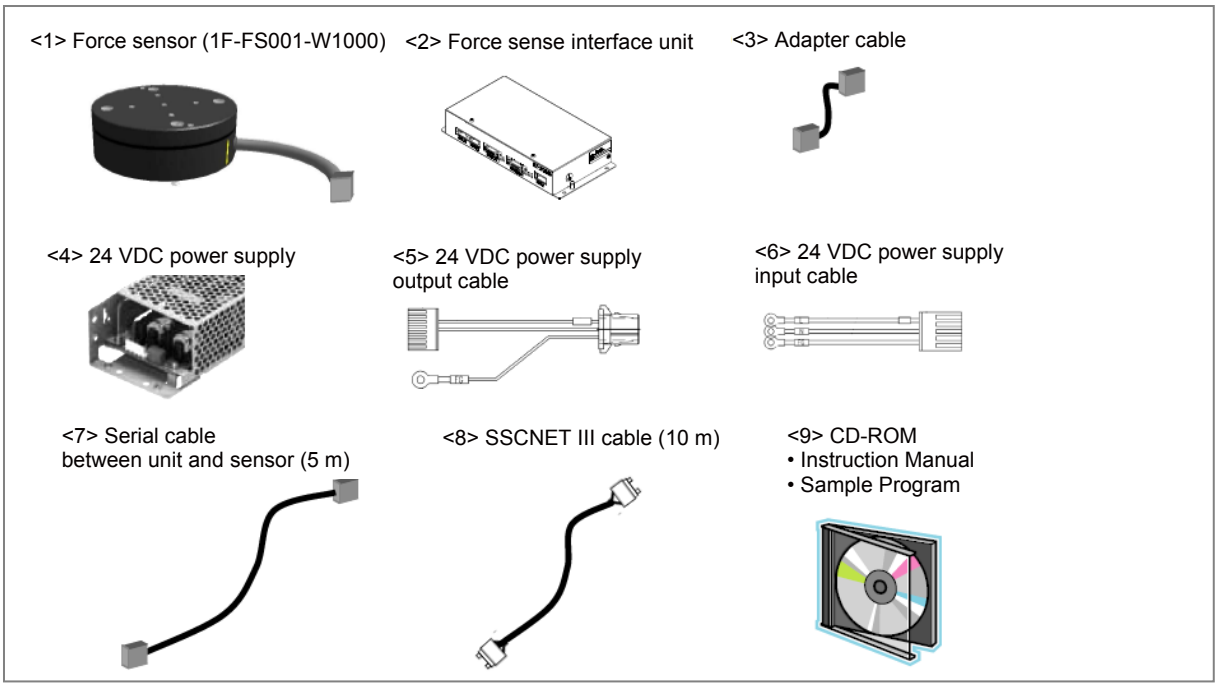
a) For 200 N

For FR series 4F-FS002H-W200, F series: 4F-FS001-W200



b) For 1000N

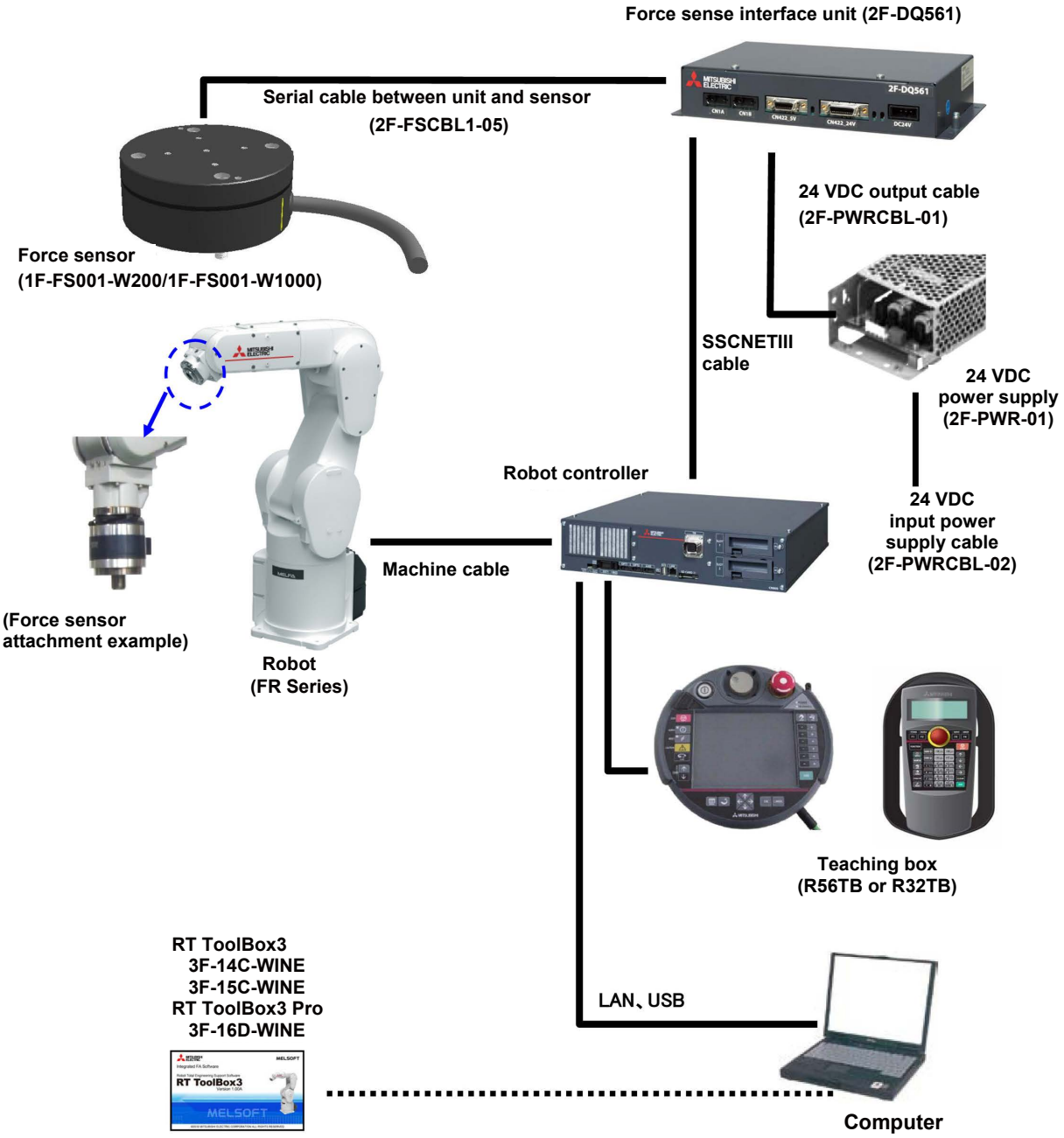
For FR series 4F-FS002H-W1000, F series: 4F-FS001-W1000



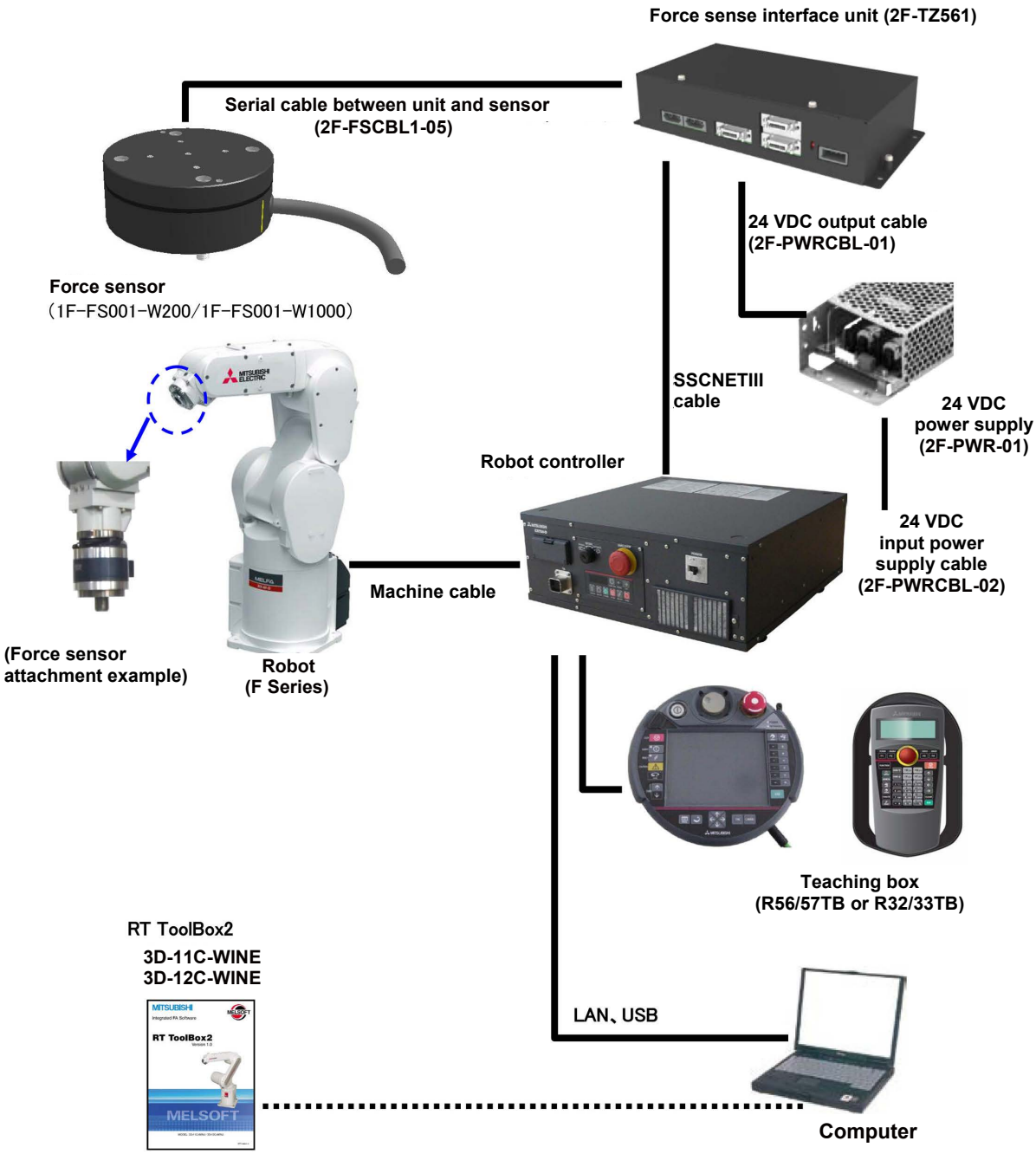
1.2 System Configuration

The device configuration required to use the force sense function is shown below.

a) FR Series



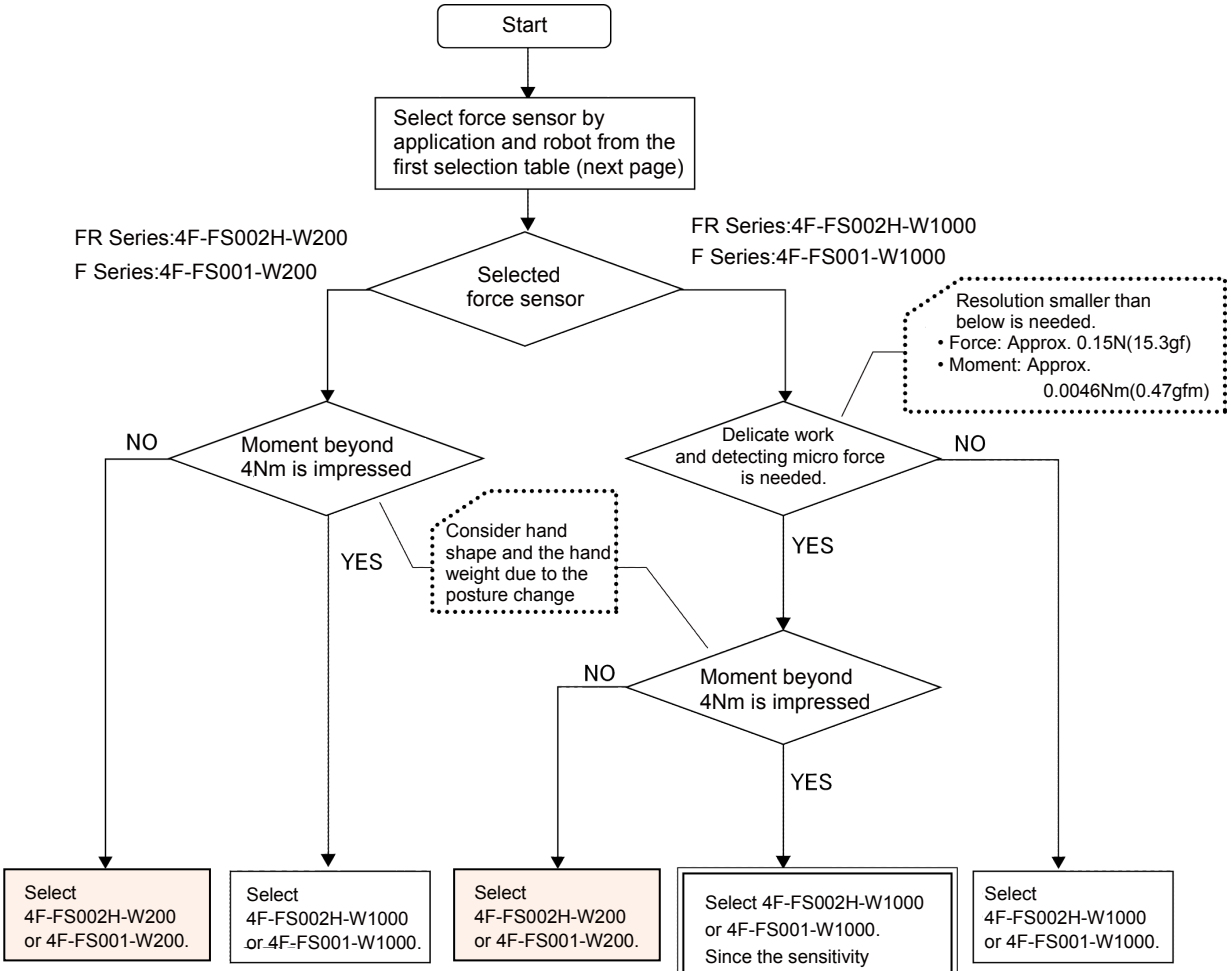
b) F Series


Force sense interface unit (2F-TZ561)
Serial cable between unit and sensor
(2F-FSCBL1-05)
Force sensor
(1F-FS001-W200/1F-FS001-W1000)
24 VDC output cable
(2F-PWRCBL-01)
SSCNETIII
cable
24 VDC
power supply
(2F-PWR-01)
Robot controller
24 VDC
input power
supply cable
(2F-PWRCBL-02)
Machine cable
(Force sensor
attachment example)
Robot
(F Series)
Teaching box
(R56/57TB or R32/33TB)
RT ToolBox2
3D-11C-WINE
3D-12C-WINE
LAN、USB
Computer

1.3 Selecting the Force Sensor Set

This section describes the selection flow for the force sensor. Confirm the selection result and check "1.1 Force Sensor Specifications" to decide the force sensor to be used. (Refer to the next page for the first selection table.)

(1) Selection flow



Force sensor set model

	200N	1000N
For FR series	4F-FS002H-W200	4F-FS002H-W1000
For F series	4F-FS001-W200	4F-FS001-W1000

* For how to calculate the moment, refer to "Chapter1 1.3 (3) Moment by the hand shape and posture change"

(2) First selection table

FR Series

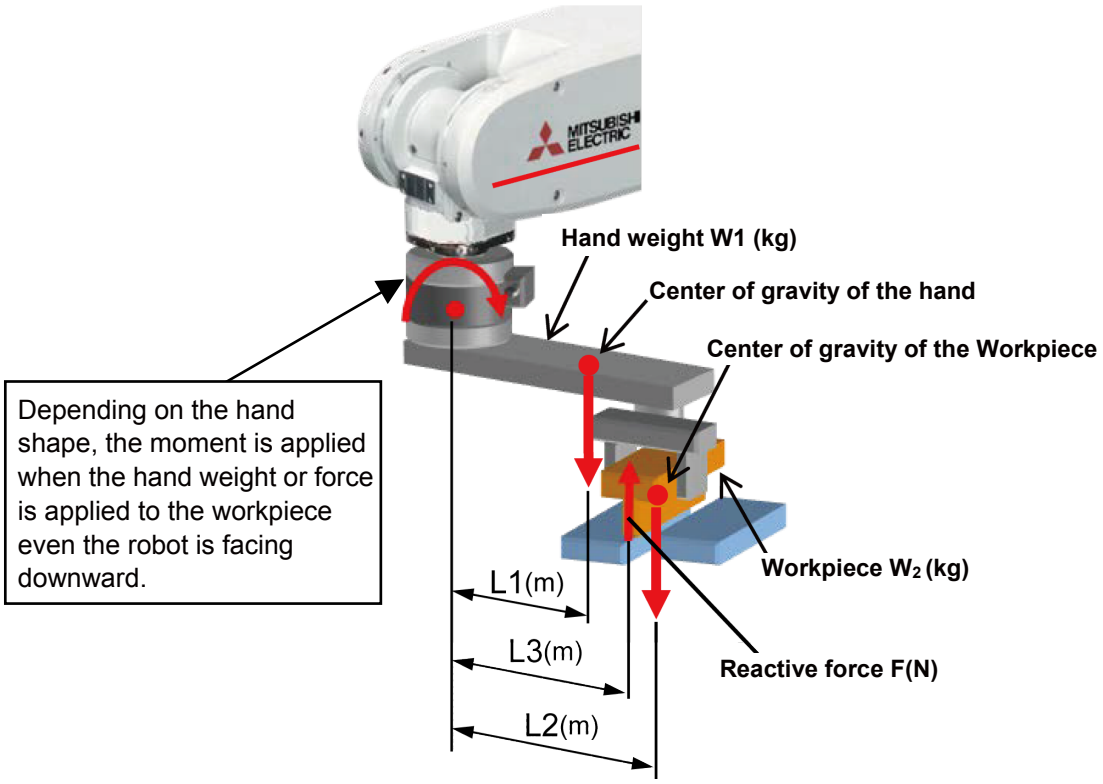
<table>
<tr><td rowspan="3">Application</td><td colspan="9">Robot</td></tr>
<tr><td colspan="5">RV-FR Series</td><td colspan="4">RH-FR Series</td></tr>
<tr><td>RV-2FR</td><td>RV-4FR</td><td>RV-7FR</td><td>RV-13FR</td><td>RV-20FR</td><td>RH-3FR</td><td>RH-6FR</td><td>RH-12FR</td><td>RH-20FR</td></tr>
<tr><td>Close tolerance fit
Phase focusing
Parts assembly
Test (Press/withdraw)
Inset</td><td colspan="2">4F-FS002H-W200</td><td colspan="3">4F-FS002H-W1000
or
4F-FS002H-W200
(Upward and downward limited)</td><td colspan="4">4F-FS002H-W200</td></tr>
<tr><td>Deburr/Polishing</td><td colspan="5">4F-FS002H-W1000</td><td colspan="4">4F-FS002H-W1000</td></tr>
</table>

F Series

<table>
<tr><td rowspan="3">Application</td><td colspan="9">Robot</td></tr>
<tr><td colspan="5">RV-F Series</td><td colspan="4">RH-F Series</td></tr>
<tr><td>RV-2F</td><td>RV-4F</td><td>RV-7F</td><td>RV-13F</td><td>RV-20F</td><td>RH-3F</td><td>RH-6F</td><td>RH-12F</td><td>RH-20F</td></tr>
<tr><td>Close tolerance fit
Phase focusing
Parts assembly
Test (Press/withdraw)
Inset</td><td colspan="2">4F-FS001-W200</td><td colspan="3">4F-FS001-W1000
or
4F-FS001-W200
(Upward and downward limited)</td><td colspan="4">4F-FS001-W200</td></tr>
<tr><td>Deburr/Polishing</td><td colspan="5">4F-FS001-W1000</td><td colspan="4">4F-FS001-W1000</td></tr>
</table>

(3) Moment by the hand shape and posture change

a) When the center of gravity position of the hand is out of the force sensor center

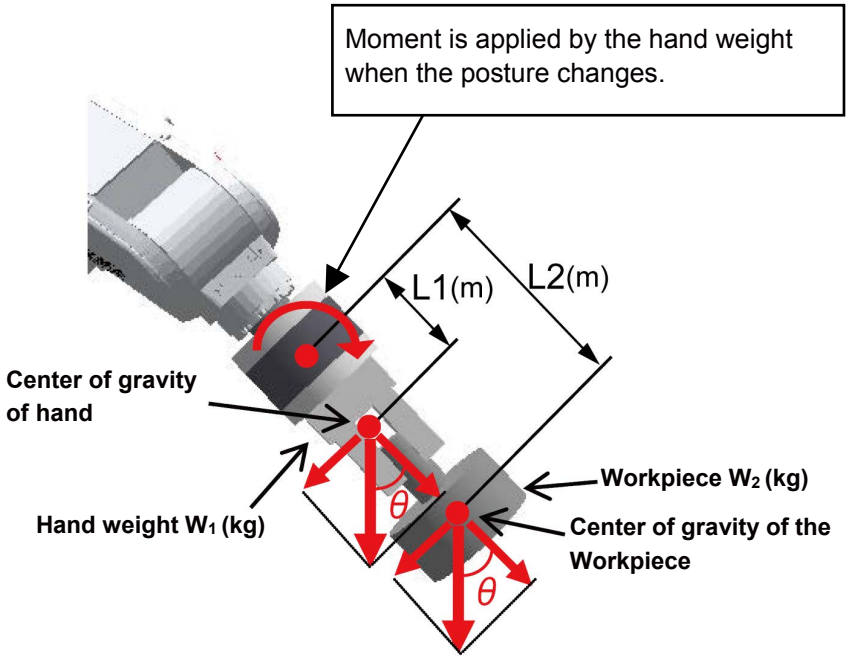


Moment around force sensor coordinate origin (Nm) :

$M = W1 \times L1 \times g + W2 \times L2 \times g - F \times L3$

*g: gravity acceleration (m/sec^2)

b) When the center of gravity position of the hand is at the force sensor center



Moment around force sensor coordinate origin (Nm) :

$$M = W_1 \times \sin\theta \times L_1 \times g + W_2 \times \sin\theta \times L_2 \times g$$

*g: gravity acceleration (m/sec^2)

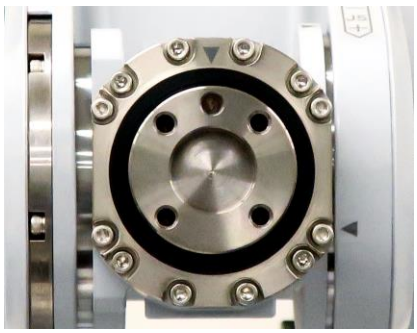
Chapter 2 Attaching the Force Sensor

A dedicated "sensor attachment adapter" is required to fix the force sensor to the robot.
Attach the sensor attachment adapter to the robot mechanical interface before installing the force sensor.
After installing the force sensor, it is necessary to define the relation between the force sensor coordinate system and robot coordinate system in the parameter setting.

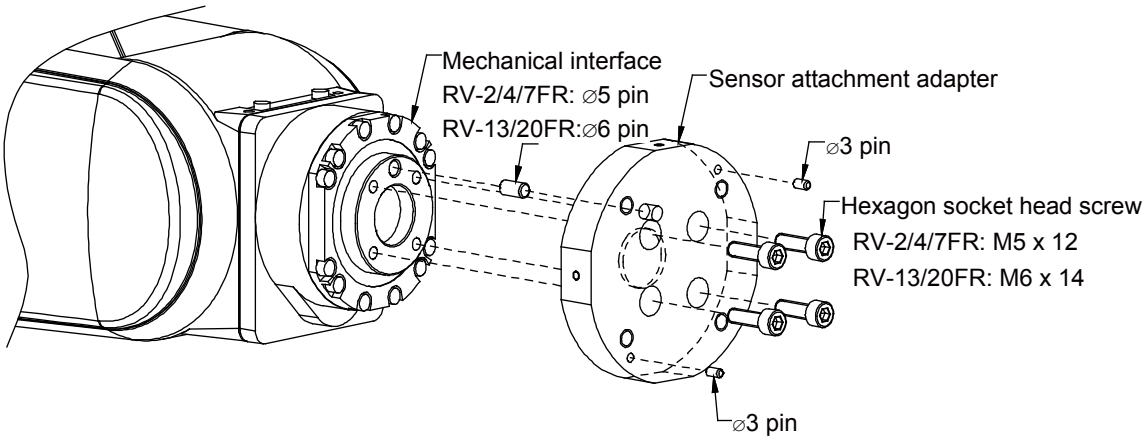
2.1 Attaching the Sensor Attachment Adapter

Attach the sensor attachment adapter to the robot mechanical interface with the following method.

Mechanical interface



Attaching method of the sensor attachment adapter

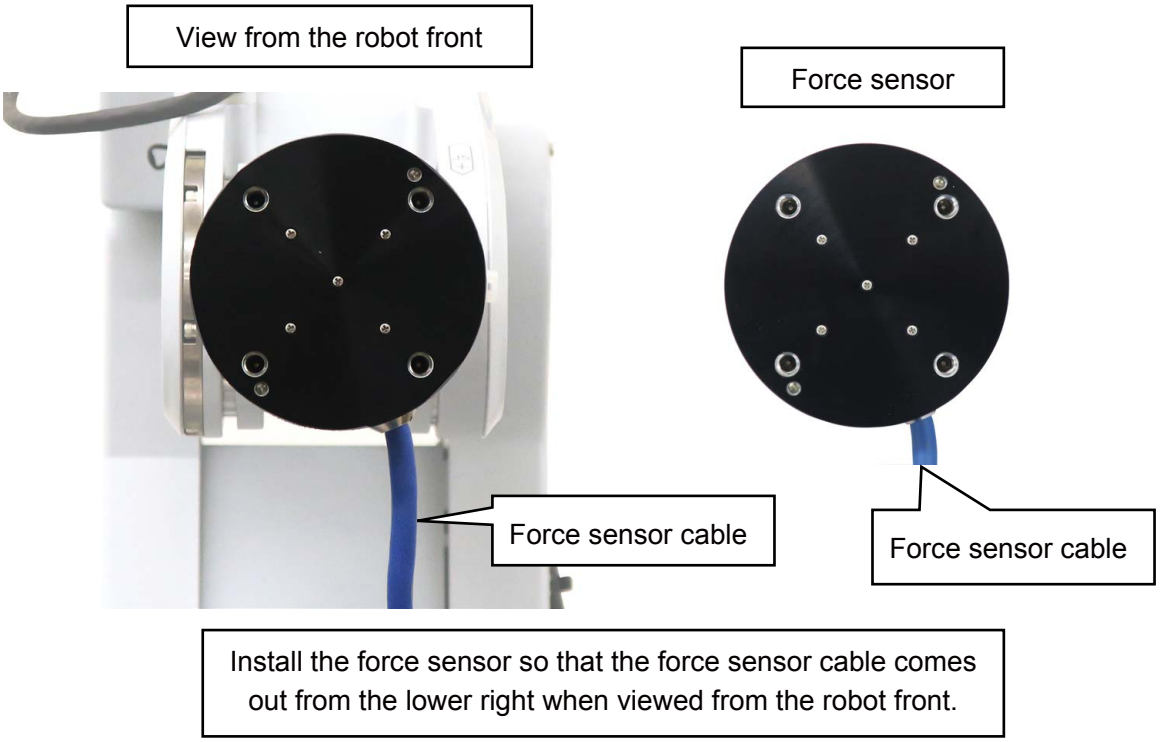


2.2 Install the Force Sensor

After attaching the sensor attachment adapter, install the force sensor.

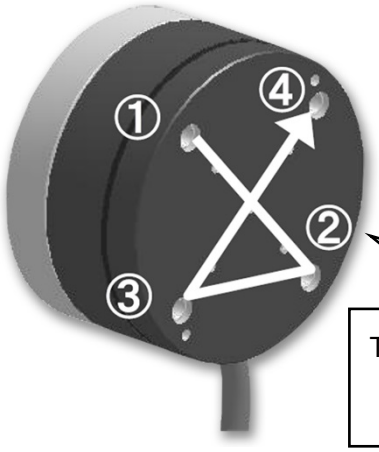
(1) Installing direction

Install the force sensor so that the force sensor cable comes out from the lower right as the following picture shows when viewed from the robot front.



(2) Fixing method

The force sensor is secured by tightening the bolts built in to the sensor from the bolt holes on the force sensor tool side. Tighten each bolt in diagonal order little at a time to ensure even contact between the sensor installation surface and sensor attachment adapter.（Figure (1) to (4) below）
Note that the sensor may be damaged if any of the bolts are overly tightened at once.
Always tighten each bolt a little at a time until the recommended torque value is reached (See below).

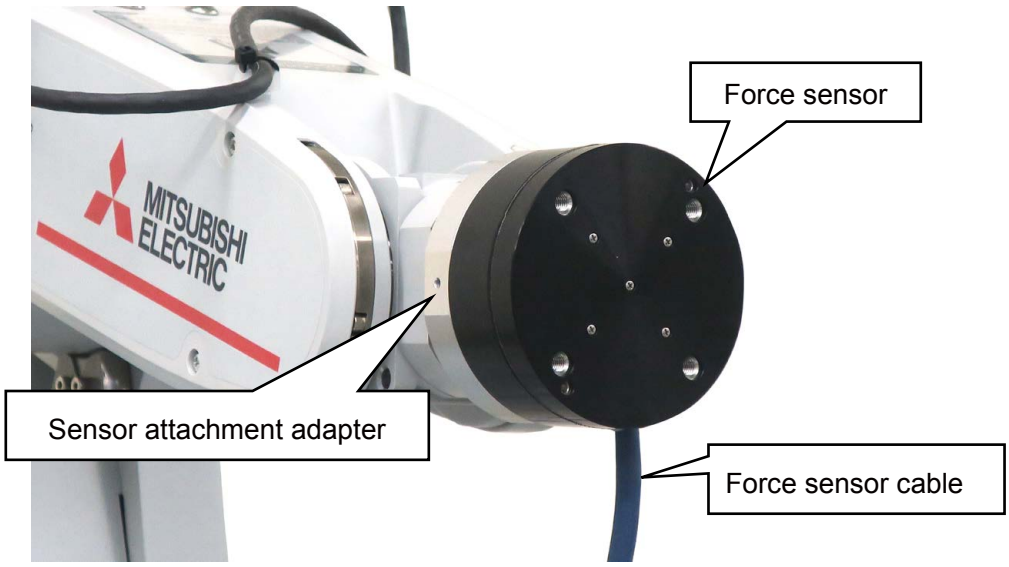


Force sensor	Tightening torque [Nm]
1F-FS001-W200	6
1F-FS001-W1000	10

Tighten each bolt in diagonal orders gradually until the torque reaches the recommended tightening torque (described above).

(3) Checking the force sensor installation condition

The following figure shows the sensor attachment adapter and force sensor after the installation.

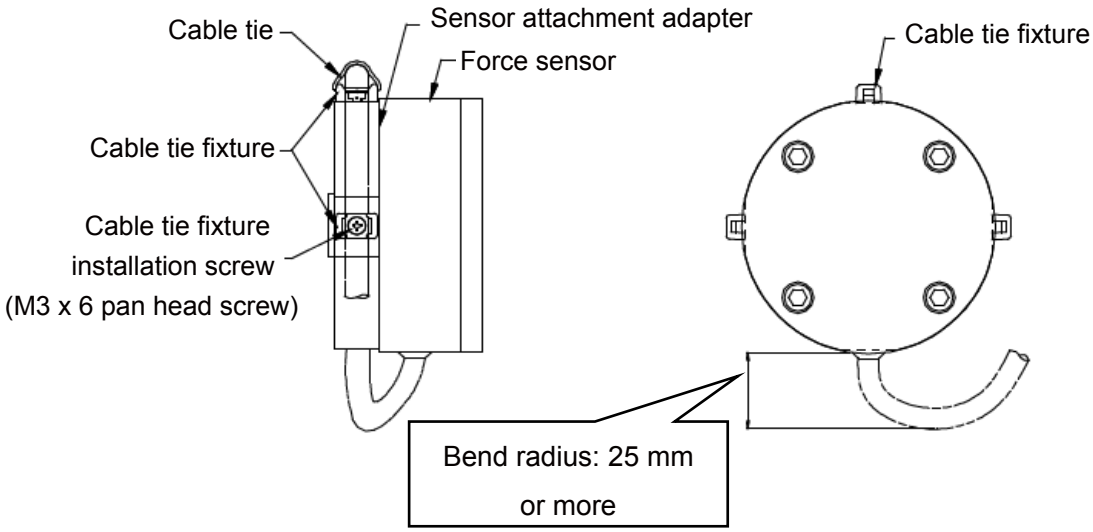


2.3 Fixing the force sensor cable

Fix the force sensor cable to the force sensor attachment adapter.

1) Mount a cable tie fixture (attachment) on the sensor attachment adapter with cable tie fixation screw (attachment).
2) Connect the force sensor cable to the hand cable or serial cable between unit and sensor.
3) Fix the cable with the cable tie and cable tie mount so that bend radius of the force sensor cable becomes 25 mm or more.

* Ensure that the force sensor cable and connector are not subject to bending forces.

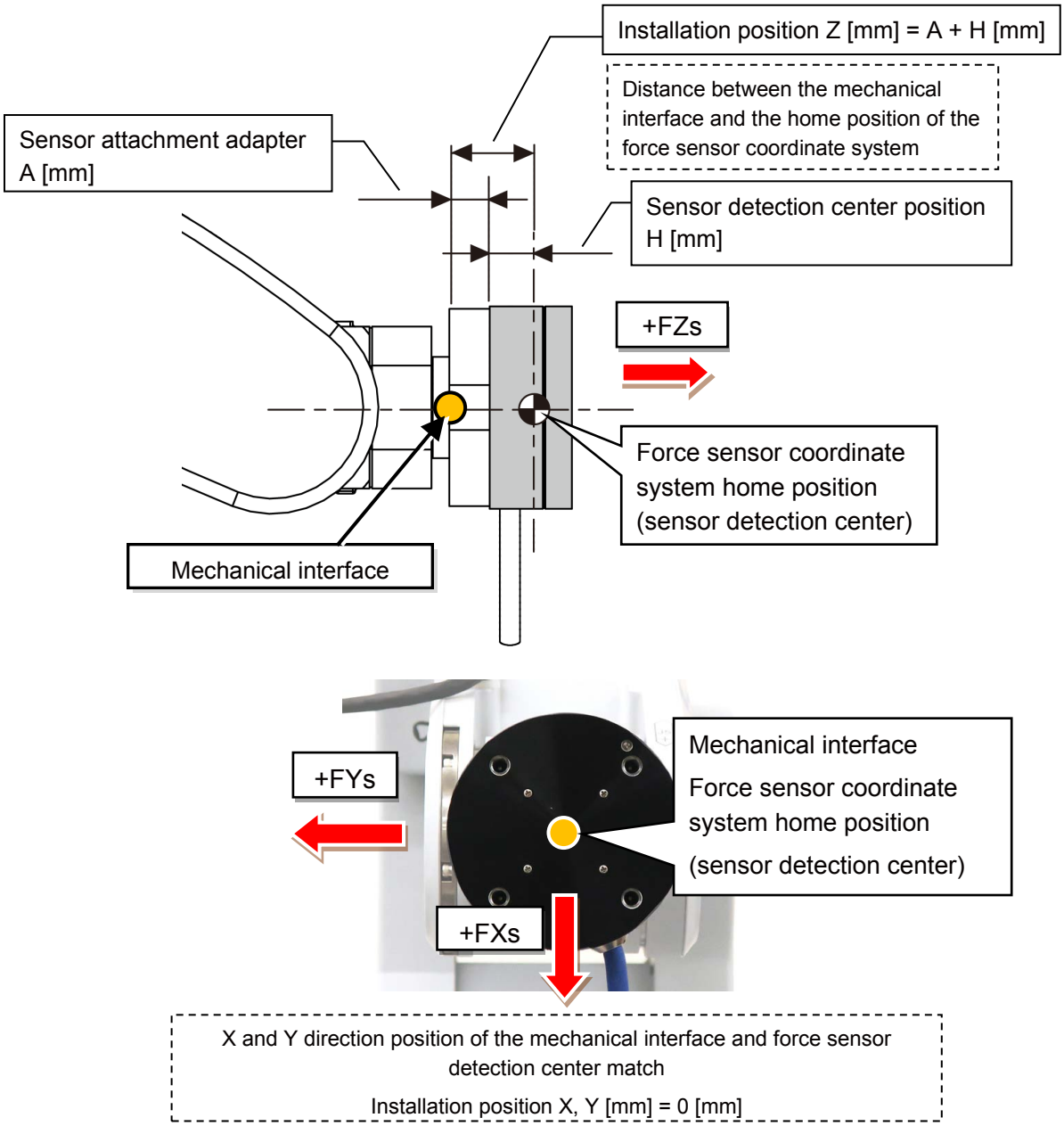


[Note for cable wiring]
If the force sensor cable is not fixed to the force sensor attachment adapter, the force sensor reacts to the external force applied to the cable when the robot is operated, and proper control cannot be performed.

2.4 Relation Between Parameter Installation Position and Angle (FSXTL)

(1) Installation position

For the installation position (FSXTL), set the position relation of the force sensor coordinate system from the mechanical interface coordinate system of the robot in the force sensor parameter setting. When using 1.1 (3) Sensor Attachment Adapter External Dimensions, the installation position is as follows.



(When using the sensor attachment adapter described in 1.1 (3))

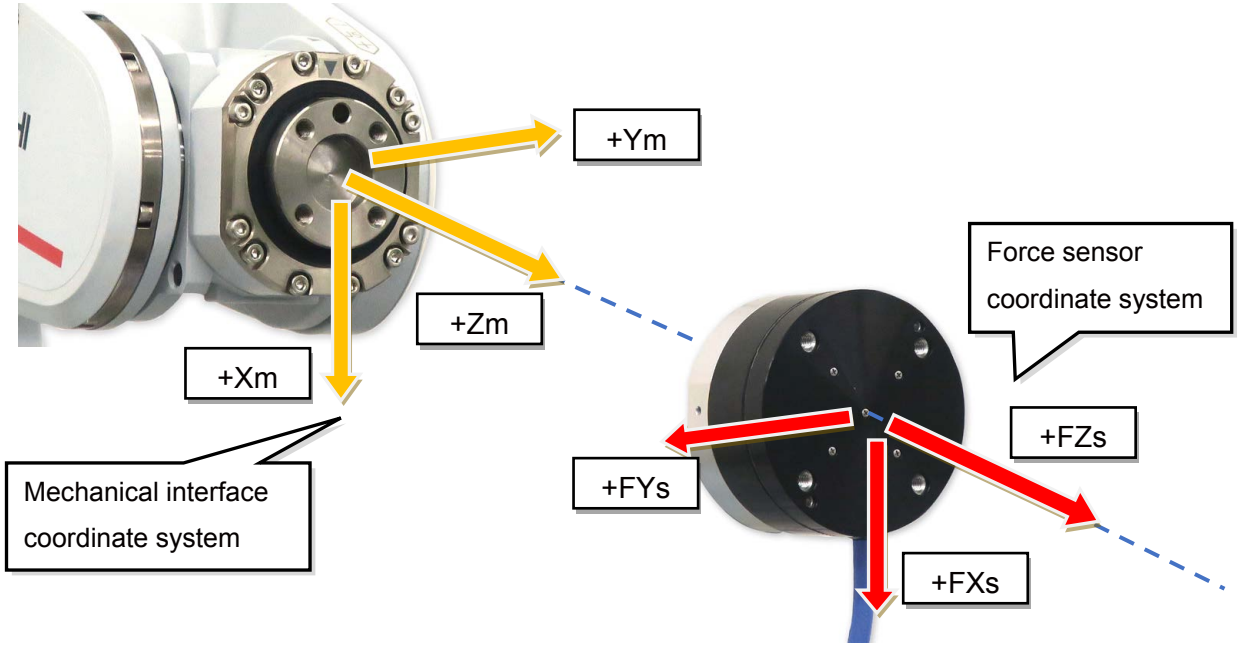
Parameter installation position (FSXTL)

Force sensor	H[mm]	A[mm]	Installation position (FSXTL) [mm]		
			X	Y	Z
1F-FS001-W200	18	14	0	0	32
1F-FS001-W1000	20		0	0	20＋A(Note 1)

Note 1: A is the thickness (mm) of the sensor attachment adapter

(2) Installation angle

For the installation angle (FSXTL), set the rotation angle of the force sensor coordinate system for the mechanical interface coordinate system in the force sensor parameter setting.
When installing in the direction described in "2.2 Install the Force Sensor", the installation angle is as follows.



Rotation angle of the force sensor coordinate system for the mechanical interface
Y axis rotation direction = B [deg] = 180 [deg]

Parameter installation angle (FSXTL)

(When installing in the direction described in "2.2 Install the Force Sensor")

Force sensor	Installation angle (FSXTL) [deg]		
	A (X axis rotation)	B (Y axis rotation)	C (Z axis rotation)
1F-FS001-W200	0	180	0
1F-FS001-W1000	0	180	0

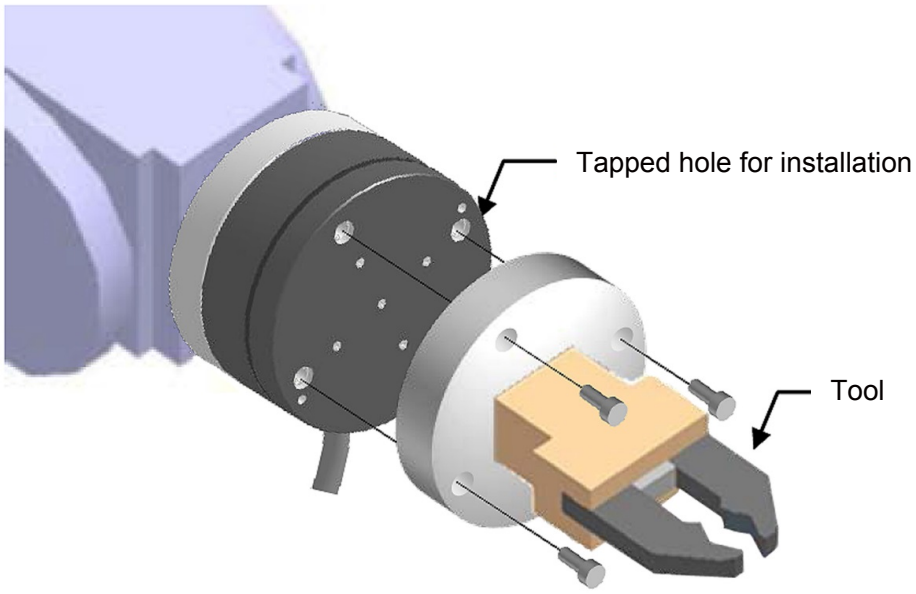
2.5 Tool installation

Install the hand to the tool side of the force sensor.
Select the bolt whose specifications are described below and tighten it little by little so that installation surfaces contact evenly.

Force sensor model	Nominal diameter	Tightening torque [Nm]	Engagement allowance [mm]
1F-FS001-W200	M6	6	8 to 11
1F-FS001-W1000	M6	10	10 to 15

[Caution]

- Ensure that the hand attachment surface is as flat as possible and ensure sufficient stiffness to avoid any loss in force or moment.
- Do not install the tool or wire cables in a way that interferes the movement of the force sensor movable parts.



⚠ Caution

For fixing the tool, do not apply the load equal to or beyond the rated load (especially the moment load) to the force sensor. When a load beyond the rated load is applied repeatedly, distortion occurs gradually inside the sensor. Therefore, the force cannot be detected precisely.

⚠ Caution

There are some hands equipped with air supply cables and/or power supply cables. Attaching them to the tool side of the force sensor will cause the cables to be swung, resulting in generation of a centrifugal force, which may adversely affect the accuracy of obtained force data. The accuracy of the data may also be affected by the weight of the cables. Take appropriate measures, such as fixing the cables to the sensor attachment adapter.

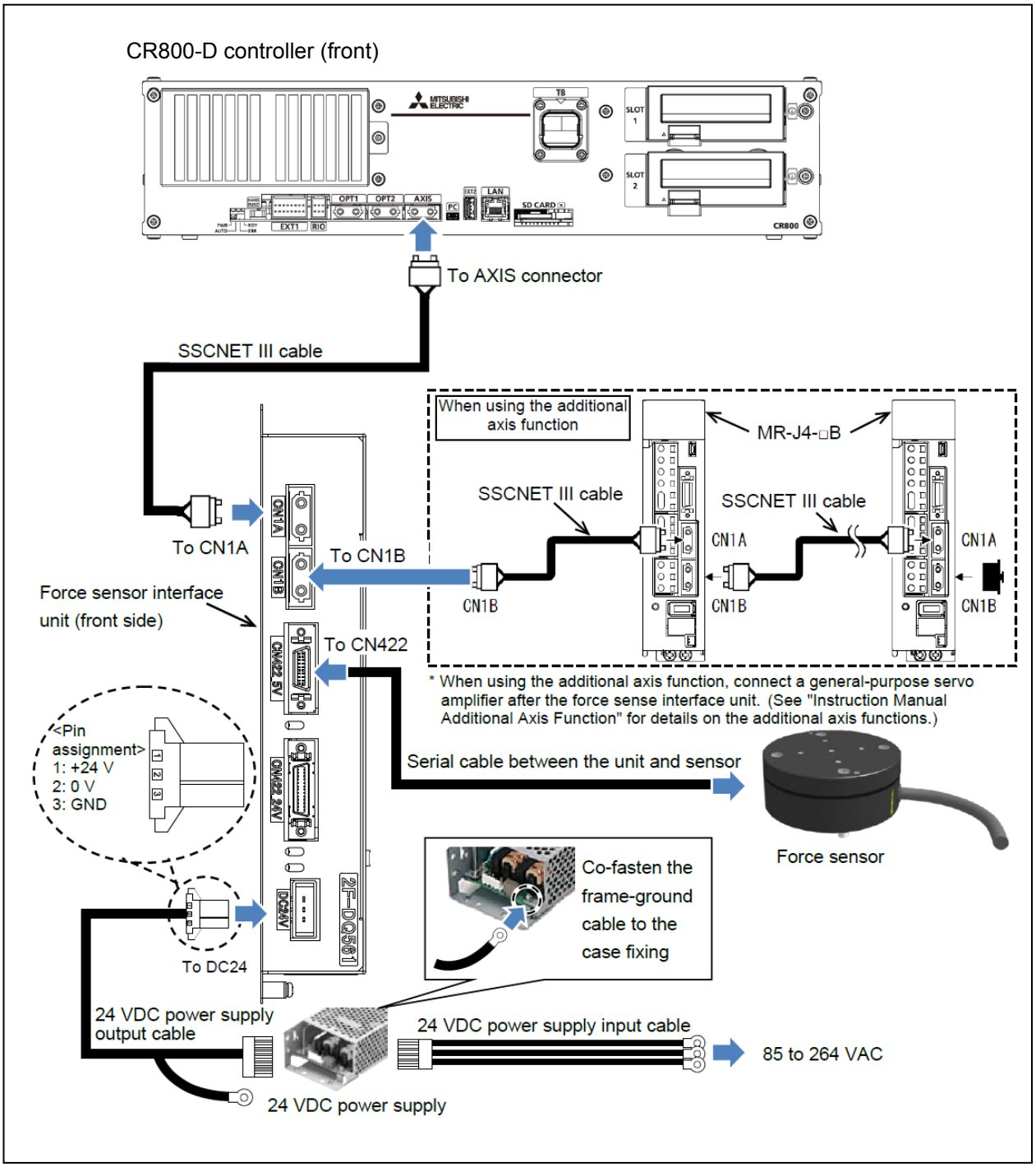
Chapter 3 Device Connection and Wiring

3.1 Force Sense Interface Unit ⇔ Robot Controller

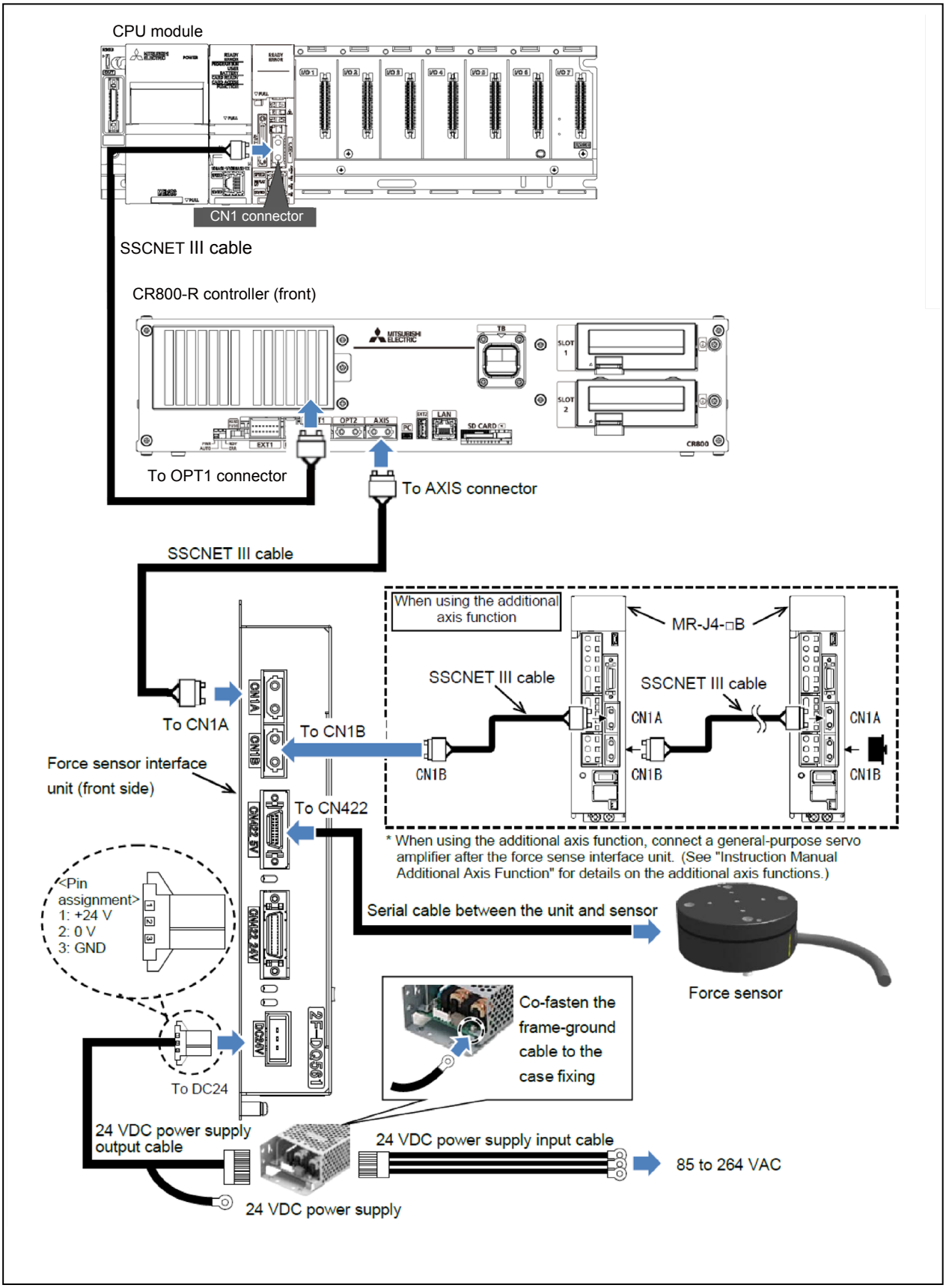
Connect the force interface unit and robot controller.

(1) FR series

(a) CR800-D controller

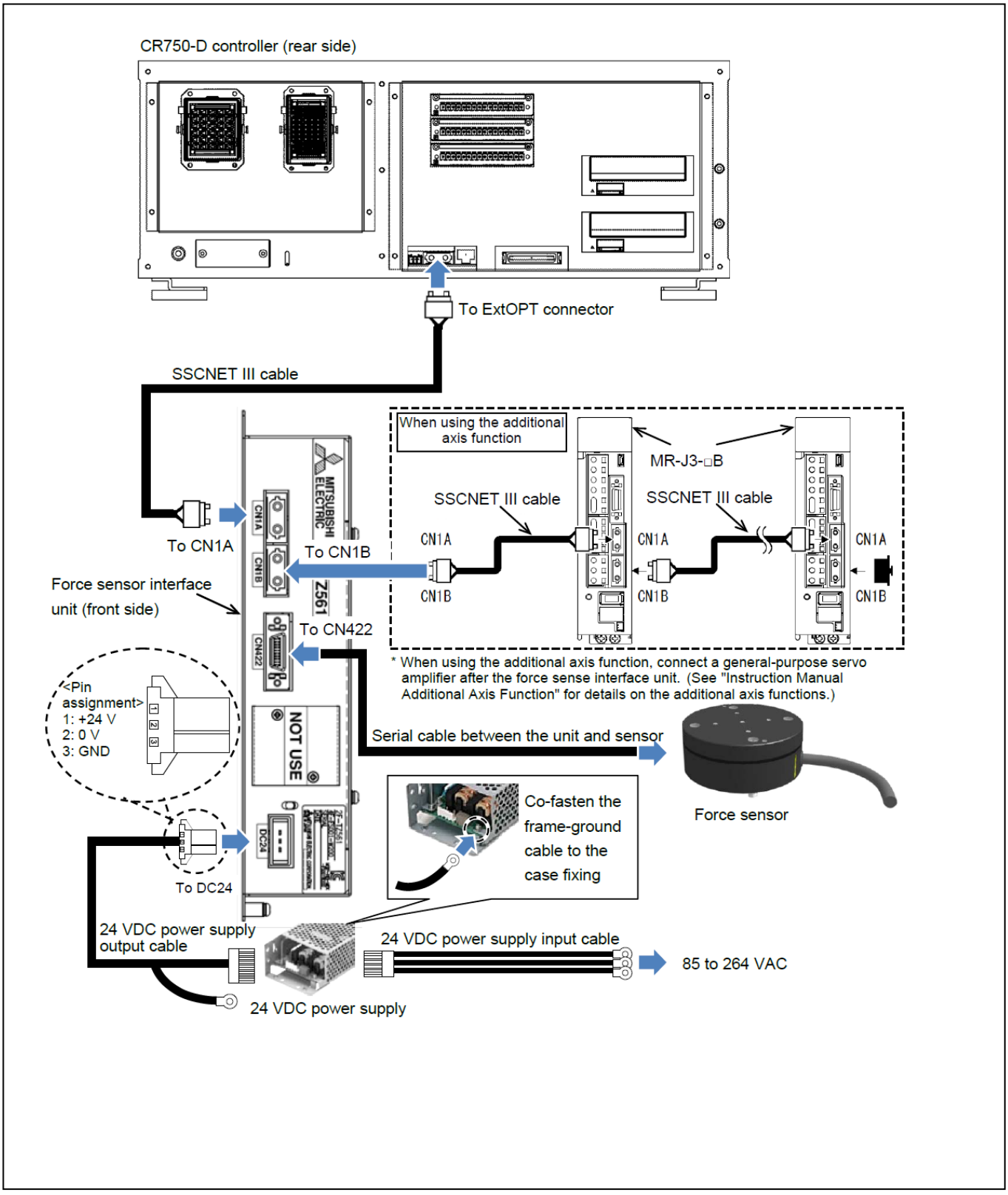


(b) CR800-R controller

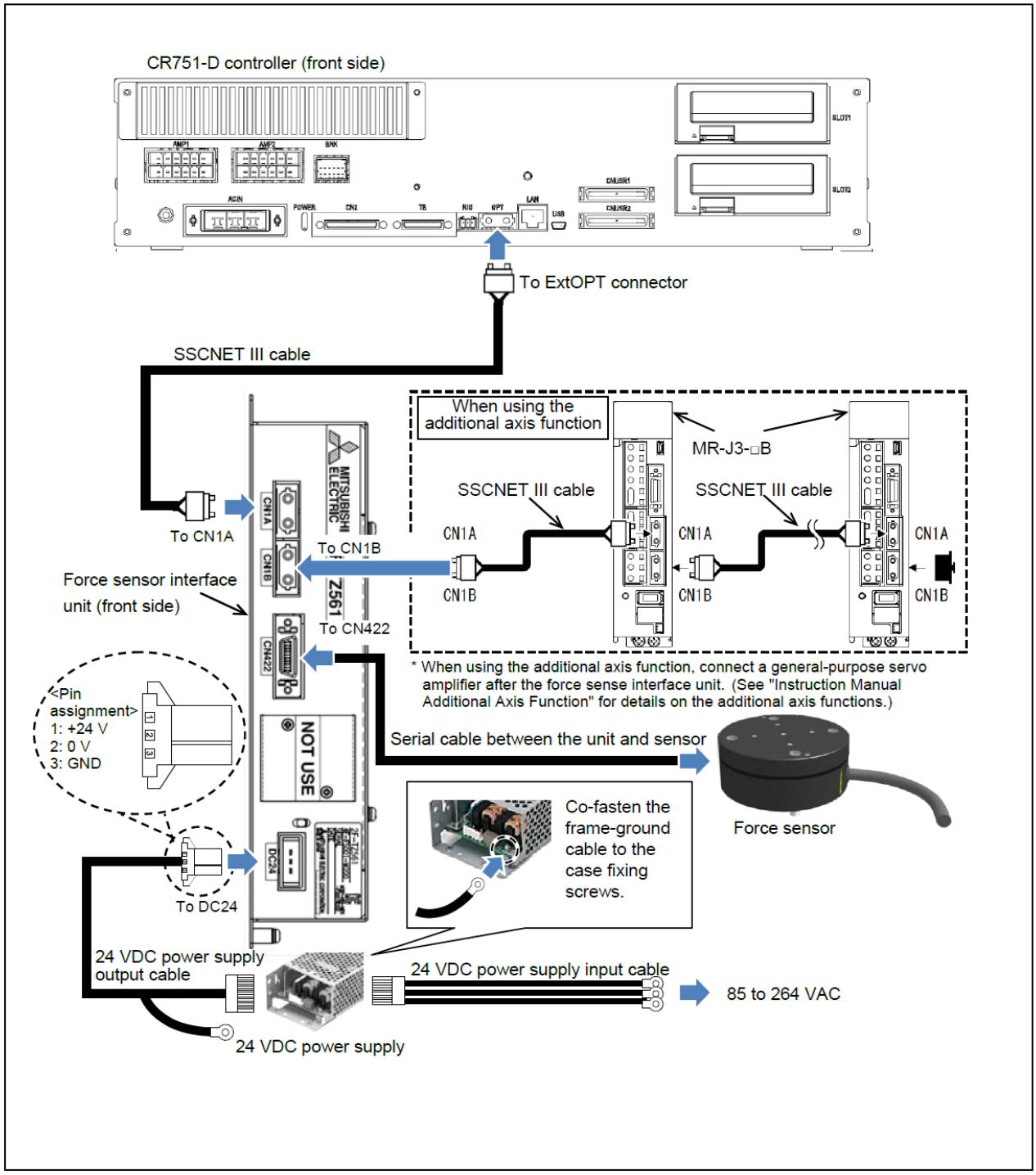


(2) F series

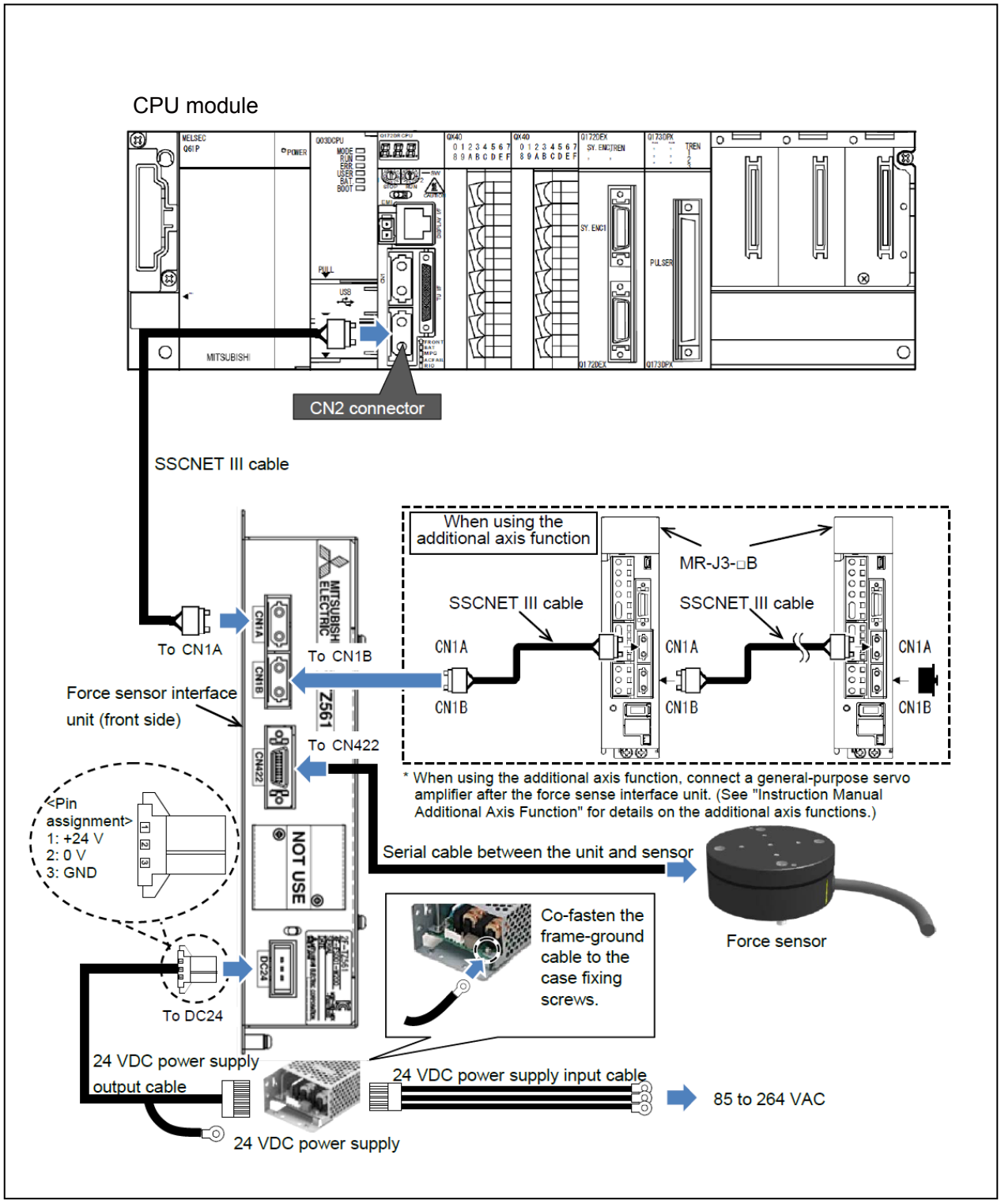
(a) CR750-D controller



(b) CR751-D controller



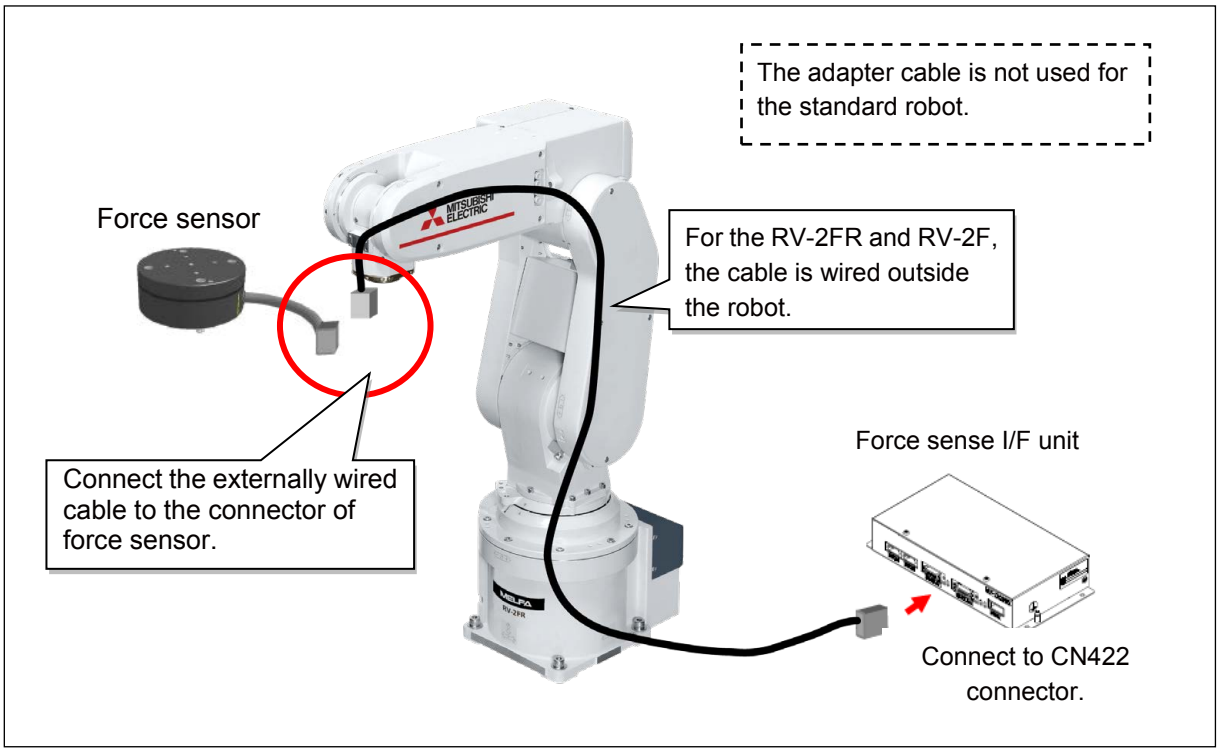
(c) CR750-Q/CR751-Q controller



3.2 Force Sense Interface Unit ⇔ Force Sensor

Connect the force sense interface unit and force sensor.
The cable for the RV-2FR and RV-2F is wired outside the robot (figure below).

Standard robot + wire externally (external wiring)



There are three methods for connecting the force sense interface unit and force sensor.
For other two connection methods, refer to "Appendix 1 Connecting the Force Sensor Appendix 1.1 Connecting the Force Sensor and the Force Sense Interface Unit"

3.3 Power ON/OFF

Turn ON the power only after checking that the force sense interface unit, robot controller, and force sensor have been properly connected. Turn the power ON and OFF in the following order.

(1) When turning the power ON

Turn ON the power to the force sense interface unit followed by the robot controller.

(2) When turning the power OFF

Turn OFF the power to the robot controller followed by the force sense interface unit.

(There is no need to turn OFF the force sense interface unit power if only the controller is ON.)

⚠Caution

Do not disconnect the SSCNET III cable after turning ON the power. Furthermore, do not look directly at the light from the end of the SSCNET III connector or SSCNET III cable. Some discomfort may be experienced with direct exposure. (The SSCNET III light source is equivalent to the Class 1 source specified in JISC6802, IEC60825-1.)

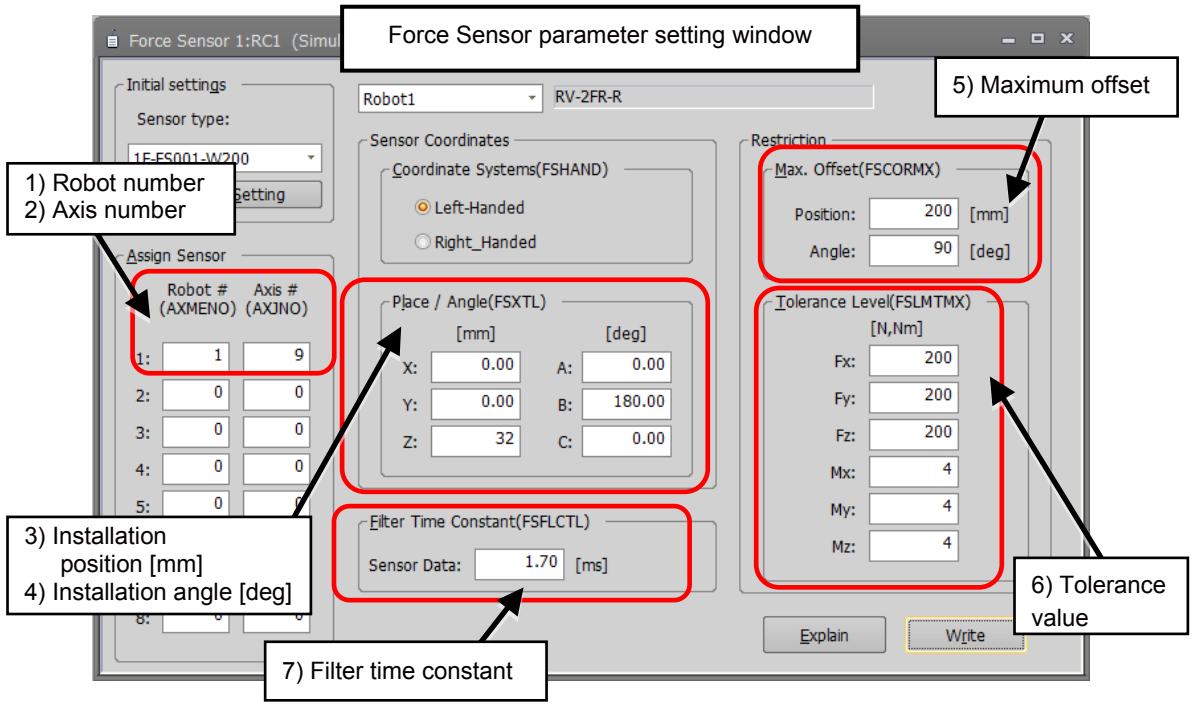
Chapter 4 Parameter Setting

The correlation of the force sensor coordinate system and robot coordinate system needs to be defined in the parameter setting.
After turning ON the power, set the parameters with RT ToolBox3.
After setting the parameters, restart the controller. The setting value will be reflected by restarting.

4.1 Force Sensor Parameter Setting

In the parameter setting window of RT ToolBox3, set the force sensor parameter, control mode, and control characteristics.
For the force sensor installed by the step in Chapter 2, input the value of the following setting example.

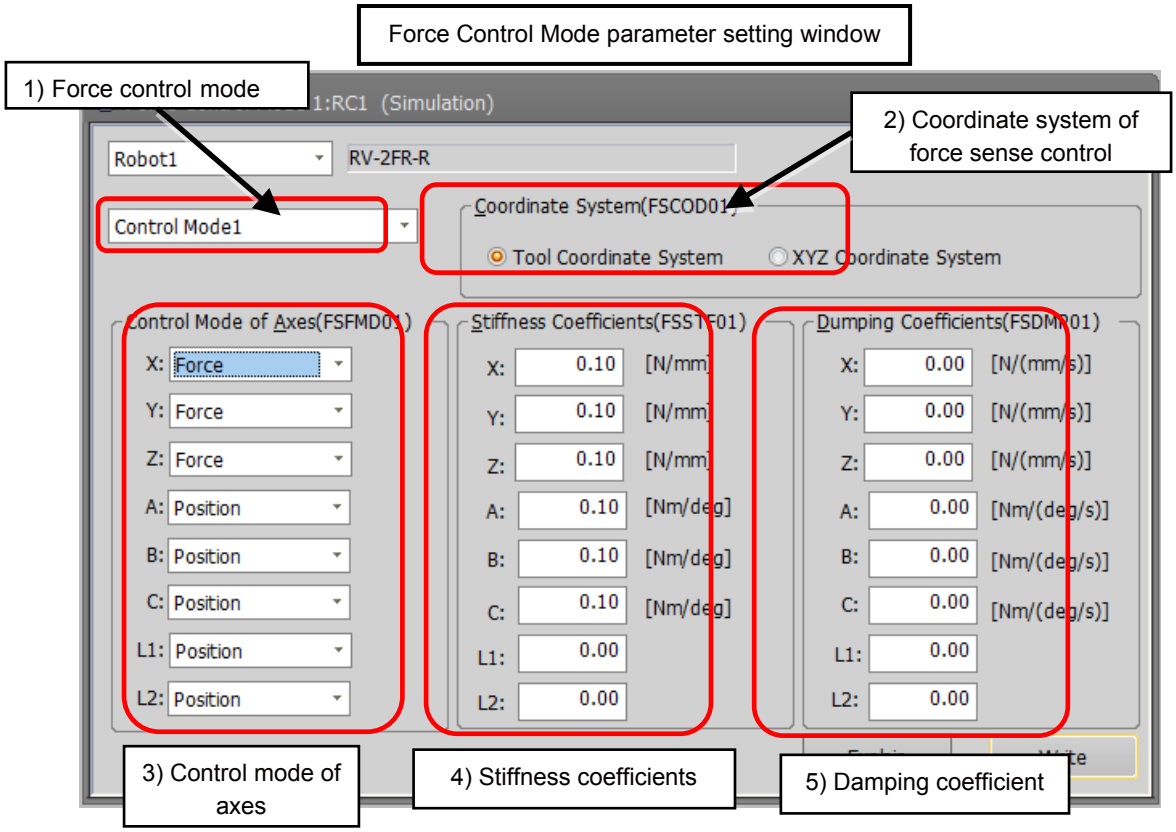
(1) Force sensor parameter



Setting example

	Item		Setting value	Description
1)	Robot # (AXMENO)		1	1…Robot arm
2)	Axis # (AXJNO)		9	9…Axis 9 of the robot
3)	Place [mm] (FSXTL)	X	0	Distance between the mechanical interface coordinate system and force sensor detection position
		Y	0	
		Z	32	
4)	Angle [deg] (FSXTL)	A	0	Rotation angle of the force sensor coordinate system for the mechanical interface coordinate system
		B	180	
		C	0	
5)	Max. Offset (FSCORMX)	Position	200	A value to limit the travel distance from the position where the force sense is enabled
		Angle	90	
6)	Tolerance Level (FSLMTMX)	Fx, Fy, Fz	200	Tolerance value of the force sensor (this example is for 200 N specifications)
		Mx, My, Mz	4	
7)	Filter Time Constant (FSFLCTL)		1.70	Set this when the sensor data is not stable or the robot vibrates during the force sense control

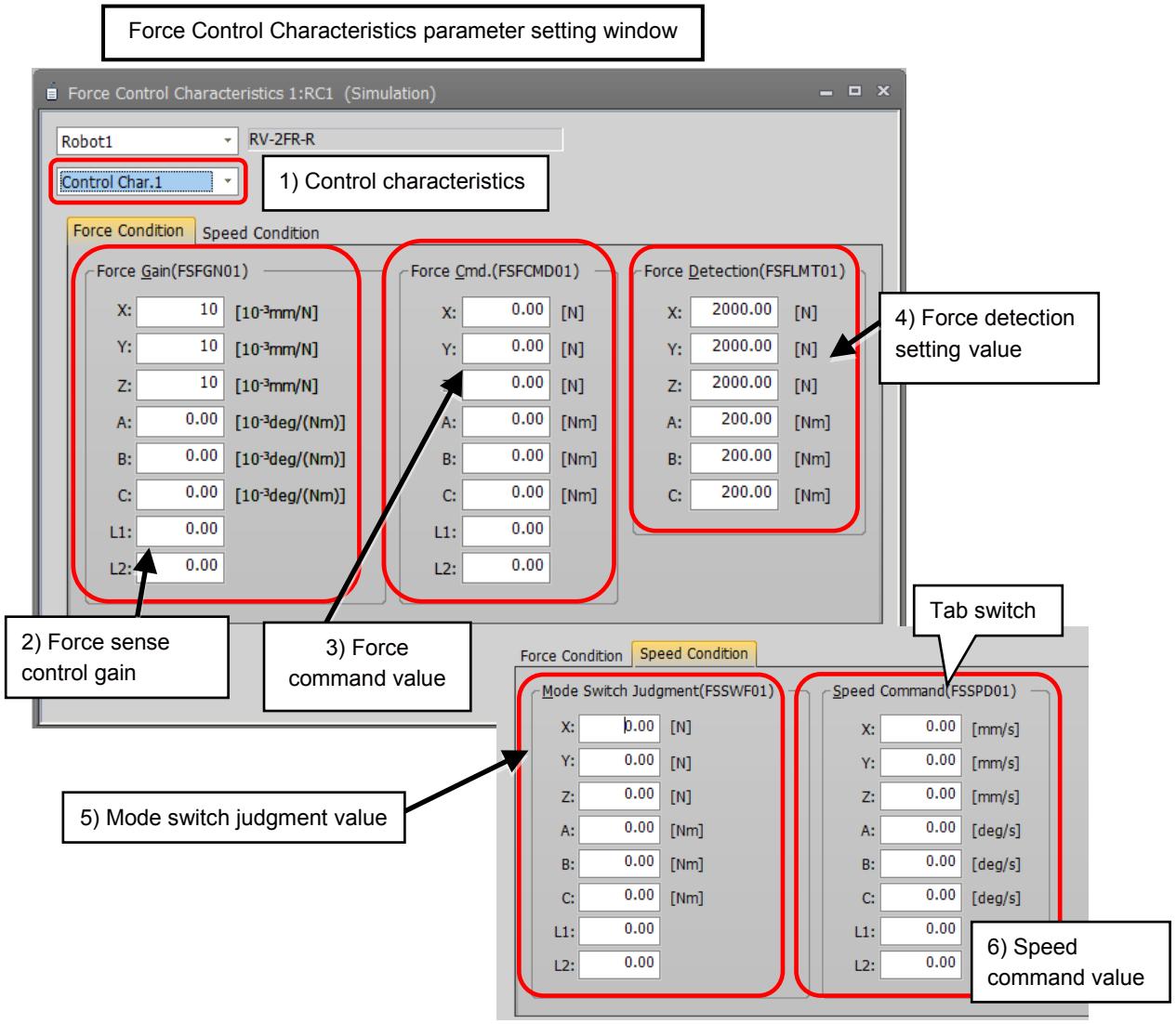
(2) Force control mode



Setting example

	Item		Setting value	Description
1)	Control mode		Control mode1	
2)	Coordinate system (FSCOD01)		Tool Coordinate System	Specify the force control coordinate system.
3)	Control mode of axes (FSFMD01)	X, Y, Z	Force control	Specify the force sense control mode of each axis in the coordinate system.
		A, B, C, L1, L2	Position	
4)	Stiffness coefficient (FSSTF01)	X, Y, Z, A, B, C	0.10	Setting value for axis flexibility (stiffness coefficient). The higher the value is, the stiffer the axis is.
		L1, L2	0	
5)	Damping coefficient (FSDMP01) (X, Y, Z, A, B, C, L1, L2)		0	Setting of the axis response characteristics (damping coefficient). Adjust this when the robot vibrates at contact.

(3) Force control characteristics



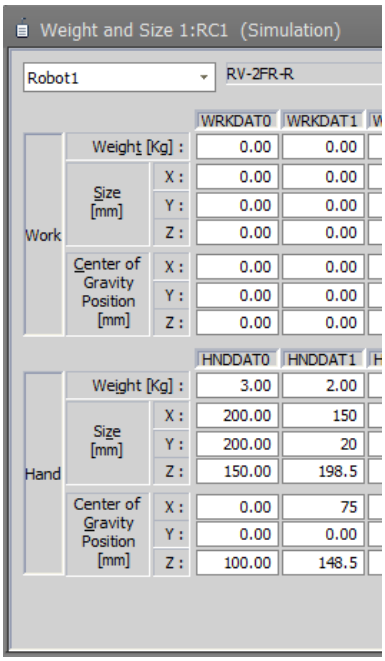
Setting example

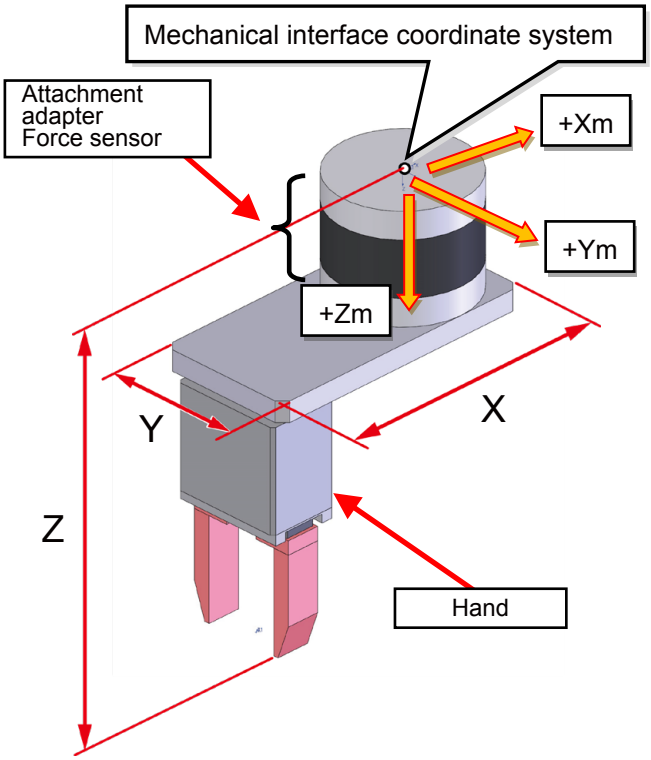
	Item		Setting value	Description
1)	Force control characteristics		Control char.1	
2)	Force Gain (FSFGN01)	X, Y, Z	10	Setting of the axis response sensitivity. Adjust depending on the stiffness of the target.
		A, B, C, L1, L2	0	
3)	Force Comd. (FSFCMD01)	X, Y, Z, A, B, C, L1, L2	0	Specify the pushing force at force control (force priority mode).
4)	Force Detection (FSFLMT01)	X, Y, Z	2000	Used for the force sense detection and contact detection function.
		A, B, C	200	
5)	Mode Switch Judgment (FSSWF01)	X, Y, Z, A, B, C, L1, L2	0	Setting for switching judgment value of the speed/force control mode. Valid when the speed command value is set.
6)	Speed Command (FSSPD01)	X, Y, Z, A, B, C, L1, L2	0	Specify the movement speed at no contact in force control (speed priority mode).

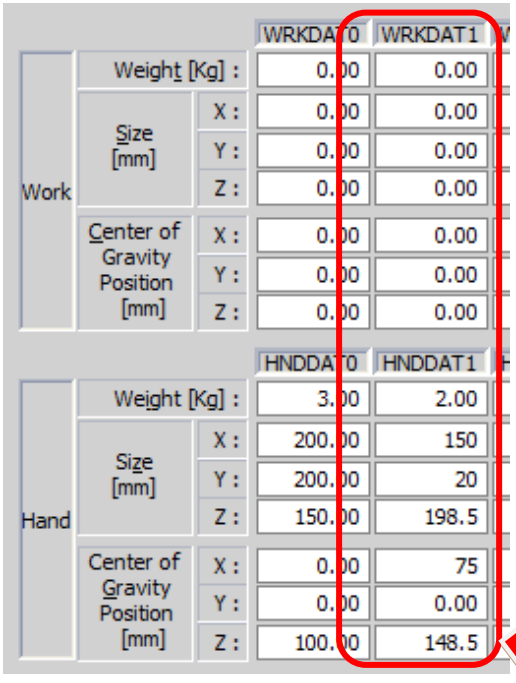
4.2 Hand Parameter Setting

Set the parameters for the weight, size, and center of gravity position of the hand in the parameter setting window of RT ToolBox3.
For the size, input the total size of the actual hand, force sensor, and attachment adapter. Input the maximum size in X, Y, or Z direction, not the specific value. (Rectangular parallelepiped)
Input the center of gravity position from the mechanical interface coordinate system when setting it.

Weight and size parameter setting window







<Setting example>

Size of hand:

X = 150 mm, Y = 20 mm, Z = 150 mm

Attachment adapter: Z = 16 mm

Force sensor: Z = 32.5 mm

Center of gravity position of hand:

X = 75 mm, Y = 0 mm, Z = 100 mm

Total weight (hand + attachment adapter + force sensor): 2 kg

Set the parameter as shown in the left (HNDDAT1).

When setting this parameter, set the center of gravity position carefully.

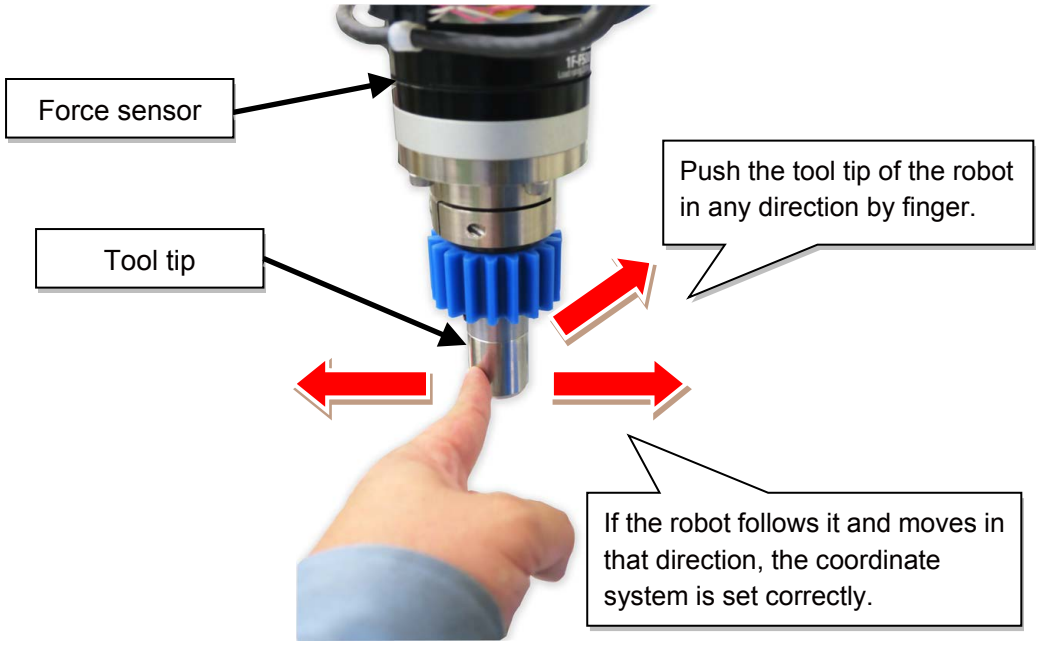
4.3 Connection and Setting Check

Before using the force sense function, check that the force sensor data is set in the correct coordinate system.

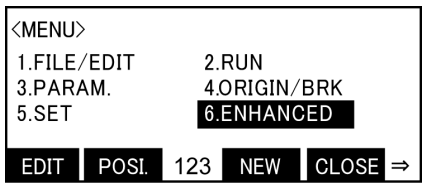
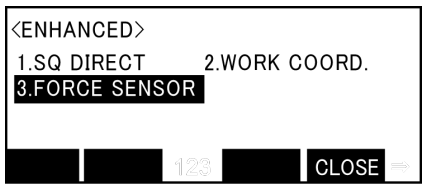
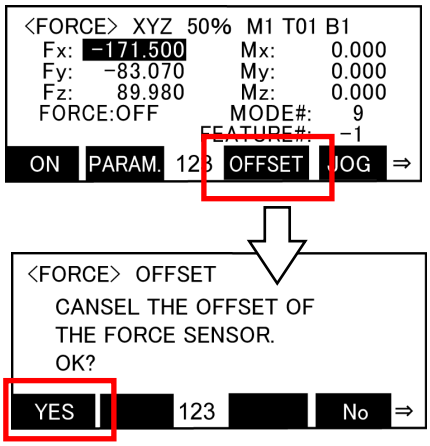
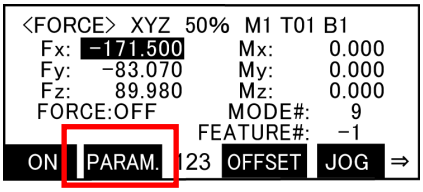
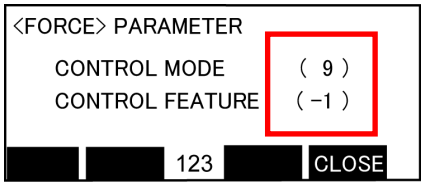
(1) Checking the coordinate system

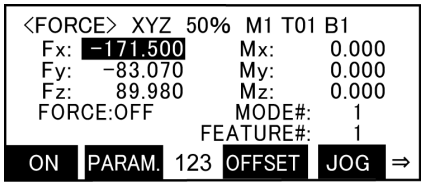
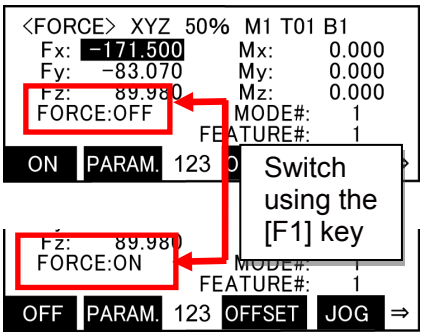
Push the tip of the tool in any direction by finger to check that the robot follows it.

1) Enable the offset cancel with the teaching box.
   (For the offset cancel, refer to "Chapter5 5.4 (12) Offset cancel designation".)
2) Set the control mode to 1, and control characteristics to 1.
   (Select the number of control mode and control characteristics set in "Chapter4 4.1 Force Sensor Parameter Setting".)
3) Turn ON the servo and enable the force sense control.
4) Push the tool tip of the robot in any direction by finger.
   Check if the robot follows it and moves in that direction. If the coordinate system is set correctly, the robot follows it.
5) If the robot does not follow, check the setting of the parameter, control mode, and control characteristics.



a) Enable offset cancel →select control mode and control characteristics → turn ON servo → force sense function enabled

Step	How to operate	T/B screen	Description of the operation method
1	+A (J4) 6 MON	<Menu screen>  	Push the [6] key ("ENHANCED") in the <MENU> screen to display the <ENHANCED> screen.
2	+Z (J3) 3 DEF	<Enhanced screen>  	Push the [3] key ("FORCE SENSOR") and display the <FORCE> screen.
3	F3 ↓ F1	<Force screen>  	First, enable the offset cancel. Push the [F3] key in the <FORCE> screen. When the offset cancel confirmation screen is displayed, press the [F1] key ("Yes"). For the offset cancel, refer to "Chapter5 5.4 (12) Offset cancel designation".
4	F2	<Force screen>  	Next, specify the number for "CONTROL MODE" and "CONTROL FEATURE". Press the [F2] key ("PARAM") in the <FORCE> screen.
5	Arrow key Number key	<Force Parameter screen>  	Specify the numbers for "CONTROL MODE" and "CONTROL CHARACTERISTICS". Return to the <FORCE> screen by pressing the [F4] key ("CLOSE").

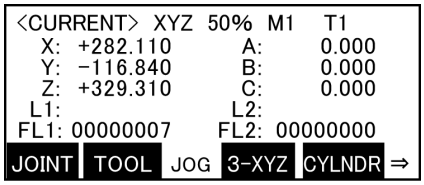
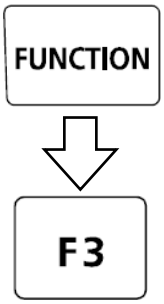
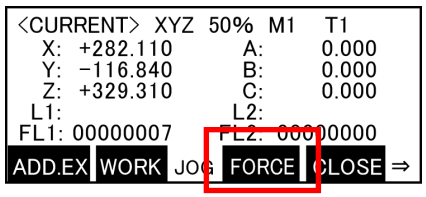
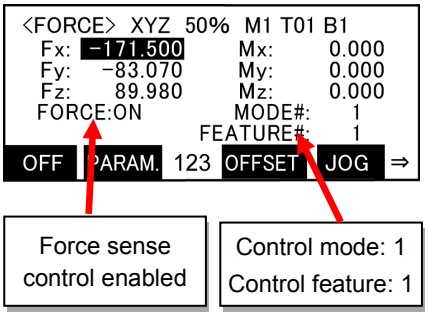
Step	How to operate	T/B screen	Description of the operation method
6		<Force screen> 	Press the [SERVO] button to turn ON the servo. (The control mode is set to "1", and control feature to "1" as an example.)
7		<Force screen> 	Press the [F1] key in the <FORCE> screen to enable the force sense control (FORCE: ON). Press the [F1] key to enable/disable ("ON/OFF") the force sense control.

(2) Display the force sensor data (force sense monitor)

The current value of the force sensor can be displayed on the force screen of the teaching box.

- The coordinate system for the displayed sensor data is based on the force sensor coordinate system set for the "control mode".
- When the displayed value does not change even the force is applied to the force sensor, there may be a problem in the connection and parameter setting of the device. Check the connection and settings again.

a) Display current value of the force sensor on teaching box

Step	How to operate	T/B screen	Description of the operation method
1		<JOG operation screen> 	Press the [JOG] key to display the JOG operation screen.
2		<JOG operation screen> 	Press the [FUNCTION] key and display "FORCE" as the function menu at the bottom of the screen. Press the [F3] key ("FORCE") and display the <FORCE> screen.
3		<Force screen Current value> 	The current value of the force sensor data is displayed. The force sensor enable (ON)/disable (OFF), control mode, and control feature are displayed below the current value.

4.4 Details of Force Sensor Parameter

■Force sensor parameter list

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sense interface unit recognition	AXJNO	16 integers	Assigns the force sense interface unit connection. Refer to: Chapter4 4.4 (1) Robot number (AXMENO), axis number (AXJNO)	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
	AXMENO	16 integers		0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Calibration	FSXTL	6 real number	Calibrates the force sensor installation. Refer to: Chapter4 4.4 (2) Calibration	0.0, 0.0, 0.0, 0.0, 180.0, 0.0 (vertical multi-joint robots) 0.0, 0.0, 0.0, 0.0, 0.0, 180.0 (horizontal multi-joint robots)
	FSHAND	1 integer		0
Force sensor tolerance	FSLMTMX	6 real number	Sets the tolerance value of the force sensor. Refer to: Chapter4 4.4 (4) Tolerance value (FSLMTMX)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0
Force sense control offset limit	FSCORMX	2 real number	Sets the "maximum position offset" by the force sense control. Refer to: Chapter4 4.4 (3) Maximum offset value (FSCORMX)	10.0, 10.0
Force sensor data filter	FSFLCTL	1 real number	Sets the filter time constant for the force sense data control. Refer to: Chapter4 4.4 (5) Filter time constant (FSFLCTL)	1.7
Force sensor minimum force control	FSMINCTL	6 real number	Sets the "minimum control force" of the force sensor. (Controller Ver.R6h/S6h and later) Refer to: Chapter4 4.4 (6) Force Sensor Minimum Control Force (FSMINCTL)	0.3, 0.3, 0.3, 0.03, 0.03, 0.03

(1) Robot number (AXMENO), axis number (AXJNO)

It is necessary to set parameters at the robot controller side in order for the robot controller to recognize the force sense interface unit. Set these parameters as follows. (The same parameters as that for the additional axis function are used.)

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Set axis No.	AXJNO	16 integers	Sets the force sense interface unit or additional axis number for the element corresponding to the servo control axis number being used. <If using force sense interface unit> Servo control axis No.: Set "9" for axis No.1.	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Mechanical No. designation	AXMENO	16 integers	Enter a mechanical number corresponding to the servo control axis number being used. Always set "0" for axes that are not being used. <If using force sense interface unit> Servo control axis No.: Set "1" for axis No.1.	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

<If not using additional axis functions>

Set these parameters as follows if not using the additional axis functions.

AXJNO = (9, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)

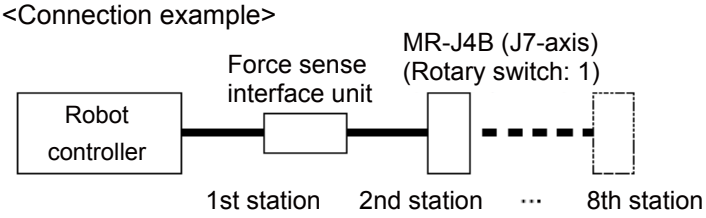
AXMENO = (1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)

<If using additional axis functions>

AXJNO = (9, 7, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)

AXMENO = (1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)

<Connection example>



The 1st station is used by the force sense interface unit, and therefore rotary switch 0 cannot be used for the additional axis (MR-J3B). Set to 1 or onward.

Up to 7 additional axes (from 2nd to 8th stations) can be used.

(2) Calibration

To use the force sense function, it is necessary to define (calibrate) the correlation between the force sensor coordinate system and force sense coordinate system (mechanical interface). Calibration is performed with the following parameter settings.

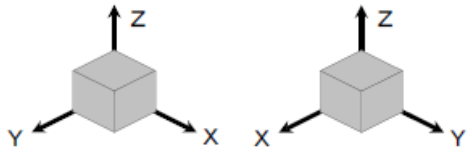
⚠Caution

There is a danger that the robot may move in an unintended direction if the calibration settings are incorrect. After setting the parameters, always check that they have been set correctly by following the procedure in "Chapter4 4.3 Connection and Setting Check".

a) Position/angle (FSXTL)

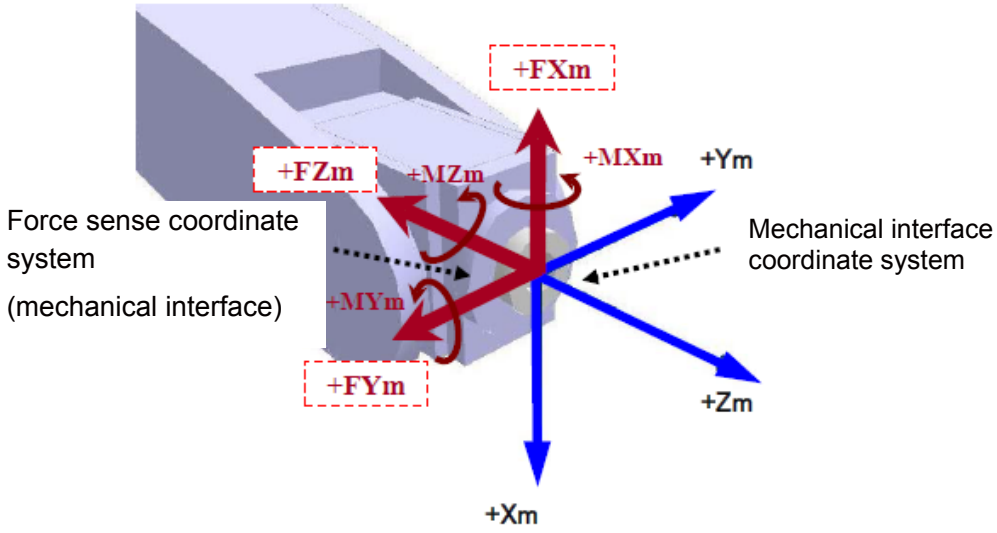
Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sensor attachment position	FSXTL	6 real numbers	Sets the positional relationship for the mechanical interface coordinate system and force sensor coordinate system. 1st element: X-axis direction coordinate system origin offset [mm] 2nd element: Y-axis direction coordinate system origin offset [mm] 3rd element: Z-axis direction coordinate system origin offset [mm] 4th element: Coordinate axis rotation angle around X-axis [deg] 5th element: Coordinate axis rotation angle around Y-axis [deg] 6th element: Coordinate axis rotation angle around Z-axis [deg]	0.0, 0.0, 0.0, 0.0, 180.0, 0.0 (vertical multi-joint robots) 0.0, 0.0, 0.0, 0.0, 0.0, 180.0 (horizontal multi-joint robots)

b) Force sense hand coordinate system (FSHAND)

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sensor coordinate system selection	FSHAND	1 integer	Selects the force sensor coordinate system hand system (left-hand system/right-hand system). The force sensor coordinate system hand system differs depending on the sensor attachment direction, and therefore it is necessary to change the setting based on the attachment direction. Set the left-hand system for recommended attachment. (Refer to Chapter4 4.4 (2) Calibration d) Parameter setting example.) 0: Force sensor coordinate system left-hand system 1: Force sensor coordinate system right-hand system <Left-hand system> <Right-hand system> 	0

c) Coordinate system definition (mechanical interface)

The force sense coordinate system (mechanical interface) is defined as follows.



For the force sense coordinate system (mechanical interface), the positive direction is the one in which the opposite force is applied when the robot moves to the positive direction in the mechanical interface coordinate system.

The home position of the coordinate system overlaps the mechanical interface coordinate system.

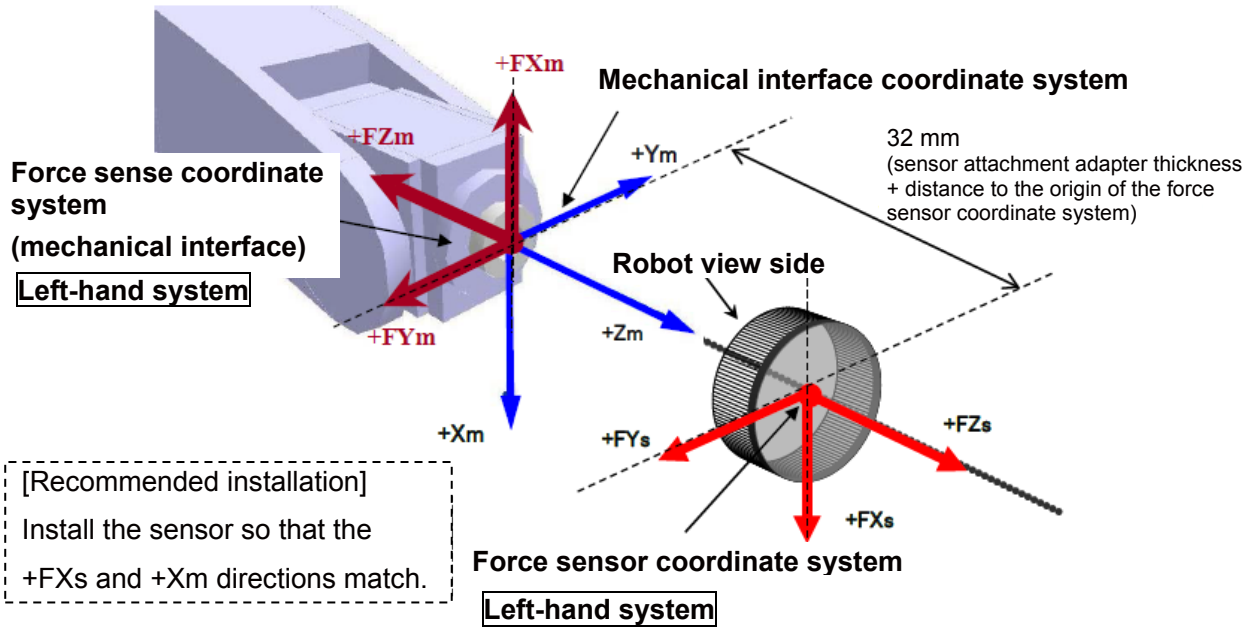
(The sign of force sense coordinate system is the reversed sign of the mechanical interface coordinate system.)

d) Parameter setting example

1) Parameter Setting Example 1 (for Recommended Installation)

When the force sensor is installed in the recommended installation (See below) the parameter settings for elements 1 to 4 for FSHAND and FSXTL will be the default factory settings. Change only elements 1 to 3 for FSXTL. The processing command can be added only to the movement command.

* The following shows a recommended installation method, which is described in "Chapter2 2.2 Install the Force Sensor".



[Coordinate system hand system]

Since the force sensor coordinate system will be the left-hand system, set as follows.
FSHAND = 0 (default)

[Parallel transfer]

Since the force sensor coordinate system home position viewed from the mechanical interface coordinate system is (0, 0, 32), FSXTL is set as follow.

FSXTL 1st element = 0

FSXTL 2nd element = 0

FSXTL 3rd element = +32

[Rotational transfer]

To align the posture of the force sense coordinate system (mechanical interface) and force sensor coordinate system, it is sufficient to rotate +180 degrees around the Ym-axis, and FSXTl is set as follows.

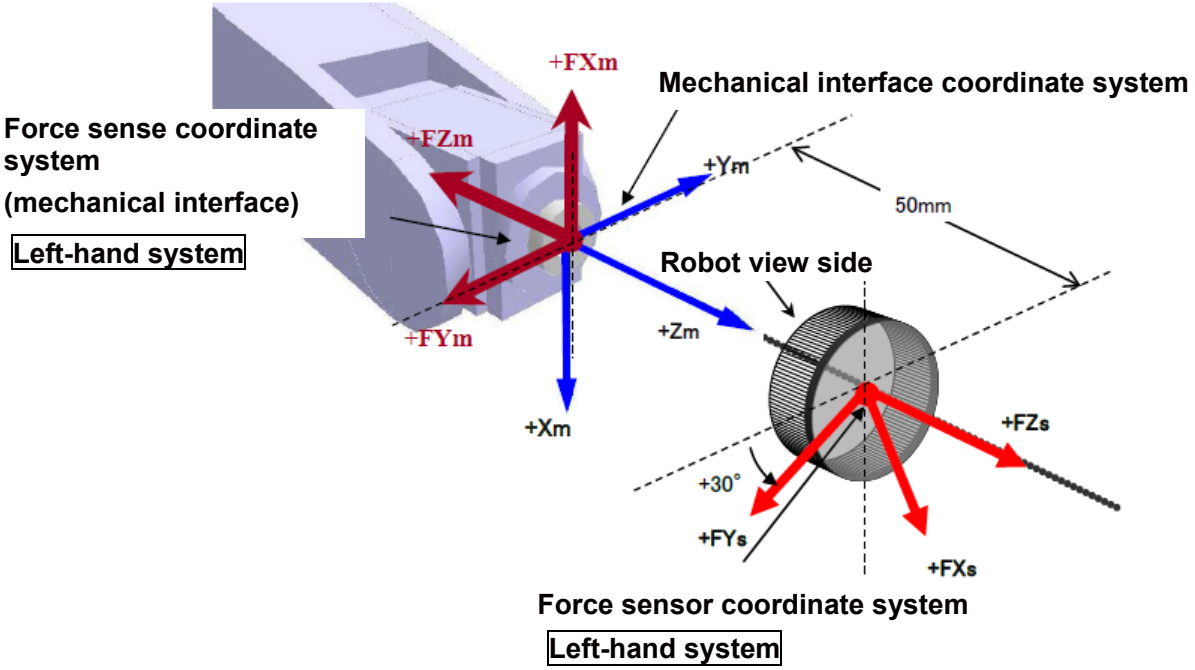
FSXTL 4th element = 0 (default)

FSXTL 5th element = +180 (default)

FSXTL 6th element = 0 (default)

2) Parameter Setting Example 2 (offset installation)

If, as shown below, the force sensor coordinate system origin is offset 50 mm in the +Zm direction and rotated 30 degrees around the Zm-axis as viewed from the mechanical interface coordinate system, set the parameters as follows.



[Coordinate system hand system]

Since the force sensor coordinate system will be the left-hand system, set as follows.

FSHAND=0

[Parallel transfer]

The force sensor coordinate system origin position as viewed from the mechanical interface coordinate system is (0, 0, 50), and therefore the FSXTL settings are as follows.

FSXTL 1st element = 0

FSXTL 2nd element = 0

FSXTL 3rd element = +50

[Rotational transfer]

To align the posture of the force sense coordinate system (mechanical interface) and force sensor coordinate system, it is sufficient to rotate +180 degrees around the Ym-axis after rotating +30 degrees around the Zm-axis, and therefore the FSXTL settings are as follows.

FSXTL 4th element = 0

FSXTL 5th element = +180

FSXTL 6th element = +30

(3) Maximum offset value (FSCORMX)

This parameter sets the position command offset upper limit for force sense control. If the offset exceeds this upper limit, an error (H2760) occurs. This acts as a protection function for inadequate operation or setting, and therefore the required minimum value should be set.

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sense control offset limit	FSCORMX	2 real numbers	Sets the maximum position offset for force sense control. 1st element: Position maximum offset [mm] 2nd element: Posture maximum offset [deg.] [Setting range] 1st element: 0 to +200.0 2nd element: 0 to +150.0	10.0, 10.0

(4) Tolerance value (FSLMTMX)

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sensor tolerance	FSLMTMX	6 real numbers	Sets the force sensor tolerance. If sensor data exceeding the force and moment set at this parameter is detected, an error (H7660) occurs and the robot is stopped. (Force sense control will be disabled.) 1st element: Force sensor data Fx tolerance [N] 2nd element: Force sensor data Fy tolerance [N] 3rd element: Force sensor data Fz tolerance [N] 4th element: Force sensor data Mx tolerance [N·m] 5th element: Force sensor data My tolerance [N·m] 6th element: Force sensor data Mz tolerance [N·m]	0.0, 0.0, 0.0, 0.0, 0.0, 0.0

* Set the minimum required tolerance for the work being performed, within the force sensor rated value. (Refer to section Chapter1 1.1 Force Sensor Specifications for details on the force sensor rated value.)

* The force sensor tolerance judgment is based not on the coordinate data converted with parameter FSXTL, but with raw data (with no offset cancel) sent from the force sensor.

<If force sensor tolerance exceeded>

If error H7660 occurs when the force sensor tolerance setting is exceeded, it will no longer be possible to turn the servo ON. In such a case, remedy the situation with either of the following method.

Temporarily clear the error from the T/B, and then retract the robot by JOG operation.

By turning the servo ON and performing JOG operation while holding down the T/B [RESET] key, the error is temporarily cleared, allowing the robot to be moved. Move the robot to a position at which the error does not occur.

⚠Caution If a value larger than the force sensor rated value is applied, it may cause damage to the sensor.

(5) Filter time constant (FSFLCTL)

The force sensor data filter time constant can be changed.
When the sensor data is not stable or the robot vibrates during the force control, increasing the constant solves the problem.

Increase the setting value···Decreases the vibration. However, because the sensor data delays, the sensitivity of the force sense detection and force sense control are lowered and the robot cannot react to micro force.

Decrease the setting value···Reacts to the micro force properly, but the robot is more likely to vibrate.

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sensor data filter	FSFLCTL	1 real number	Sets the force sensor data filter time constant. [Unit]: ms [Setting range]: 0 to +1000.0	1.7

(6) Force Sensor Minimum Control Force (FSMINCTL)

The minimum control force of force sensor can be changed.
Even if the force sensor does not touch the workpiece, etc. during force sense control, the robot may vibrate due to stationary noise of sensor data. In this case, increasing the minimum control force solves the problem.
However, increasing the minimum control force widens the dead zone. Therefore, the sensitivity of the force sense detection/force sense control will be deteriorated.

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sensor minimum force control	FSMINCTL	6 real numbers	Sets the minimum control force of the force sensor. 1st element: Minimum control force of force sensor Fx [N] 2nd element: Minimum control force of force sensor Fy [N] 3rd element: Minimum control force of force sensor Fz [N] 4th element: Minimum control force of force sensor Mx [Nm] 5th element: Minimum control force of force sensor My [Nm] 6th element: Minimum control force of force sensor Mz [Nm]	0.3, 0.3, 0.3, 0.03, 0.03, 0.03

Chapter 5 Force Sense Function (Programming)

■ Force sense function list

This chapter describes the robot programming using the force sense function.

The force sense function consists of "force sense control", "force sense detection", and "force sense log" functions.

Function Class		Function Overview
Force sense control	Force control	Controls push force.
		Controls force and speed.
	Stiffness control	Controls flexibility.
	Limited stiffness control	Controls flexibility. Limits the robot's force.
	Control characteristics change	Changes control characteristics during robot movement.
		Changes control characteristics in the trigger conditions.
	Gravity offset cancel	Performs offset cancel in response to a change in the direction of gravity applied to the force sensor by hand load at the time of posture change.
Force sense detection	Interrupt execution	Detects contact status and performs interrupt processing.
		Defines interrupt conditions and uses the conditions in the program.
	Data latch / referencing	Latches force sense data and uses the data in the program.
Force sense log	Log data acquisition	Acquires time series data during work.
	Log data display	Displays log data in a graph.
	Log data transfer	Transfers log data to the FTP server.

5.1 What is Force Sense Control?

The force sense control function is used to control robot flexibility and push force. Depending on the application, this function switches between "force control" and "stiffness control".

1) Force control

This control mode controls the robot while pushing with a specified force. The robot moves automatically to the position at which the specified reactive force applies.

The robot can be moved while pushing the workpiece with constant force and maintaining the contact status.

Force control has the following 2 modes.

<Speed priority mode>

If no contact has been made with the target object, the robot switches to speed control mode and moves at the specified speed toward the object.

<Force priority mode>

If contact has been made with the target object, the robot switches to force control mode and the robot is controlled in order that the specified reactive force applies.

2) Stiffness control/limited stiffness control

This control mode is used to control the robot flexibly like a spring. By applying external force, the robot moves automatically in the direction that allows it to release the external force.

This type of control can be used to suppress the force applied on the workpiece when performing insertion work.

Furthermore, the robot position is offset while following the assembly part shape, allowing teaching position displacements to be absorbed.

In the stiffness control, the reactive force will increase in proportion to displacement. If the reaction force is too large, please set the limit value for the reactive force using the limited stiffness control.

3) Position control

This control mode is used to control the robot position. Position control is applied to axes for which neither force control nor stiffness control are specified.

Pick Up!

Offset and offset speed limits

The following table shows the limit for the position offset amount and offset speed by the force sense control.
The positional offset limit can be changed in parameter FSCORMX.

	X, Y, Z	A, B, C	Remarks
Positional offset limit	10 [mm]	10 [deg]	Can be changed in FSCORMX.
Speed offset limit (Automatic)	80 [mm/s]	80 [deg/s]	
Speed offset limit (Manual)	Approx.8 [mm/s]	Approx.8 [deg/s]	

Singular point adjacent operation restrictions

Singular point adjacent operation cannot be performed while force sense control is enabled, regardless of interpolation or JOG operation.
(The error L3986 occurs.)
If necessary to move the robot adjacent to a singular point, or if wishing to pass through the singular point using the singular point pass function, disable the force sense function.

5.2 Enable/Disable the Force Sense Control

Enable the force sense control when using the force sense control function of the force sensor, and disable the force sense control when ending the force sense control function of the force sensor.

(1) Force sense control enable/disable command (FscOn/FscOff) with a program

Start the force sense control based on the condition settings specified in the argument "Control mode", "Control feature" "Offset cancel designation" by FscOn command of MELFA-BASIC.

End the force sense control by FscOff command.

a) Force sense control enable command (FscOn)

Enable the force sense control function using the force sensor in a program.

For details, refer to "Chapter5 5.3 Condition Groups and Condition Numbers".

```
Fsc On,  <Control mode>,  <Control characteristics>,  <Offset cancel designation>
```

<Control mode> Specify the control mode number for force sense control.
(Setting range: -1 to 9)

<Control characteristics > Specify the control characteristics number for force sense control.
(Setting range: -1 to 9)

<Offset cancel designation> Specify whether to cancel the force sensor data offset component.
(Setting range: 0 or 1)

0: Not cancel (disable)
1: Cancel (enable)

For details, refer to "Chapter5 5.4 (12) Offset cancel designation".

b) Force sense control disable command (FscOff)

Disables the force sense control function using the force sensor.

```
Fsc Off
```

(2) Force sense control enable/disable selection with the teaching box

The following describes how to enable/disable the force sense control with the teaching box.

If performing JOG operation using force sense control, select "Enable", and if performing normal JOG operation, select "Disable".

The enable/disable selection is common to both automatic operation and JOG operation. The enable/disable status is retained even if the controller mode is changed between MANUAL and AUTOMATIC.

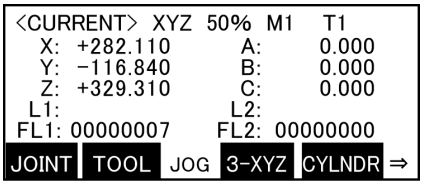
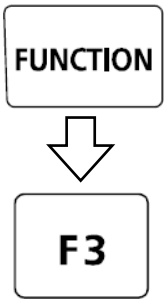
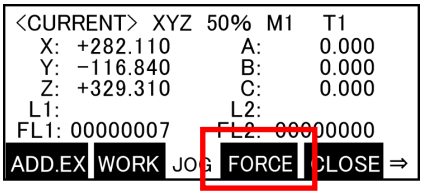
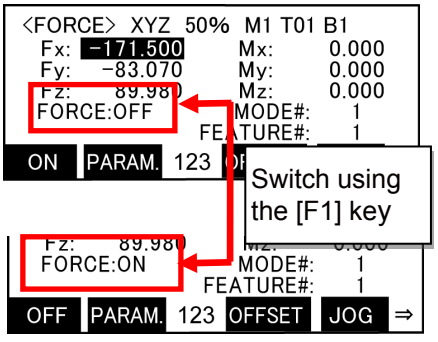
However, if the enabled/disabled status differs when interrupting and resuming robot program automatic operation, error L3986 occurs when resuming operation.

⚠Caution

The force sense control enable/disable status is retained even when automatic operation is stopped and the operation mode changed to MANUAL mode. Perform teaching after checking the force sense control enable/disable status, and control mode/control characteristics settings sufficiently.

[Force sense control enable/disable operation]

- Enable/disable force sense control with the ON/OFF button.
- The enabled/disabled status is displayed on the T/B screen.

Step	How to operate	T/B screen	Description of the operation method
1		<JOG operation screen> 	Press the [JOG] key to display the JOG operation screen.
2		<JOG operation screen> 	Press the [FUNCTION] key and display "FORCE" as the function menu at the bottom of the screen. Press the [F3] key ("FORCE") and display the <FORCE> screen.
3		< Force screen > 	Press the [F1] key ("ON/OFF") to enable/disable the force sense control.

*For the operation of the R56TB, refer to "Appendix 4 Operation of the Teaching Box (R56TB) (4) Force Sense Control Enable/Disable Selection".

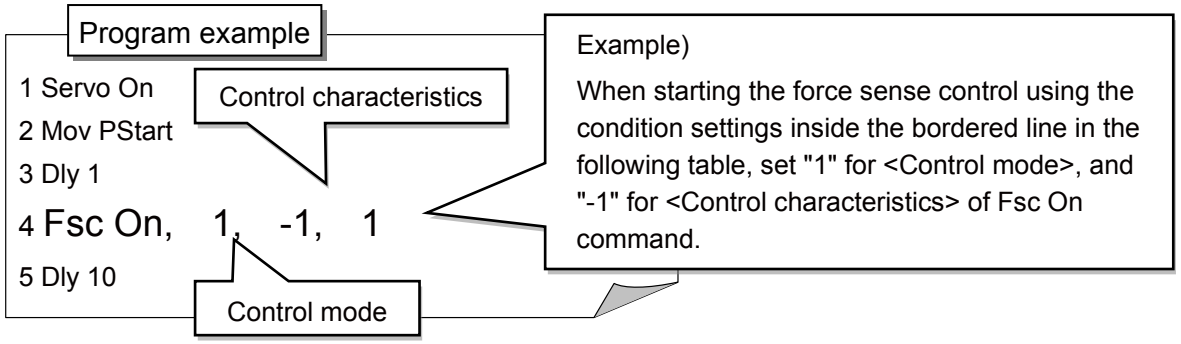
5.3 Condition Groups and Condition Numbers

(1) Setting method

All parameter settings are classified by "condition groups" consisting of the control mode and control characteristics, and "condition numbers." -1 to 9. When specifying conditions with the Fsc On command, they are specified with a combination of these "condition groups" and "condition numbers." Each parameter can be set by setting in the program (set as status variable) or setting in the parameter settings.

The condition numbers "-1" and "0" are set by substituting to the status variable. The condition numbers "1" to "9" are set in the parameters.

Fsc On, <Control mode>, <Control characteristics >,<Offset cancel designation>



Condition group <Control mode>

Setting Item	Condition Numbers.			
	-1	0	1	2 to 9
Force sense control coordinate system	M_FsCod1	M_FsCod0	FSCOD01	FSCOD0#
Force sense control mode	P_FsMod1	P_FsMod0	FSFMD01	FSFMD0#
Stiffness coefficient	P_FsStf1	P_FsStf0	FSSTF01	FSSTF0#
Damping coefficient	P_FsDmp1	P_FsDmp0	FSDMP01	FSDMP0#
Force sensor bias value	P_FsBias1	P_FsBias0	FSBIAS01	FSBIAS0#
Load center of gravity position	P_FsGrPos1	P_FsGrPos0	FSGRP01	FSGRP0#
Load mass	M_FsMass1	M_FsMass0	FSMASS01	FSMASS0#

(# corresponds to group Nos. 2 to 9.)

Condition group <Control characteristics>

Setting Item	Condition Numbers.			
	-1	0	-1	2～9
Force command value/limit value	P_FsFCd1	P_FsFCd0	FSBIAS01	FSBIAS0#
Speed command value	P_FsSpd1	P_FsSpd0	FSGRP01	FSGRP0#
Mode switching judgment value	P_FsSwF1	P_FsSwF0	FSMASS01	FSMASS0#
Force sense control gain	P_FsGn1	P_FsGn0	FSFCMD01	FSFCMD0#
Force detection setting value	P_FsFLm1	P_FsFLm0	FSSPD01	FSSPD0#

(# corresponds to group Nos. 2 to 9.)

(2) Setting example

a) Setting in the program (set as status variable)

The following describes how to set the setting value to the program as status variable.

Condition numbers "-1" and "0" can be used.

```
'[Control mode (0)]
P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Stiffness coefficient [N/mm]
P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)  'Damping coefficient
P_FsMod0 = (+1.00,+1.00,+1.00,+0.00,+0.00,+0.00)(0,0)   'Force sense control mode (X, Y,
                                                          Z-axis, force control)
M_FsCod0 = 0                                             'Force sense control coordinate
                                                          system (tool)
```

Status variable name + condition number (last number)

```
'[Control characteristics (0)]
P_FsGn0 = (+3.00,+3.00,+3.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [µm/N]
P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)  'Force detection setting value [N]
P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)   'Force command (X, Y-axis: 0.0 [N],
                                                          Z-axis: 5.0 [N])
P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)   'Set the speed of the speed control mode
P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)   'Set the force/speed judgment value
```

```
'[Control characteristics (-1)]
P_FsGn1 = (+0.00,+0.00,+4.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [µm/N]
P_FsFLm1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)  'Force detection setting value [N]
P_FsFCd1 = (+0.00,+0.00,+12.00,+0.00,+0.00,+0.00)(0,0) 'Force command
P_FsSpd1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)   'Set the speed of the speed control mode
P_FsSwF1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)   'Set the force/speed judgment value
```

Status variable name + condition number (last number)
"1" is condition number "-1"

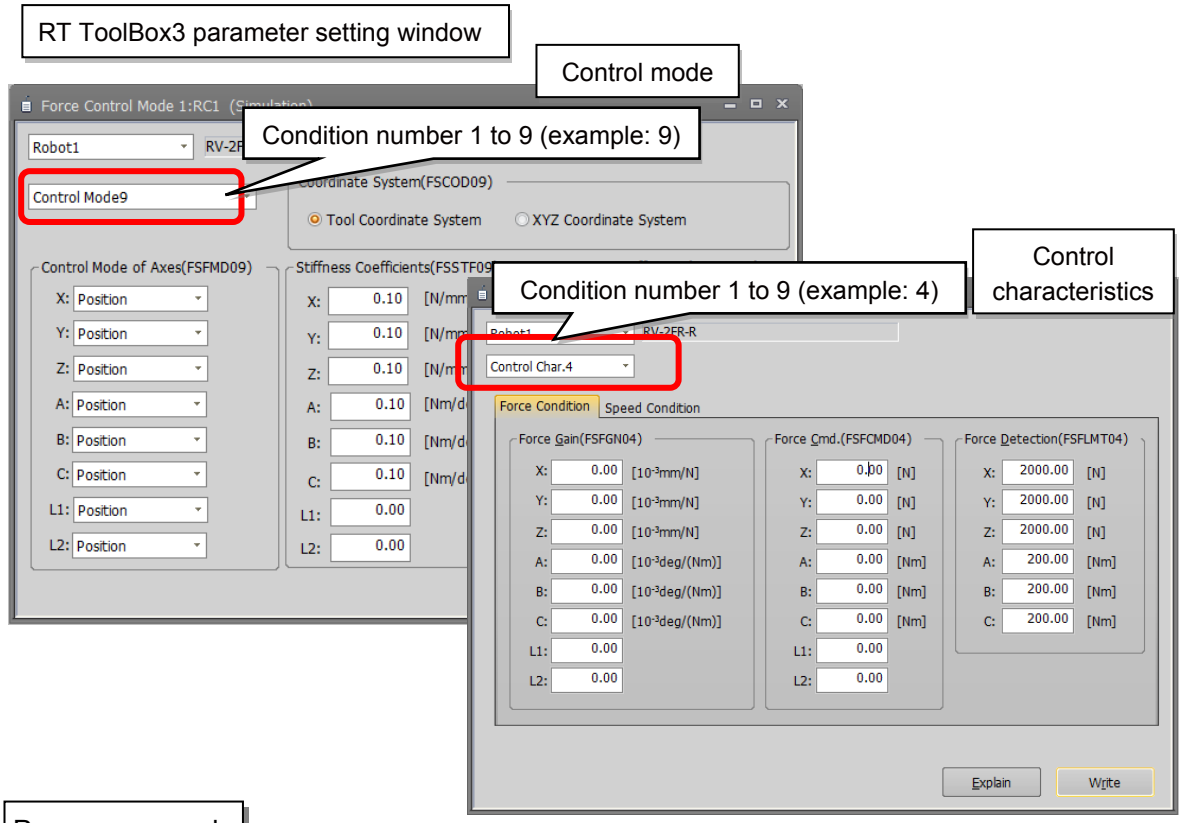
```
.....
Spd 10
Servo On
Mvs P1,-3
Dly 1                  'Input Dly before the offset cancel (wait until the control completely stops)
Fsc On, 0, -1, 1       'Force sensor control enabled (control mode = 0, control characteristics =
                         -1, offset cancel enabled)
```

Operates with control mode "0", control characteristics "-1" as set in the program

```
.....
*Insert complete conditions are input (interrupt, IF condition statement, and others.)*
.....
Fsc Off                                                  'Disable the force sense control
End
```

b) Setting by the parameter

Set conditions to the parameters by RT ToolBox3. Condition number "1" to "9" can be used.



Program example

```
• • • • • •
Spd 10
Servo On
Mvs P1,-3
Dly 0.5                    'Input Dly before the offset cancel
Fsc On, 9, 4, 1            'Enable the force sense control with control mode = 9, control
                           characteristics = 4, and offset cancel enabled (operates with the
                           control mode "9", control characteristics "4" set in the parameter)
• • • • • •
*Insert complete conditions are input (interrupt, IF condition statement, and others.)*
• • • • • •
Fsc Off                                    'Disable the force sense control
End
```

(3) Selecting control mode and control feature in teaching box

Before enabling force sense control, it is necessary to set the force sense control "control mode" and "control feature" beforehand.

[Control mode/ Control feature selection operation]

- Specify the used "control mode" and "control feature" number.
- Ensure that the numbers used have been set correctly before enabling force sense control.

a) Operation from the JOG operation screen

Step	How to operate	T/B screen	Description of the operation method
1	FUNCTION ⇩ F3	<JOG operation screen> <CURRENT> XYZ 50% M1 T1 X: +282.110 A: 0.000 Y: −116.840 B: 0.000 Z: +329.310 C: 0.000 L1: L2: FL1: 00000007 FL2: 00000000 ADD.EX WORK JOG FORCE CLOSE ⇒	Press the [FUNCTION] key and display "FORCE" as the function menu at the bottom of the screen. Press the [F3] key ("FORCE") to display the <FORCE> screen.
2	F2	<Force screen> <FORCE> XYZ 50% M1 T01 B1 Fx: −171.500 Mx: 0.000 Fy: −83.070 My: 0.000 Fz: 89.980 Mz: 0.000 FORCE:OFF MODE#: 9 FEATURE#: −1 ON PARAM. 123 OFFSET JOG ⇒	Press the [F2] key ("PARAM.").
3	Arrow key Number key	<Force condition screen> <FORCE> PARAMETER CONTROL MODE (9) CONTROL FEATURE (−1) 123 CLOSE	Specify the numbers for "CONTROL MODE" and "CONTROL FEATURE".
4	F4	<Force screen> <FORCE> XYZ 50% M1 T01 B1 Fx: −171.500 Mx: 0.000 Fy: −83.070 My: 0.000 Fz: 89.980 Mz: 0.000 FORCE:OFF MODE#: 1 FEATURE#: 1 ON PARAM. 123 OFFSET JOG ⇒	Return to the <FORCE> screen by pressing the [F4] key ("CLOSE"). (The control mode is set to "1", and control feature set to "1" as an example.)
5	F4	<Force screen> <FORCE> XYZ 50% M1 T01 B1 Fx: −171.500 Mx: 0.000 Fy: −83.070 My: 0.000 Fz: 89.980 Mz: 0.000 FORCE:ON MODE#: 1 FEATURE#: 1 OFF PARAM. 123 OFFSET JOG ⇒	Press the [F1] key in the <FORCE> screen to enable the force sense control (FORCE: ON).

*For operation of the R56TB, refer to " Appendix 4 Operation of the Teaching Box (R56TB) (3) Selecting the Control Mode/Control characteristics".

5.4 Control Mode and Control Characteristics Details

(1) Settings for the force sense control conditions

When enabling force sense control, it is necessary to specify conditions for starting force sense control. Register these conditions by using the parameters and status variables. Up to 11 types of settings can be registered for each setting item. (9 types of parameter, 2 types of status variable)

a) Control mode

Setting Item	Description	Reference
Force sense control coordinate system	Defines the coordinate system for force sense control. Select from Tool coordinate system/XYZ coordinate system.	(3) Specifying the force sense control coordinate system
Force sense control mode	Selects the force sense control method for each force sense control coordinate system axis. Select from Positional control/Force control/Stiffness control/limited stiffness control.	(4) Specifying the force control mode
Stiffness coefficient	Sets the flexibility for axes for which stiffness control/limited stiffness control is selected.	(6) Specifying the stiffness coefficient
Damping coefficient	Sets the responsiveness for axes for which force control or stiffness control/limited stiffness control is selected. Adjust when the robot vibrates at contact.	(7) Specifying the damping coefficient

The following three items are set when using the gravity off set cancel.
(This settings are set automatically by the force sensor calibration function. It is not necessary to set it again.)

Setting Item	Description	Reference
Force sensor bias value	Bias value of the force sensor is set. The bias value of the force sensor will be a constant offset occurring in the sensor with no load. (by tightening at the time of installation a force sensor)	(13) Gravity offset cancel
Load center of gravity position	Sets the center of gravity position of the load that installed to the force sensor.	
Load mass	Sets the mass of the load that installed to the force sensor.	

b) Control characteri stics

Setting Item	Description	Reference
Force command value	Sets the force command for force control (force priority mode). The robot pushes with the specified force.	(5) Specifying the force command value and limit value
Limit value	Sets the limit value for the limited stiffness control. Controls the robot's force within the setting value.	
Speed command value	Sets the speed command for force control (speed priority mode). Used when specifying the operation speed at no contact, etc.	(9) Specifying the speed command value
Mode switching judgment value	Sets the speed/force control mode switching judgment value. This is valid only when a speed command value has been set.	(10) Specifying the mode switch judgment value
Force sense control gain	Sets the response sensitivity for axes for which force control/limited stiffness control or stiffness control is selected. Adjustment is required based on the stiffness of the target object.	(8) Specifying the force sense control gain
Force detection setting value	Sets the force detection setting value. This is used for the force sense detection and contact detection functions.	(11) Specifying the force detection setting value

(2) Control mode and control characteristics setting compatibility table

The following is the compatibility table for the setting item of the control mode and control characteristics when using the force control mode (position control, force control, stiffness control).

◆Position control···Maintains the position and posture.
◆Force control···Continuously applies the specified force to the specified axis direction.
◆Stiffness control···Decreases the stiffness of the specified axis.

(○: Setting is necessary, △: Set if necessary, ×: Setting is not necessary)

Setting item		Status variable (*=0, -1)	Parameter (#=1 to 9)	Force control mode			
				Position control	Force control	Stiffness control	Limited stiffness control
Control mode	Force sense control coordinate system	M_FsCod*	FSCOD0#	○	○	○	○
	Force sense control mode	P_FsMod*	FSFMD0#	○	○	○	○
	Stiffness coefficient	P_FsStf*	FSSTF0#	×	×	○	○
	Damping coefficient	P_FsDmp*	FSDMP0#	×	△	△	△
	Force sensor bias value	P_FsBias*	FSBIAS0#	△	△	△	△
	Load center of gravity position	P_FsGrPos*	FSGRP0#	△	△	△	△
	Load mass	M_FsMass*	FSMASS0#	△	△	△	△
Control characteristics	Force command value	P_FsFCd*	FSFCMD0#	×	○	×	×
	Limit value			×	×	×	○
	Speed command value	P_FsSpd*	FSSPD0#	×	○	×	×
	Mode switching judgment value	P_FsSwF*	FSSWF0#	×	○	×	×
	Force sense control gain	P_FsGn*	FSFGN0#	×	○	○	○
	Force detection setting value	P_FsFLm*	FSFLMT0#	△	△	△	△

(# corresponds to the group number 1 to 9.)

(3) Specifying the force sense control coordinate system (M_FsCod0／M_FsCod1, FSCOD0#)

Specify the coordinate system controlling with the force sensor.

M_FsCod0 / M_FsCod1 = 0 or 1
0: Tool coordinate system
1: XYZ coordinate system

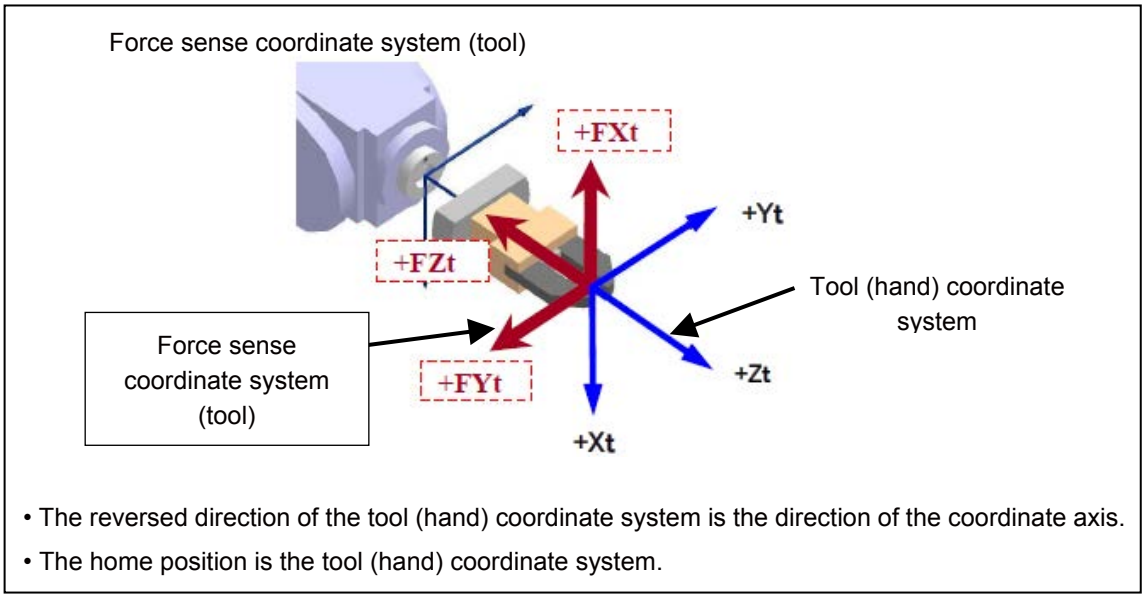
Program example

```
M_FsCod0=0
```

Set the force sense control coordinate system to "Tool coordinate system".

a) Tool coordinate system

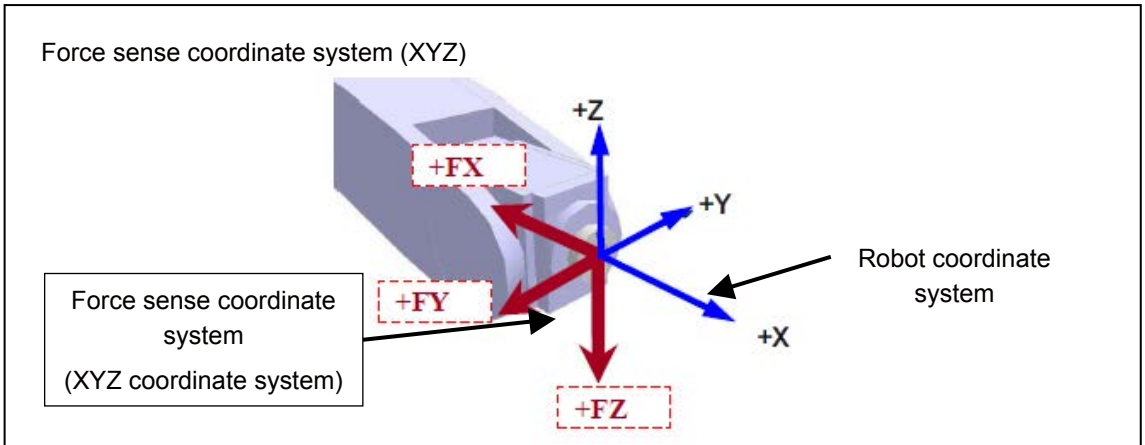
Controls based on the tool (hand) coordinate system.



- The reversed direction of the tool (hand) coordinate system is the direction of the coordinate axis.
- The home position is the tool (hand) coordinate system.

b) XYZ coordinate system

Controls based on the robot coordinate system.



- The reversed direction of the XYZ coordinate system is the direction of the coordinate axis.
- The home position is the robot coordinate system.

(4) Specifying the force control mode (P_FsMod0／P_FsMod1, FSFMD0#)

Set the control mode for X, Y, Z, A, B, and C-axis each.

P_FsMod0 / P_FsMod1 = (△, △, △, △, △, △,0,0)(0,0)

△= 0 or 1 or 2 or 3

0: Position control (normal control)

1: Force control

2: Stiffness control

3: Limited stiffness control

Program example

P_FsMod0 = (+2.00,+2.00,+0.00,+0.00,+0.00,+0.00)(0,0)

Force sense control type: Specify the stiffness control in X, Y-axis direction

a) Position Control Mode

Control method	Application
Maintains the position and posture. As with normal robot control, the robot is controlled with position commands.	This is used in combination with force control and stiffness control.

b) Force Control Mode

Control method	Application
The robot is controlled while pushing with a specified force. (*) The force size and direction are set with the "Force command value". (* Specify with P_FsFCd0/P_FsFCd1.)	Force pressing Grinding work

c) Stiffness Control Mode/Limited stiffness control

Control method	Application
Decreases the stiffness of the specified axis. Flexibility is set with the "Stiffness coefficient". The limit value for the limited stiffness control is set with the "limit value".	Fitting/insertion work Following /teaching work

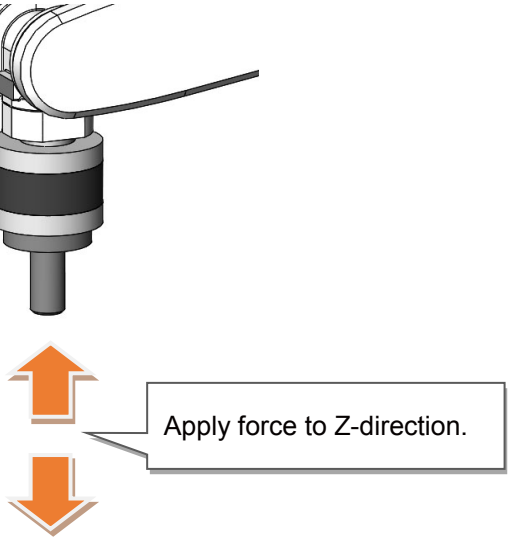
◆Practice 1: Specifying the force coordinate system

1) Execute program "1" to check the movement.
2) Create program "1" with RT ToolBox3 and write it to the robot.
3) When the writing is completed, close the program. Open the program again, and check that the 8th line is "M_FsCod0=0" (tool coordinate system).
4) Operate the robot by the JOG operation and move it to the PStart position.
5) Turn OFF the enable switch of the T/B, switch to "Automatic" with the mode selection switch, and lower OVRD to 10%. Then execute the automatic operation.
6) The force sensor is enabled for 60 seconds in the program. When the force in the upper direction is applied to the tip of the hand, check that the Z-axis data displayed on the GOT changes to the "+" side.
7) When the servo of the robot is turned OFF, set "M_FsCod0 = 1" of program "1" with RT ToolBox3 again, and write the program to the robot.
8) After OVRD is lowered to 10%, execute the automatic operation.

   The force sensor is enabled for 60 seconds in the program. When the force in upper direction is applied to the tip of the hand, check that the Z-axis data displayed on the GOT changes to "+" side.

◇◆ Key learning points ◆◇

The value displayed on the GOT is the value that is converted to the one in the robot coordinate system. It is not the value of the force sensor itself.
When the FSC On command is executed, the value is displayed on the coordinate system set in the control mode, and when the FSC Off command is executed, the value is displayed on the tool coordinate system (installation position specified in "force sensor" of the parameter).



◆**Program "1"**

```
1 '------------------------------------------------------------------------
2 ' Practice 1 Selecting force sense control coordinate system and specifying force control mode
3 '------------------------------------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
7   P_FsMod0 = (+1.00,+1.00,+1.00,+0.00,+0.00,+0.00)(0,0)          'Force control mode (XYZ-axis
                                                                    enabled)
8   M_FsCod0 = 0                                  'Force sense control coordinate system (0/1: Tool/XYZ)
9 '[Control characteristics (0)]
10  P_FsGn0   = (+8.00,+8.00,+8.00,+0.00,+0.00,+0.00)(0,0)      'Force control gain [µm/N]
11  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force detection setting value [N]
12  P_FsFCd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force command
13  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set speed control mode speed.
14  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set force/speed judgment value.
15 '*** <Force control> ***
16  PStart=(+235.00,+0.00,+220.00,+180.00,+0.00,+180.00)(7,0)
17  '----- Move the robot to PStart position in advance!
18  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
19  Loadset 1,1
20  OAdl On
21  Spd M_NSpd                    'Set the speed to initial value. (* Valid only for CP control)
22  Ovrd M_Novrd                  'Set the override to initial value.
23  Cnt 0                         'Set the continuous operation for interpolation to initial value.
24  Servo On
25  Wait M_Svo=1
26  Fsc On, 0, 0, 1               'Start force sense control
27  Dly 60                        'Enabled for 60 seconds
28  Fsc Off
29  Servo Off
30  Wait M_Svo=0
31  Hlt
32 End
```

(5) Specifying the stiffness coefficient (P_FsStf0/P_FsStf1, FSSTF0#)

Stiffness control/limited stiffness control softness is specified with the stiffness coefficient. Set the stiffness coefficient for X, Y, Z, A, B, and C-axis each.

The stiffness coefficient is equivalent to the spring constant. The stiffness of the control increases as the value increases, and decreases the control as the value decreases.

P_FsStf0 / P_FsStf1 = (△, △, △, △, △, △,0,0)(0,0)
△= 0.0 to 1000.0
X, Y, Z · · · [N / mm]
A, B, C · · · [N·m / deg]

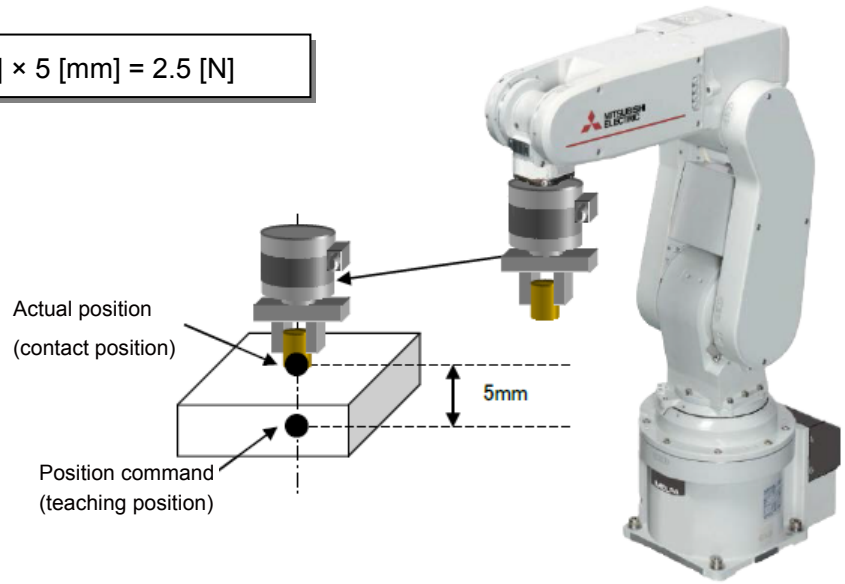
Program example

```
P_FsStf0=(+0.01,+0.01,+0.00,+0.00,+0.00,+0.00)(0,0)
```

Stiffness coefficient: Specify 0.01 [N/mm] for X, Y-axis component.

<Correlation between teaching position and reaction force>
If stiffness control mode is selected, when an external force acts on the arm tip, resulting in displacement between the teach position and actual position, the robot moves to a position at which the reactive force corresponding to the "displacement" and "stiffness coefficient" can be obtained.In the following image, stiffness control is performed only for the tool Z-axis. By setting 0.5 [N/mm] for the Z-direction stiffness coefficient, and the teaching position at 5 mm below the contact surface, force F produced on the contact surface is calculated as follows.

F = 0.5 [N/mm] × 5 [mm] = 2.5 [N]



- The smaller the stiffness coefficient, the smaller the reactive force, helping to deal with greater displacements.
- When 0.0 is set with the stiffness coefficient, the reactive force is not generated in the case of the position is changed by external force.
- When the limited stiffness control, the robot is controlled within the specified reactive force that is set with limit value.

◆Practice 2: Specifying the stiffness coefficient

1) Execute program "2" to check the movement.

2) Create program "2" with RT ToolBox3 and write it to the robot.

3) When the writing is completed, close the program. Open the program again, and check that the 8th line is "M_FsCod0=0" (tool coordinate system).

4) Operate the robot by the JOG operation and move it to the PStart position.

5) Turn OFF the enable switch of the T/B, and switch to "Automatic" with the mode selection switch, and lower OVRD to 10%. Then execute the automatic operation.

6) The force sensor is enabled for 60 seconds in the program. When the force is applied in any direction to the tip of the hand, check that the robot returns to the original position when the hand is released.

7) When the servo of the robot is turned OFF, change the XYZ component of "P_FsStf0" in the 5th line of program "2" from "0.1" to "0.5" with RT ToolBox3 again, and save it. Then execute the automatic operation.

8) As step 6), check the difference of stiffness when the force is applied to the tip of the robot, and the difference of the movement when the hand is released from the robot.

◇◆ Key learning points ◆◇

Understand how the stiffness control performs compared to the force control in Practice 1).

Understand how the characteristics changes by changing the stiffness control.

Check the stiffness when the force is applied from any direction and the reaction force when the hand is released.

Check the changes such as stiffness by changing the stiffness coefficient value.

◆Program "2"

```
1 '-----------------------------------------------
2 ' Practice 2: Specifying the stiffness coefficient
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.10,+0.10,+0.10,+0.00,+0.00,+0.00)(0,0)      'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)    'Damping coefficient
7   P_FsMod0 = (+2.00,+2.00,+2.00,+0.00,+0.00,+0.00)(0,0)    'Stiffness control mode (XYZ-axis
                                                               enabled)
8   M_FsCod0 = 0                                          'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10   P_FsGn0   = (+8.00,+8.00,+8.00,+0.00,+0.00,+0.00)(0,0)        'Force control gain [μm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set force/speed judgment value.
15 '*** <Stiffness control> ***
16   PStart=(+235.00,+0.00,+220.00,+180.00,+0.00,+180.00)(7,0)
17   '----- Move the robot to PStart position in advance!
18   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
19   Loadset 1,1
20   OAdl On
21   Spd M_NSpd                        'Set the speed to initial value. (* Valid only for CP control)
22   Ovrd M_Novrd                      'Set the override to initial value.
23   Cnt 0                            'Set the continuous operation for interpolation to initial value.
24   Servo On
25   Wait M_Svo=1
26   Fsc On, 0, 0, 1                   'Start force sense control
27   Dly 60                            'Enabled for 60 seconds
28   Fsc Off
29   Servo Off
30   Wait M_Svo=0
31   Hlt
32 End
```

(6) Specifying the damping coefficient (P_FsDmp0/P_FsDmp, FSDMP0#)

Set the damping coefficient when the robot vibrates at hand and workpiece contact, or when setting the response of the axis to which the force control and stiffness control are selected.

P_FsDmp0 / P_FsDmp1 = (△, △, △, △, △, △,0,0)(0,0)

△= 0.0 to 1.0

X, Y, Z · · · [N / (mm/s)]

A, B, C · · · [N·m / (deg/s)]

Program example

```
P_FsDmp0=(+0.01,+0.01,+0.00,+0.00,+0.00,+0.00)(0,0)
```

Damping coefficient: Specify 0.01 [N/(mm/s)] for X, Y-axis component.

- Used when the vibration does not stop even the force sense control gain is adjusted.
- The greater the value, the greater the effect in suppressing vibrations, however, positional offsetting is delayed with sudden changes in force, resulting in a greater force applied the moment contact is made with the workpiece.
- Adjust the damping coefficient after adjusting the force sense control gain.
  (Vibrations also occur if the force sense control gain is too great.)

(7) Specifying the force command value and limit value (P_FsFCd0/P_FsFCd, FSFCMD0#)

a) Force command value

Set the force command value for force control (force priority mode). Set the force command value for each specified axis.

When force control is enabled, the robot moves so that the reactive force specified with the force command value can be obtained.

When there is no contact (no force applied), the robot operates to the opposite direction (direction which the specified force is generated at contact) of the force command value.

P_FsFCd0 / P_FsFCd1 = (△, △, △, △, △, △,0,0)(0,0)

At force control:

△ = - (force sensor tolerance value) to + (force sensor tolerance value)

X, Y, Z · · · [N]
A, B, C · · · [N·m]
L1, L2 · · · Not used

At limited stiffness control:

△ = 0.0 to + (force sensor tolerance value)

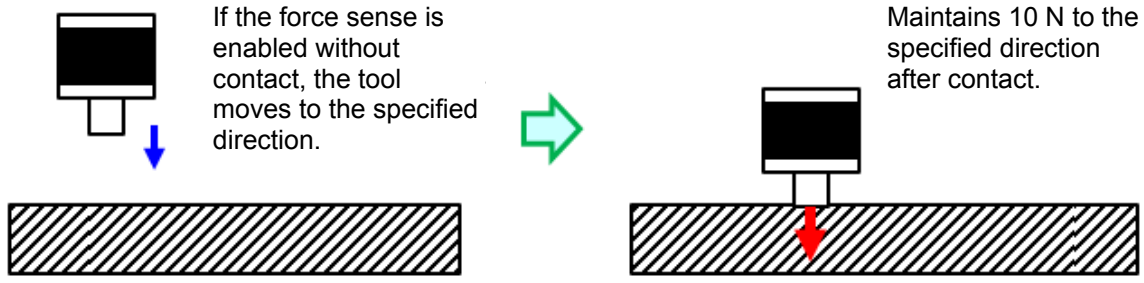
X, Y, Z · · · [N]
A, B, C · · · [N·m]
L1 · · · [N], L2 · · · [N·m]

Program example

```
P_FsFCd0=(+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)
                Force command (specify 10.0 [N] for Z-axis direction)
```

<Example>

"+10 N to Z-direction", and the tool coordinate system is set as the control coordinate system



b) Limit value

Sets the limit value for the limited stiffness control. When an external force applies on the arm tip and the displacement occurs between the teach position and actual position while the limited stiffness control is enabled, the robot moves to a position at which the reactive force corresponding to the "displacement" and "stiffness coefficient" can be obtained. In the normal stiffness control, when the stiffness coefficient or displacement is increased, the reactive force becomes large. On the other hand, in the limited stiffness control, the force is automatically controlled so that the reactive force does not exceed the specified limit value. Since the limit is applied to the command value, as the value of the sensor may temporarily exceed the limit value.

(8) Specifying the force sense control gain (P_FsGn0/P_FsGn1, FSSWF0#)

Adjust the response of the force sense control. When using the force control and stiffness control, this setting is required.

The response improves as the setting value increases. If the setting value is too high, the operation may be unstable and increase the possibility of vibration due to high sensitivity at contact.

Because the stiffness of the contact target affects the force sense control gain, the gain setting value needs to be changed according to the contact target. Adjust the setting value according to the contact target and hand stiffness.

P_FsGn0 / P_FsGn1 = (△, △, △, △, △, △,0,0)(0,0)

△= 0.0 to 300.0

X, Y, Z · · · [μmm / N]

A, B, C · · · [μdeg / N]

Program example

```
P_FsGn0=(+80.00,+80.00,+0.00,+0.00,+0.00,+0.00)(0,0)
```

Gain (specify 80 [10-3 mm/N] for X, Y-axis direction)

[Adjustment method]

1) Set 1.0 as an initial value to adjust the gain setting value to the axis which executes the force sense control.
2) Move the robot at low speed by JOG operation in the axis direction for which force sense control (force control/stiffness control/limited stiffness control) is enabled until contact is made with the target object. (speed override: approx. 5%)
3) If the robot rebounds in the opposite direction from the movement direction when contact is made, it is necessary to lower the gain setting value. (The gain setting value can be increased if the robot does not rebound.)

* When 0.0 is set, the offset by the force sense control is not performed. A control equivalent to position control (normal control) is performed.

* Control can be changed from position control to force control/stiffness control/limited stiffness control or vice versa by changing the gain setting value during robot movement. (Use the FsGChg command or the FsCTrg command.)

<<MEMO>> *Please use this page for your memo.

◆Practice 3: Specifying the force command value and the damping coefficient

1) Execute program "3" to check the movement.

2) Create program "3" with RT ToolBox3 and write it to the robot.

3) When the writing is completed, close the program.

Open the program again, and check that the 8th line is "M_FsCod0=0" (tool coordinate system).

4) Operate the robot by the JOG operation and move it to the PStart position.

(* Teach the scale plate center position over the contact position again.)

5) Turn OFF the enable switch of the T/B, switch to "Automatic" with the mode selection switch, and lower OVRD to 10%. Then execute the automatic operation.

6) The robot stops for 10 seconds when the scale points at approximately 0.5 kg. Wait for the robot moving above and the servo turning OFF。

7) Open program "3", and adjust P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00) in the 10th line, and change the Z-axis gain from "5" to between "40" and "50". Then execute the automatic operation again.

8) Check that the needle of the scale points at 0.5 kg unstably.

(If it is stable, adjust the gain within the range in which an error occurs.)

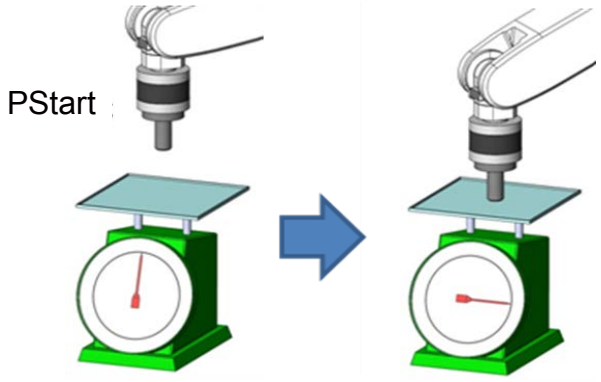
9) Input "0.05" to the Z-axis component in the 6th line P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00) in the program. Then execute the automatic operation again.

10) Check that the scale pointer settles at 0.5 kg.

◇◆ Key learning points ◆◇

Use the damping coefficient when the robot vibrates even the gain or force command value is adjusted in any method.

Understand the effect of the damping coefficient through this practice.



⚠Caution

In this practice, the robot is vibrated on purpose to understand the effect of the damping coefficient.

Normally, the damping coefficient is used when the robot does not stop vibrating even the gain is adjusted.

◆**Program "3"**

```
1 '-----------------------------------------------
2 ' Practice 3 Specifying the force command and damping coefficient
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)    'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)    'Force control mode (Z-axis
                                                               enabled)
8   M_FsCod0 = 0                                          'Force sense control coordinate system (XYZ)
9 '[Control characteristics (0)]
10   P_FsGn0   = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [µm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+4.90,+0.00,+0.00,+0.00)(0,0)     'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Set force/speed judgment value.
15 '*** <Control> ***
16   '----- Reference: PStart -----
17   'PStart=(-60.00,-250.00,+290.00,+180.00,+0.00,+90.00)(7,0)
18   '----- Move the robot to PStart position in advance!
19   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
20   Loadset 1,1
21   OAdl On
22   Spd M_NSpd                    'Set the speed to initial value. (* Valid only for CP control)
23   Ovrd M_Novrd                  'Set the override to initial value.
24   Cnt 0
25   Servo On
26   Wait M_Svo=1
27   Mov PStart
28   Dly 0.5
29   Fsc On, 0, 0, 1               'Start force sense control
30   *Loop1
31   If P_FsCurD.Z<=4.9 Then *Loop1
32   Dly 0.2
33   Fsc Off
34   Dly 10
35   Mvs PStart
36   Dly 0.5
37   Servo Off
38   Wait M_Svo=0
39   Hlt
40 End
```

(9) Specifying the speed command value (P_FsSpd0/P_FsSpd1, FSSPD0#)

The speed when the force control is enabled can be specified for each axis in the force control (speed priority mode).

Specify the operation speed when the robot is not contacting the target.

Use if performing work while automatically switching between speed control and force control, or to minimize impact by limiting the approach speed to the target object.

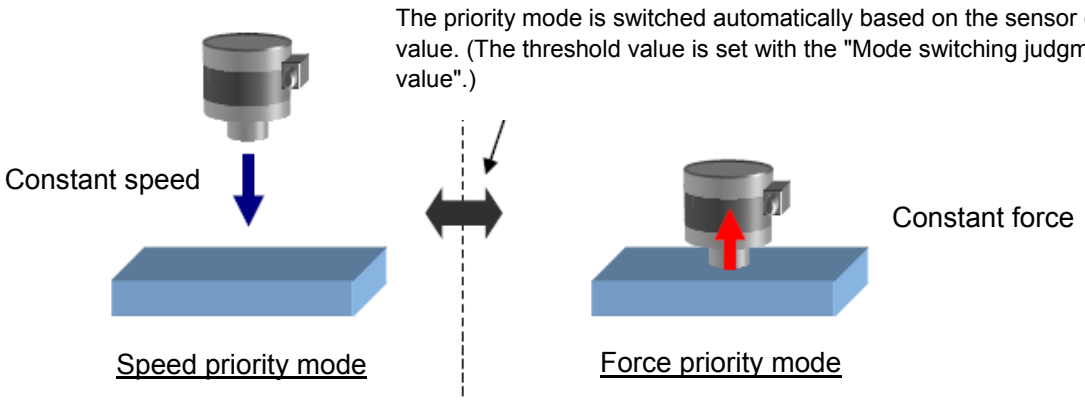
Set the switching condition for "speed priority mode" and "force priority mode" with the "Mode switching judgment value".
Refer to "Chapter5 5.4 (10) Specifying the mode switching judgment value (P_FsSwf0/P_FsSwf1, FSSWF0#)" in the next page.

P_FsSpd0 / P_FsSpd1 = (△, △, △, △, △, △,0,0)(0,0)
△= 0.0 to 50.0
X, Y, Z · · · [mm / s]
A, B, C · · · [deg / s)]

Program example

```
P_FsSpd0 = (+0.00,+10.00,+0.00,+0.00,+0.00,+0.00)(0,0)
           Set the speed of the speed control mode
```

* Adjust the speed command value from low-speed.
* When 0.0 is set with the speed command value, the priority mode is not switched. The robot always operates in the force priority mode.



⚠Caution

The speed specified with the speed command value is the offset speed of the force sense control. It is not the actual operation speed of the robot. When the robot is not operating with the force sense control (operating with speed compensation command or jog operation), and operating only in the speed priority mode, "specified offset speed = robot operation speed".

When the compensation command and jog operation are executed with the speed priority mode, "specified offset speed + specified speed of the jog operation and offset = robot operation speed".

(10) Specifying the mode switching judgment value (P_FsSwf0/P_FsSwf1, FSSWF0#)

Set the threshold used for the switching judgment for "speed priority mode" and "force priority mode" when the speed command value is set.
When the force control is enabled, the speed priority mode and force priority mode can be switched based on the force specified in each axis.

P_FsSwf0 / P_FsSwf1 = (△, △, △, △, △, △,0,0)(0,0)

△= - (force sensor tolerance value) to + (force sensor tolerance value)

X, Y, Z · · · [N]

A, B, C · · · [N·m]

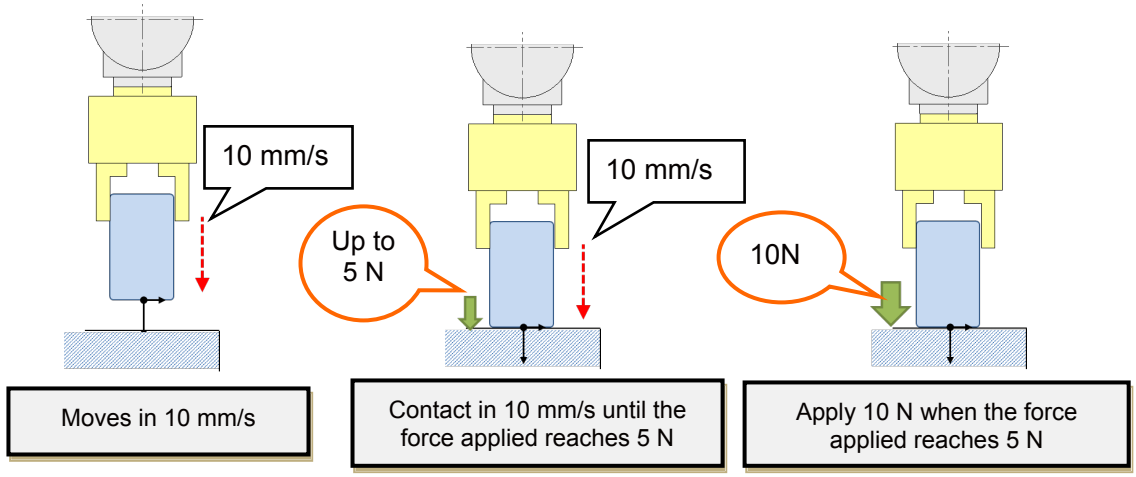
Program example

Operate in 10 [mm/s] until the robot contacts the target in -Z-direction with 5 [N], and apply 10 [N] after contact.

P_FsFCd0 = (0, 0, 1.0, 0, 0, 0, 0, 0)(0, 0) · · · Apply +10 N to tool Z-direction when switched to force priority mode

P_FsSpd0 = (0, 0, 10, 0, 0, 0, 0, 0)(0, 0) · · · Set the speed of Z-direction to 10 mm/s

P_FsSwf0 = (0, 0, 5, 0, 0, 0, 0, 0)(0, 0) · · · Switch to force priority mode when +5 N is applied to Z-direction



<Force priority mode>

- Data from the force sensor is used to control the robot until the force specified with the force specification value is reached.
- The robot moves in the direction which satisfies the force specification value by following the axis direction for which force control is specified.
- The offset speed for force control is limited to the speed command value or below.

<Speed priority mode>

- The robot is controlled so that the speed specified with the speed command value is reached.
- The robot moves in the direction which satisfies the force specification value by following the axis direction for which force control is specified.

◆Practice 4: Specifying the speed command value and mode switching judgment value

1) Execute program "4" to check the movement.

2) Create program "3" with RT ToolBox3 and write it to the robot.

3) When the writing is completed, close the program. Open the program again, and check that the 8th line is "M_FsCod0=0" (tool coordinate system).

4) Operate the robot by the JOG operation and move it to the PStart position.

(* Teach the position 40 mm or more above the scale plate center again.)

5) Turn OFF the enable switch of the T/B, switch to "Automatic" with the mode selection switch, and lower OVRD to 10%. Then execute the automatic operation.

* It will take a lot of time to push the scale.

6) When the program has stopped, open the program again with RT3, and input "+20" to the Z component of P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0) in the 13th line.

Then, write "+0.5" to the Z component of P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0, 0) in 14th line, and write it to the robot controller.

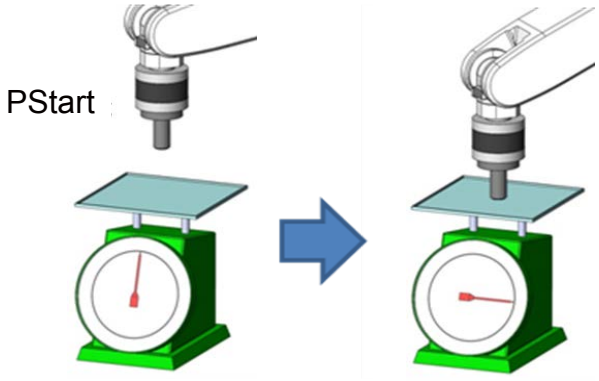
◇◆ Key learning points ◆◇

Understand the speed priority mode and force priority mode using the mode switching judgment value.

Experience shorter operation time by combining the speed priority mode and force priority mode compared to the operation only in the force priority mode.

When the speed priority mode is used, the detection of the judgment value delays as the speed increases, and the force more than the speed command value may be applied to the target workpiece.

Therefore, an appropriate value needs to be set by checking the target workpiece and working details carefully.



◆**Program "4"**

```
1 '-----------------------------------------------
2 ' Practice 4 Specifying the speed command value and mode switching judgment value
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)    'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)    'Force control mode (Z-axis
                                                              enabled)
8   M_FsCod0 = 0                                          'Force sense control coordinate system (XYZ)
9 '[Control characteristics (0)]
10   P_FsGn0   = (+0.00,+0.00,+3.00,+0.00,+0.00,+0.00)(0,0)      'Force control gain [µm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)      'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Set force/speed judgment
                                                                value.
15 '*** <Control> ***
16   PStart=(-60.00,-250.00,+350.00,+180.00,+0.00,+90.00)(7,0)
17   '----- Move the robot to PStart position in advance!
18   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
19   Loadset 1,1
20   OAdl On
21   Spd M_NSpd                    'Set the speed to initial value. (* Valid only for CP control)
22   Ovrd M_Novrd                  'Set the override to initial value.
23   Cnt 0                        'Set the continuous operation for interpolation to initial value.
24   Servo On
25   Wait M_Svo=1
26   Mov PStart
27   Dly 0.5
28   Fsc On, 0, 0, 1               'Start force sense control
29   *Loop1
30   If P_FsCurD.Z<=5 Then *Loop1
31   Dly 10
32   Fsc Off
33   Mvs PStart
34   Dly 0.5
35   Hlt
36 End
```

(11) Specifying the force detection setting value (P_FsFLm0/P_FsFLm1, FSFLMT0#)

Set the force detection setting for interrupt signals and data retention trigger for each coordinate axis.

P_FsFLm0 / P_FsFLm1 = (△, △, △, △, △, △, 0,0)(0,0)

△= 0.0 to + (force sensor tolerance value)

X, Y, Z · · · [N]

A, B, C · · · [N·m]

Program example

P_FsFLm0=(+20.00,+20.00,+5.00,+5.00,+5.00,+5.00)(0,0)

Force detection setting value (specify 5 [N] for Z-axis direction.)

The force detection setting value is used with the following functions.

Function Class		Description	Reference
Force sense detection	Interrupt execution	Monitors the status with regard to the force detection setting value. (The start-up and shut-down status with regard to the force detection setting value can be obtained.)	Chapter 9 Force Sense Detection
	Data latch	Retains the sensor data and position data at the moment when exceeded the force detection setting value.	
Force sense control (T/B)	Contact detection	Stops the JOG operation at the moment when exceeded the specified force (moment).	Appendix 3 Contact Detection

(12) Offset cancel designation

To operate the force sense control function properly, it is necessary to perform a force/moment offset cancel (error component elimination) for each axis with no external force (robot stopped or with no contact made) other than gravity acting on the sensor.

If the offset cancel is set to "1 (enable)", the sensor offset components are offset to set all axis of the force sensor data to 0. Normally, the offset cancel is used when enabled.

<Influence of gravity>

If changing the robot posture significantly, the force component applied to the sensor by gravity will change, which offset cancel needs to be performed again. If the posture changes significantly in every work, it is necessary to perform offset cancel again after the posture changes.

<Offset cancel conditions>

Always satisfy the following conditions when performing offset cancel.

- Robot at complete stop
- No contact with hand/workpiece, etc. (no external force applied)

<Offset cancel setting method>

The offset cancel is set in the following two methods.

1) Using Fsc On command in the program

Set the argument <Offset cancel designation> of Fsc On command to 1.

Fsc On, <Control mode>, <Control characteristics>, <Offset cancel designation>

<Offset cancel designation> = 0 or 1

0: Not cancel (disable)

1: Cancel (enable)

Program example

```
Dly 0.5          'Input Dly before the offset cancel (wait until the control
                   completely stops)
Fsc On, 0, 0, 1  'Enable the force sense control.
                 (Control mode = 0, control characteristics = 0, offset
                 cancel enabled)
```

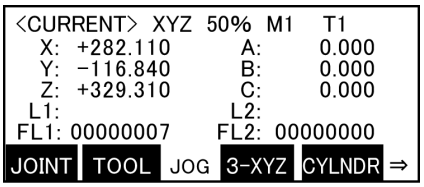
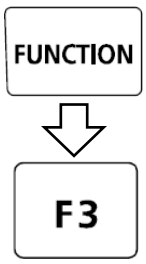
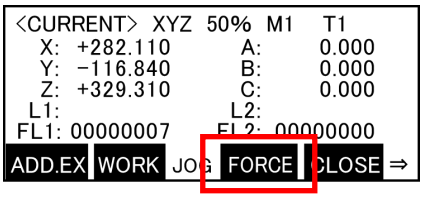
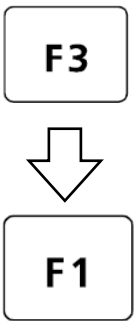
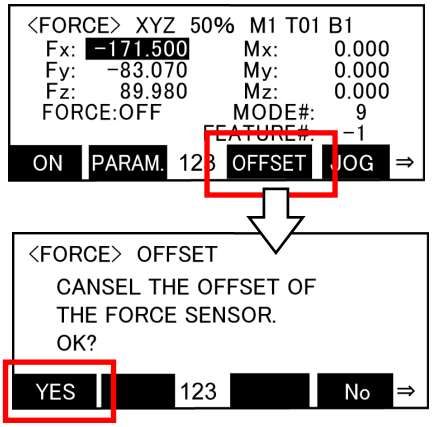
2) Operating offset cancel with the teaching box

Perform jog operation using the force sense control with the teaching box.

* If the force sensor data zero point is offset, the force sense control will not function properly. Always perform the offset cancel operation (sensor zero point offset) before use.

* The offset cancel operation can be performed only when the force sense control is disabled.

- Move the robot to a position where no external force applies on the sensor (position where no contact with hand and others).
- Check that the robot has completely stopped, then perform the offset cancel operation.

Step	How to operate	T/B screen	Description of the operation method
1		<JOG operation screen> 	Press the [JOG] key to display the JOG operation screen.
2		<JOG operation screen> 	Press the [FUNCTION] key and display "FORCE" as the function menu at the bottom of the screen. Press the [F3] key ("FORCE") and display the <FORCE> screen.
3		< Force screen > 	Push the [F3] key in the <FORCE> screen. When the offset cancel confirmation screen is displayed, press the [F1] key ("Yes").

Pick Up!

Precautions for offset cancel operation

- The offset cancel status is reset by restarting the controller. If the controller is restarted, perform the offset cancel operation again.
- Since the gravity effect is included in the sensor offset component, when the robot arm posture is changed significantly, it is necessary to perform the offset cancel operation again.
- The offset amount may change if used for long periods of time due to changes in sensor temperature (temperature drift). In such case, perform the offset cancel operation again.

◆Practice 5: Designating offset cancel

1) Switch to manual mode and then move the ABC-axis to any angle by JOG operation.

2) Switch the teaching box to the force screen to check that the value of Mx to Mz is other than "0".

3) Press the "OFFSET" in the teaching box, and then press "YES".

4) Switch the teaching box to the force screen to check that the value of Mx to Mz is "0.0**".

* Due to the noise and error, the value will not be exactly 0.

(13) Gravity Offset Cancel Function

Gravity offset cancel is a function that the offset cancels in response to a change in the direction of gravity applied to the force sensor by hand load at the time of posture change. To use this function, it is necessary to estimate the bias value of the force sensor, position of the center of gravity and the weight of hand load by the force calibration.

a) Data estimated by the force sensor calibration

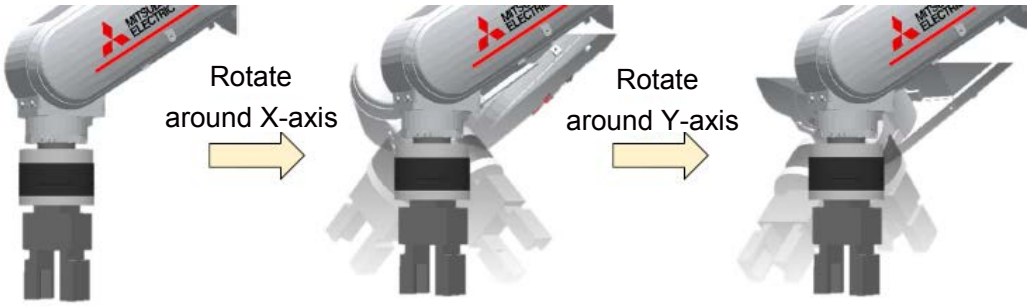
Setting item	Description	Status variable, parameter name
Force sensor bias value	A constant offset amount generated in the sensor in no load (by tightening at the sensor installation).	P_FsBias0／P_FsBias1 FSBIAS0#
Load center of gravity position	The center of gravity position of the load installed to the force sensor.	P_FsGrPos0／P_FsGrPos1 FSGRP0#
Load mass	The mass of the load installed to the force sensor.	M_FsMass0／M_FsMass1 FSMASS0#

(# corresponds to the group number 1 to 8.)

b) Posture required for calibration

The force calibration is required nine postures shown in below.

Posture No.	Condition
1	Posture that the mechanical interface is parallel to the ground.
2	Posture rotated in +X-axis direction of mechanical interface from posture 1.
3	Posture rotated in -X-axis direction of mechanical interface from posture 1.
4	Posture rotated in +Y-axis direction of mechanical interface from posture 1.
5	Posture rotated in -Y-axis direction of mechanical interface from posture 1.
6	Posture rotated in +X-axis direction of mechanical interface from posture 1. * Rotate in different angle from posture No.2.
7	Posture rotated in -X-axis direction of mechanical interface from posture 1. * Rotate in different angle from posture No.3.
8	Posture rotated in +Y-axis direction of mechanical interface from posture 1. * Rotate in different angle from posture No.4.
9	Posture rotated in -Y-axis direction of mechanical interface from posture 1. * Rotate in different angle from posture No.5.



c) Calibration Procedure

Estimation by the force calibration has the following two ways.

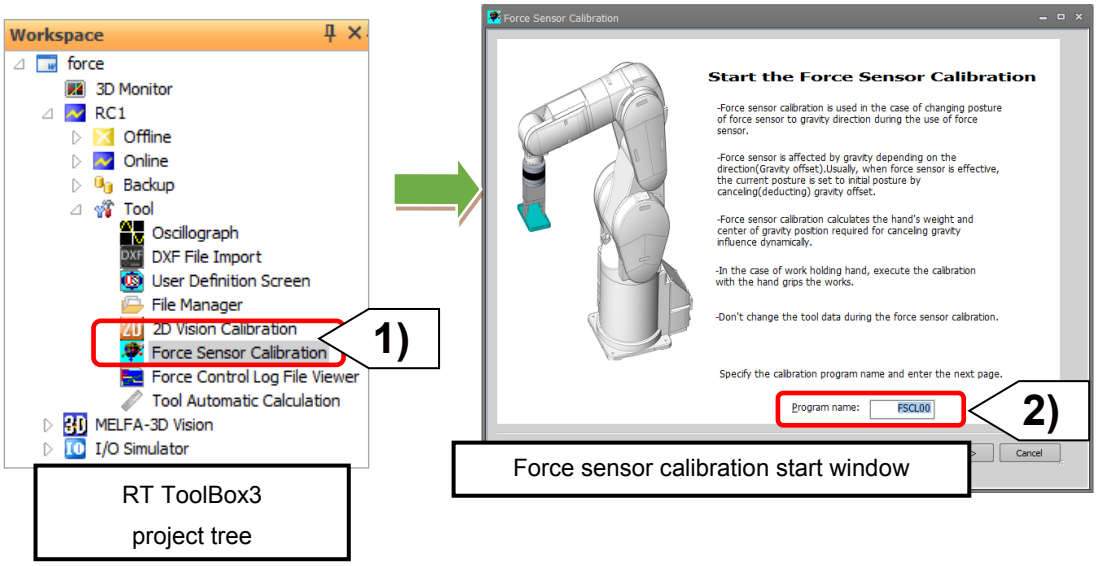
1) Estimate by using the force sensor calibration window of RT ToolBox3
2) Estimated using the robot program.

1) Procedure for estimating by using the force sensor calibration window of RT ToolBox3

1)-1 Specify the program name for the calibration

1) Select [Tool] → [Force Sensor Calibration] from the project tree, Please Start force calibration screen.
2) Please input the program name for the force calibration in the force calibration start screen.
(Input program is generated automatically, and force sensor calibration is executed.)

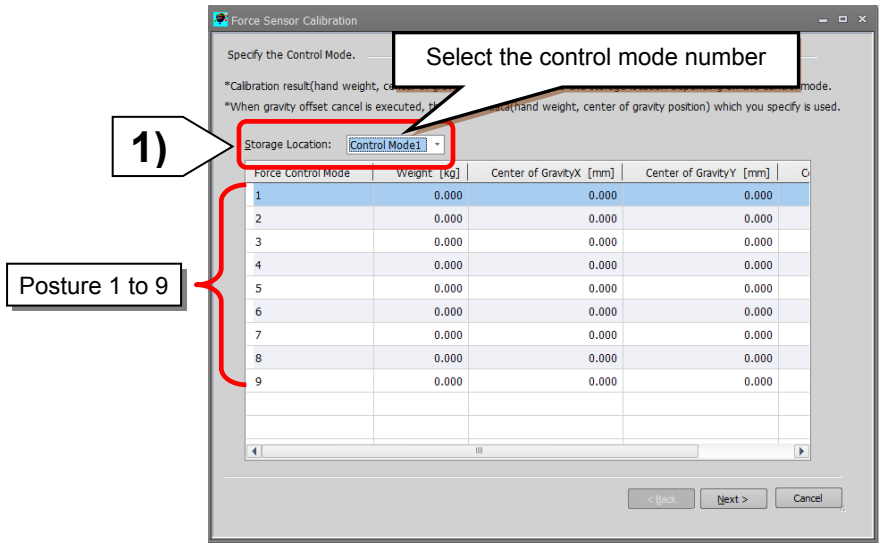
[Note] After calibration is complete, the program will be deleted from the controller.



1)-2 Specify the control mode number (1 to 9) that stores the force sensor calibration result

1) Select the control mode number from the drop-down list of "Storage location" that stores the result.

* At gravity offset cancel, the data of storage location specified by the control mode number is used.



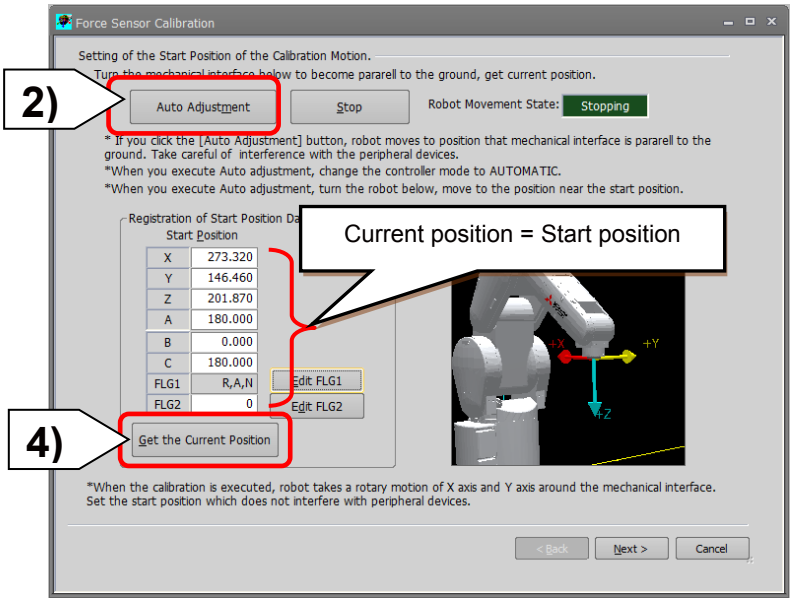
1)-3 Register the start position for the force sensor calibration

1) Move the robot close to the start position to be set.
2) Click the [Auto adjustment] button.
3) The robot moves to the position where the mechanical interface is parallel to the ground.
4) After moving the robot, the current position data of the robot can be imported by clicking the [Get the current position] button. The imported data is the start position.

[Note]

・Set the position at which the mechanical interface of robot is parallel to the ground to the start position.

・The force sense calibration rotates around the mechanical interface twice in the specified angle in X-axis and Y-axis rotation. Adjust the start position to the position that does not interfere with the peripheral device.



⚠Caution

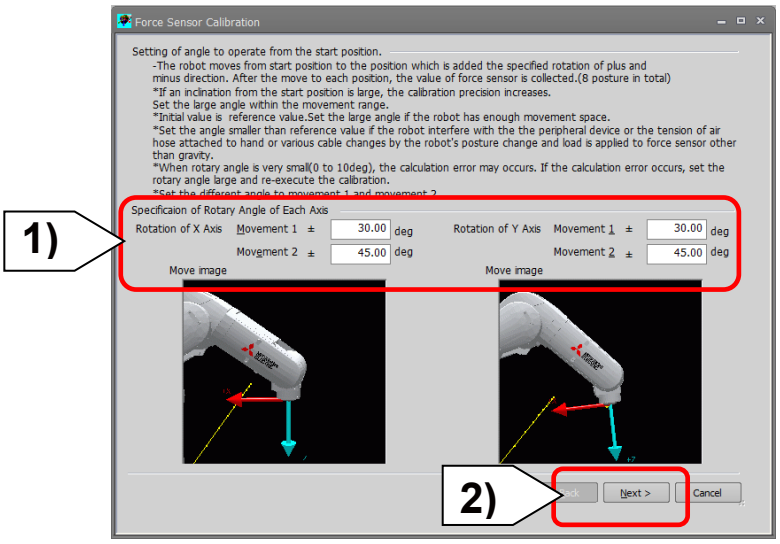
If [Auto adjustment] button is clicked, robot moves. Please check the safety of around the robot. If the override is greater than 10%, override is changed to 10% for safety.
Please prepare T/B to stop anytime in the emergency.

1)-4 Specify the rotary angle at calibration

1) Input the rotary angle from the start position.

2) Click the [Next] button to automatically generate the position data for calibration for 9 points.

[Note] If a same value is set for the angle of movement 1 and movement 2, a correct calibration result cannot be calculated. Set the different angle to movement 1 and movement 2.



⚠Caution

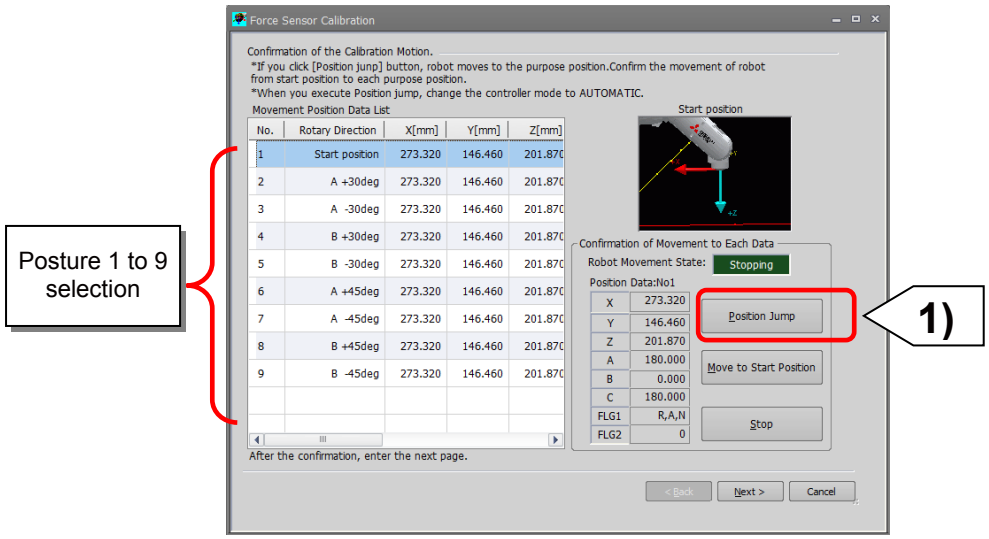
(1) Set the angle smaller than reference value if the robot interferes with the peripheral device or the tension of air hose attached to hand of various cable changes by the robot's posture change and load is applied to force sensor other than gravity.

(2) If the rotary angle is below 10[deg], calibration calculation error can occur. In that case, set the rotary angle large and re-execute the calibration.

1)-5 Check the calibration motion

Check the robot movement with the position data of calibration for 9 points that was automatically generated from the rotary angle from the start position.

1) Select the position data to be checked from "Movement position data list", and then click the [Position jump] button to check the robot movement.



1)-6 Execute the calibration movement

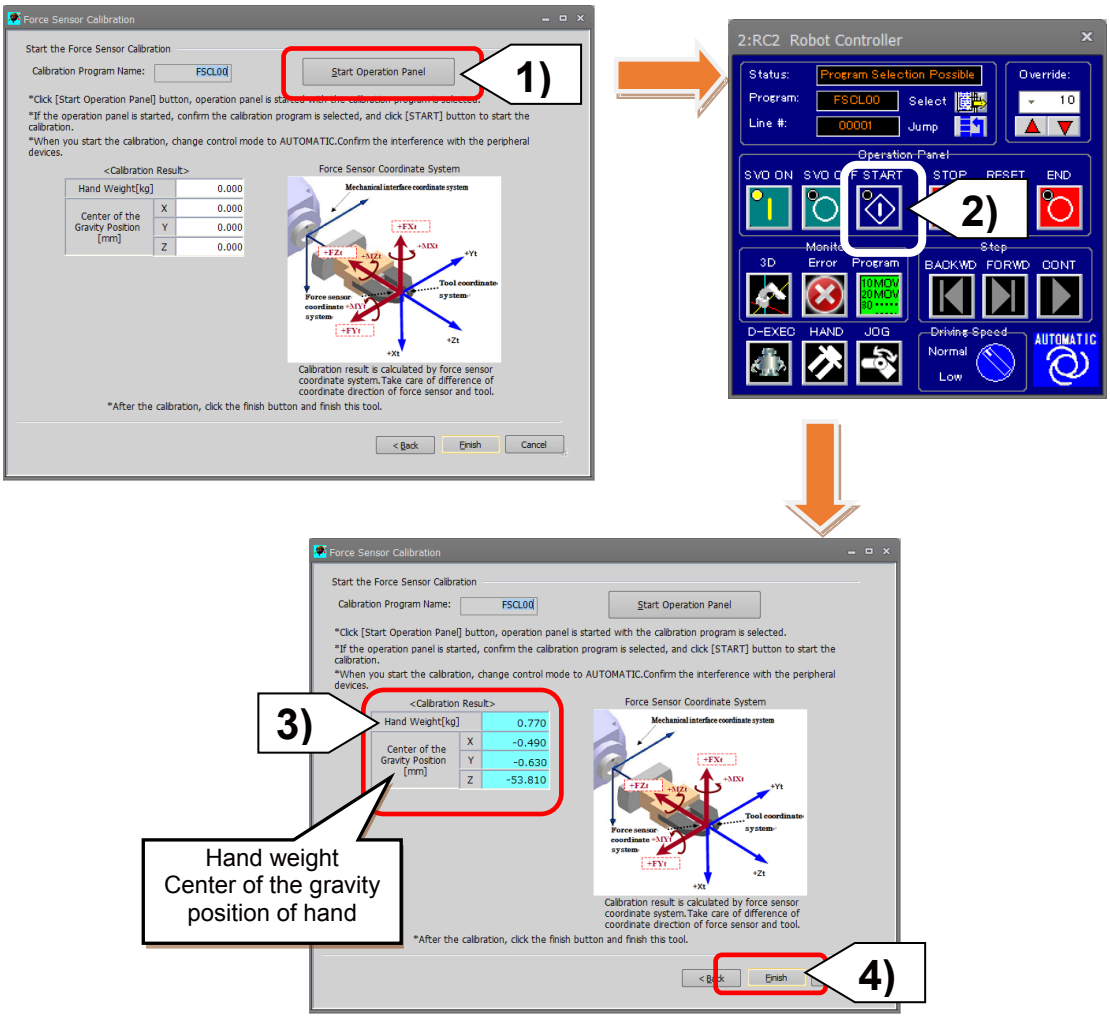
1) If [Start operation panel] button is clicked, operation panel is started that the force calibration program is selected.

2) Please click [Start] button from operation panel and start the calibration.

3) If the calibration is completed, calibration result (hand's weight and center of gravity position) is displayed after the showing of complete message.

4) Please click [Finish] button and end the calibration.

[Note] If the force sensor calibration is finished by clicking the [Finish] button, the program used in the calibration is deleted.



⚠Caution

(1) If [Start] button is clicked, robot moves. Please check the safety of around the robot. If the override is greater than 10%, override is changed to 10% for safety. Please prepare T/B to stop anytime in the emergency.

(2) If the movement speed of robot increases, calibration precision decreases. Do not change default override value as much as possible.

2) Estimated Using the Robot Program

Using the robot program estimate the weight and the position of the center of gravity of the hand load. If you want to estimate a robot program, use the following commands.

No.	Command	Function Overview
1	FsHndEst On	Begin the processing of the force calibration.
2	FsHndEst Off	Estimate the force calibration result, to complete the process.
3	FsGetDat	Get the data (current position and the force sensor data) required to the force calibration.

Estimate the hand load by executing the following program.

◆Program example

```
1 '*** < Force sense calibration execution > ***
2 Dim PP(9)
3 Servo On
4 Mov PP(1)                    'Robot moves to the start point.
5 Dly 1
6 FsHndEst On,0                'Execute the calibration
7 For M1=1 To 9 Step 1
8 Mov PP(M1)                   'Robot moves to the calibration posture
9 Dly 1.5                      'Wait until the robot stops
10 FsGetDat M1                 'The current position and force sense data acquisition
11 Mov PP(1)                   'Robot moves to the start point.
12 Dly 0.5
13 Next M1
14 FsHndEst Off                'Calibration is completed. Estiamte the load.
15 End
```

◆Practice 6: Specifying the gravity offset cancel

1) Execute program "6".

2) Open program "6" and teach PP(1) to PP(9).

PP(1): Reference position

PP(2) to PP(5): Tilt A-axis and B-axis to the positive and negative direction slightly (approximately 10 to 20 degrees) against the reference position.

PP(6) to PP(9): Tilt A-axis and B-axis to the positive and negative direction gradually (approximately 20 to 45 degrees) against the reference position.

3) Execute automatic operation and check that

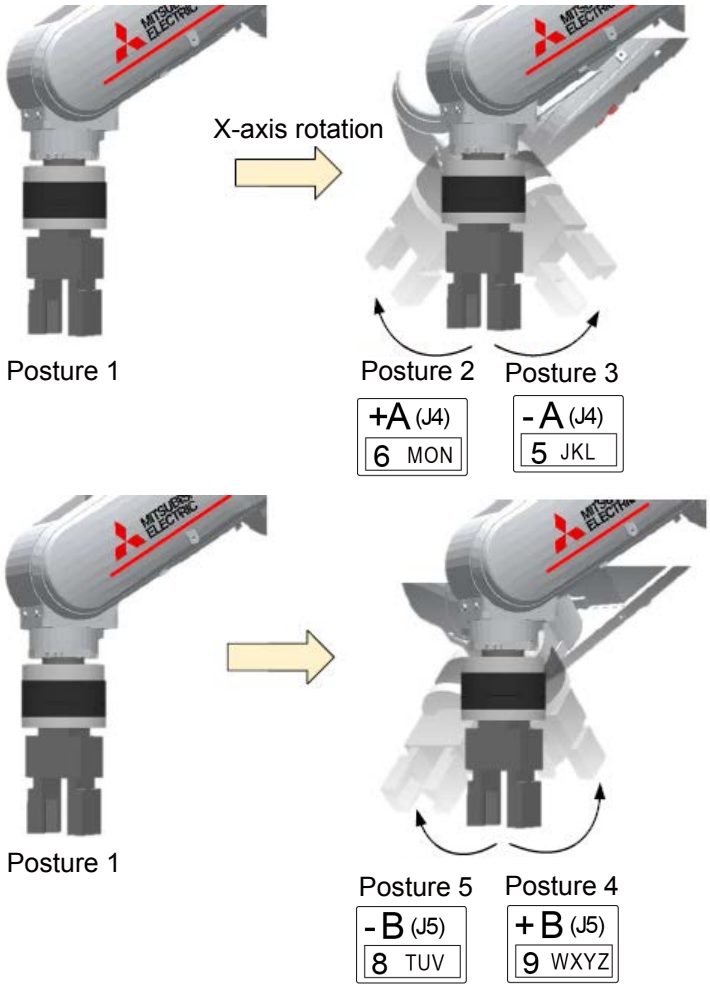
P_FsBias0

P_FsGrPos0

M_FsMass0

are changed after the program has stopped.

Calibration posture movement image



* When teaching PP(2) to PP(9), set the position as a reference (PP(1)) where the A-axis and B-axis can move ±40 degrees from PP(1) by JOG operation.

◆**Program "6"**

```
1 '-----------------------------------------------
2 ' Practice 6 Gravity calibration
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)        'Force control mode (Z-axis enabled)
8   M_FsCod0 = 0                                                 'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10   P_FsGn0    = (+0.00,+0.00,+3.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [μm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)      'Force command
13   P_FsSpd0 = (+0.00,+0.00,+30.00,+0.00,+0.00,+0.00)(0,0)     'Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Set force/speed judgment value.
15 '*** <Control> ***
16   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
17   PBias0=P_FsBias0                                           'Bias value with control mode 0
18   PGrav0=P_FsGrPos0                                          'Center of gravity position of hand tip
                                                                 with control mode 0
19   PHand0.X=M_FsMass0                                         'Hand tip weight with control mode 0
20   Dim PP(9)
21   Loadset 1,1
22   OAdl On
23   Servo On
24   Wait M_Svo=1
25 *Main
26   Mov PP(1)
27   Dly 0.5
28   GoSub *Grav                                                'Automatically calculate gravity offset
29   Servo Off
30   Wait M_Svo=0
31   Hlt
32 End
```

(Continue to the next page →)

(→ Continuation of program "6")

```
33 '----- Subroute -----
34 *Grav
35   FsHndEst On,0
36   For M1 =1 To 9 Step 1
37     Mov PP(M1)
38     Dly 1.5
39     FsGetDat M1
40     Mov PP(1)
41     Dly 0.5
42   Next M1
43   FsHndEst Off
44   PBias=P_FsBias0                          'Bias value with control mode 0
45   PGrav=P_FsGrPos0          'Center of gravity position of hand tip with control mode 0
46   PHand.X=M_FsMass0                        'Hand tip weight with control mode 0
47 Return
48 '--------------------
```

```
[Reference Teaching point data]
PP(1)=(+327.37,+0.00,+233.46,+180.00,+0.00,+180.00)(7,0)
PP(2)=(+327.37,+0.00,+233.46,-160.21,+0.00,+180.00)(7,0)
PP(3)=(+327.37,+0.00,+233.46,+160.15,+0.00,+180.00)(7,0)
PP(4)=(+327.37,+0.00,+233.46,-180.00,-20.90,+180.00)(7,0)
PP(5)=(+327.37,+0.00,+233.46,-180.00,+20.00,+180.00)(7,0)
PP(6)=(+327.37,+0.00,+233.46,-150.00,+0.00,+180.00)(7,0)
PP(7)=(+327.37,+0.00,+233.46,+150.00,+0.00,+180.00)(7,0)
PP(8)=(+327.37,+0.00,+233.46,+180.00,+30.00,+180.00)(7,0)
PP(9)=(+327.37,+0.00,+233.46,+180.00,-29.90,+180.00)(7,0)
PBias=(+5.97,-3.40,-4.10,+0.05,+0.17,+0.18,+0.00,+0.00)(0,0)
PGrav=(-3.33,+6.88,-85.33,+180.00,+0.00,+180.00,+0.00,+0.00)(0,0)
PHand=(+1.89,+0.00,+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(,)
PStart=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(,)
```

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Chapter 6 Force Log

The force log function is used to acquire and display the log data such as force sensor data and position data at automatic operation.
Log data can be viewed in a graph using the RT ToolBox3 force sense control log file viewer.

This function can be used for such tasks as force sense control related parameter adjustments and checking the work status.

Furthermore, this function is equipped with a feature to transfer force sense log files to the computer by FTP, facilitating robot quality control during operation by checking work quality and analyzing data when errors occur.

6.1 Force Log Parameters

It is necessary to set parameter FSLOGFN in order to use the force sense log function.

Parameter	Parameter Name	No. of Elements	Description	Default Factory Setting
Log function	FSLOGFN	3 integers	Specifies settings for the force sense log function. 1st element: Enables/disabled the log function. [Setting range] 0 (disable), 1 (enable) 2nd element: Selects the collected force sensor data type. [Setting range] 0: Raw data (with offset cancel) 1: Raw data (without offset cancel) 2: Data after coordinate conversion (offset cancel designation updated) 3rd element: Specifies whether to use/not use FTP. [Setting range] 0 (Do not use), 1 (Use)	0, 2, 0
Log data transfer	FTPID	1 character string	Sets the user ID used with FsOutLog command FTP communication. 1st element: user ID	ftpuser
	FTPPASS	1 character string	Sets the password used with FsOutLog command FTP communication. 1st element: password	ftppassword
	FTPSVRIP	1 character string	Sets the FTP server IP address used with FsOutLog command FTP communication. 1st element: IP address	192.168.0.99

6.2 Force Log Data Acquisition (FsLog On/FsLog Off)

Robot language MELFA-BASIC FsLog On and FsLog Off commands are used to specify the start and end of log data acquisition. When the FsLog Off command is executed, a log file with specified file No. name is generated.

a) Start acquiring log data

Starts force sensor data and position command, position FB, and current FB value logging.

```
FsLog On
```

b) End acquiring log data

Ends force sensor data and position command, position FB, and current FB value logging.

```
FsLog Off, <Log File No.>
```

<Log File No.>	Specifies the log file No. containing collected data. Setting range: 1 to 999999999

◆Practice 7: Force log

1) Execute program "7" to check the movement.

2) Create program "7" with RT ToolBox3 and write it to the robot.

3) When the writing is complete, close the program. Open the program again, and check that the 8th line is "M_FsCod0=0" (tool coordinate system).

4) Operate the robot by the JOG operation and move it to the PStart position.

5) Turn OFF the enable switch of the T/B, and switch to "Automatic" with the mode selection switch, and lower OVRD to 10%. Then execute the automatic operation.

6) When the automatic operation starts, the log is acquired for 20 seconds followed by the external force, and save it as "999".

7) Turn OFF the servo and check that the automatic operation program has stopped. Then check the log with RT3. (Select "Force Control Log File Viewer" in "Tool" of RT ToolBox3, and then select "999" from the robot controller.)

◇◆ Key learning points ◆◇

Understand the force log function. The force log function can record the value of the force sensor for a certain period of time, which is effective for managing the quality and for tracing.

Apply force to each axis to check that the log is acquired properly.

◆**Program "7"**

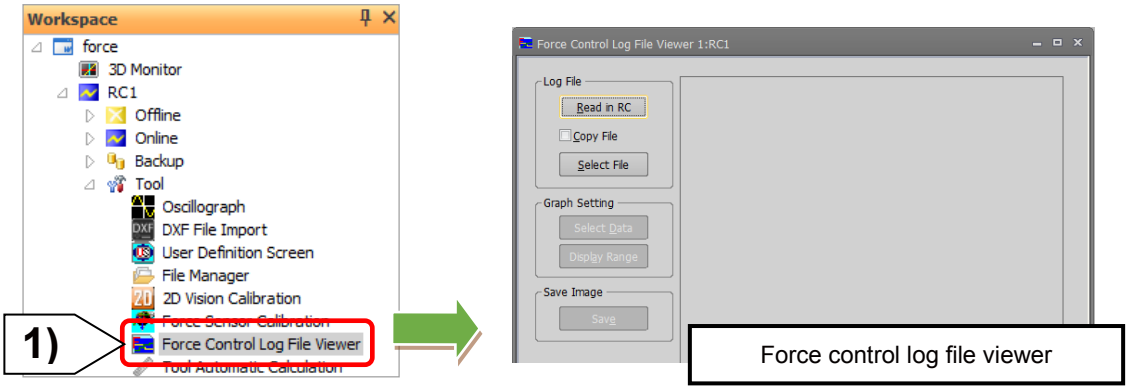
```
1 '-----------------------------------------------
2 ' Practice 7 Force log
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient
7   P_FsMod0 = (+1.00,+1.00,+1.00,+0.00,+0.00,+0.00)(0,0)        'Force control mode (XYZ-axis
                                                                 enabled)
8   M_FsCod0 = 0                                          'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10   P_FsGn0   = (+5.00,+5.00,+5.00,+0.00,+0.00,+0.00)(0,0)      'Force control gain [µm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set force/speed judgment value.
15 '*** <Control> ***
16   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
17   GoSub *INIT
18 *Main
19   FsLog On
20   Fsc On,0,0,1                                          'Start force sense control
21   Dly 15
22   Fsc Off
23   FsLog Off,999
24   Hlt
25 End
26 '----- Subroute -----
27 *INIT
28   P_FsBias0=P_Zero                                      'Bias value with control mode 0
29   P_FsGrPos0=P_Zero                  'Center of gravity position of hand tip with control mode 0
30   M_FsMass0=0                                           'Hand tip weight with control mode 0
31   Loadset 1,1
32   OAdl On
33   Servo On
34   Wait M_Svo=1
35 Return
36 '--------------------
```

6.3 Force Sense Log Data Display (RT ToolBox3)

The method used to display force sense log data in a graph using the RT ToolBox3 force control log file viewer function is described below.

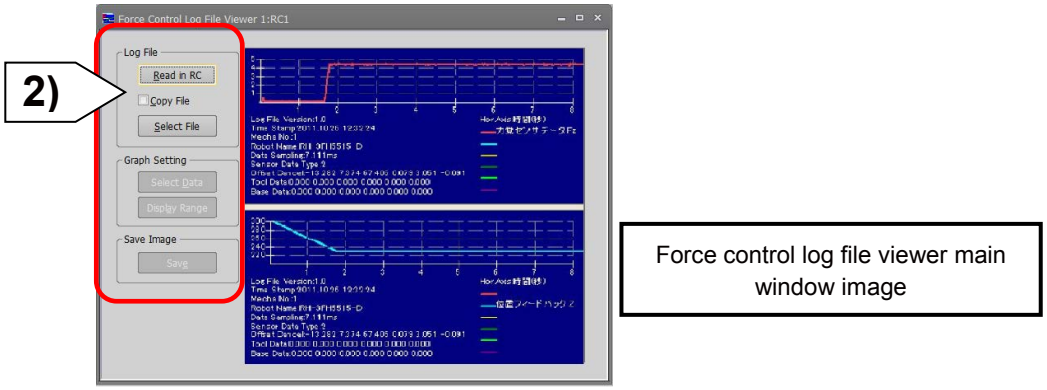
(1) Start Method

Select [Tool] → [Force Control Log File Viewer] in the RT ToolBox3 workspace to display the force control log file viewer window.



(2) Main Window

Log files are imported and displayed in a graph using the buttons on the force control log file viewer main window.



1) [Read in RC]
Read the force log file saved in the R/C (robot controller) to personal computer.

2) [Copy file] check box
When this is selected and the force log file is read with the [Read in RC] button, the save force log window appears after the reading completes, and the force log file can be saved to the personal computer.

3) [Select File]
Read the log file selected in the log file list.

4) [Select Data]
Select the data to display in graph.

5) [Display Range]
Set max./min. of vertical axis/horizontal axis for the wave data graph to be displayed.

6) [Save]
Convert the data displayed on the display area to bitmap file and save it to the personal computer.

6.4 Force Log File FTP Transfer

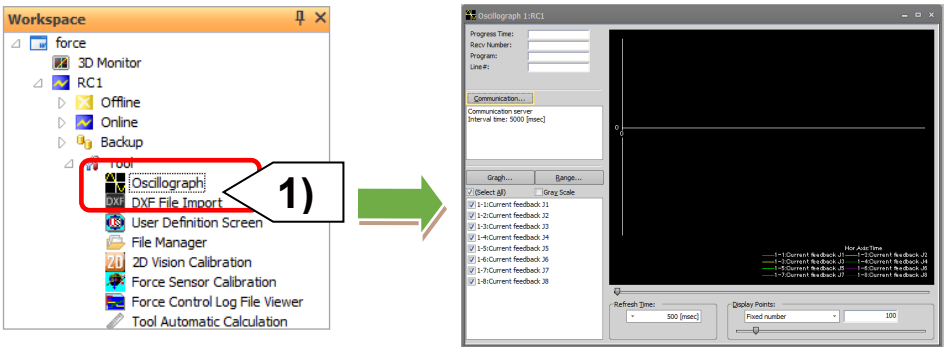
The force log file created in the robot controller can be transferred to the FTP server (personal computer) by using FsOutLog command of robot language MELFA-BASIC.

The transferred data can be used for checking the work quality, and analyzing at error occurrence. For details, refer to " Appendix 5 Force Sense Log File FTP Transfer ".

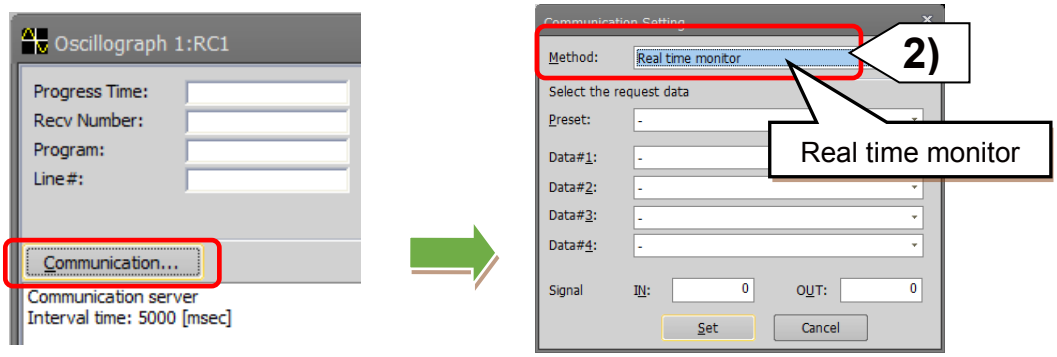
6.5 Oscillograph (RT ToolBox3)

The force transition can be monitored and converted to data by the oscillograph of RT ToolBox3. The oscillograph can display the internal data of robot in a graph. The data acquired from the robot can be saved and read to the CSV file.

1) Select [Oscillograph] in [Tool] from the project tree.



2) Open the communication setting window and select "Real time monitor" for "Method".

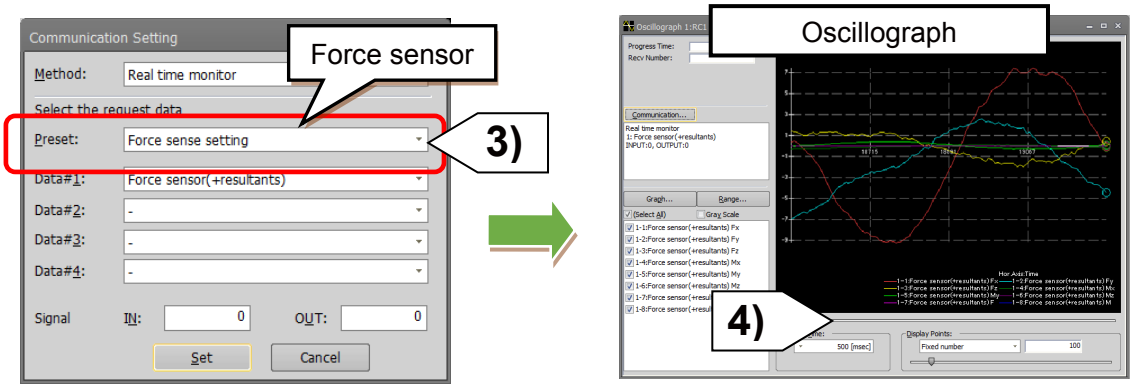


* When using the real time monitor, use Ethernet for communicating the personal computer and robot. (Note 1)

3) Select "Force sensor" from the list in "Select the request data".

4) The oscillograph is displayed. The force information of each axis can be monitored.

The data can be managed in the CSV file.



Note 1) For the Ethernet communication, refer to " Appendix 5 Appendix 5.2 RT ToolBox3 Creating a project for the oscillograph ".

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Chapter 7 Teaching Operation

This Chapter describes teaching operation using force sense control.

Pick Up!

Teaching operation precautions

If using force sense control, the position displayed on the teaching pendant and the actual robot position will differ. Since the difference affects the teaching operation, fully understand the following "Teaching Position Precautions" and perform the teaching operation.

7.1 Teaching Position Precautions

When using force sense control, the robot control controls the following two types of position.

	Position Command Type	Description
(1)	Position command	This is a movement command generated by the robot program and JOG operation. It is referenced by the current position display and teaching operations. (Position displayed on T/B)
(2)	Force sense position command	Position command offset by force sense control. When force sense control is enabled, the robot moves based on this command.

By performing teaching operation (teaching operation from T/B or current position reading from RT ToolBox3) from the teaching box or RT ToolBox3 while force control is enabled, the position command (1) is taught, and a position different from the actual robot position (2) is taught.

When teaching the position offset by the force sense control, perform "teaching position search" with the force sense control enabled, or disable the force sense control.

7.2 Teaching Position Search

The "teaching position search" function is used for teaching the current position with the force sense control enabled.

The "position displayed on the teaching box" is defined with the position data when the force sense control is enabled.

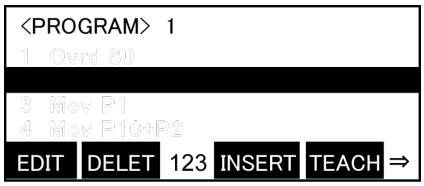
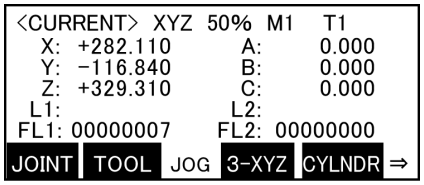
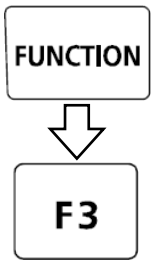
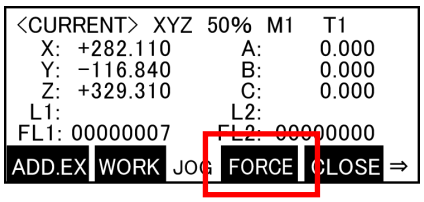
When the robot is moved by using the force sense control after the force sense control is enabled, the actual position of the robot will be the "position displayed on the teaching box" with the amount of offset by the force sense control, which is different from the "position displayed on the teaching box". (The position displayed on the teaching box does not change.)

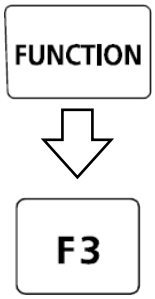
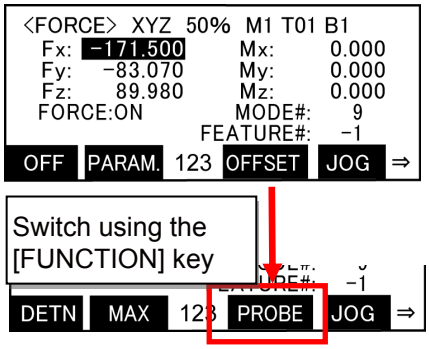
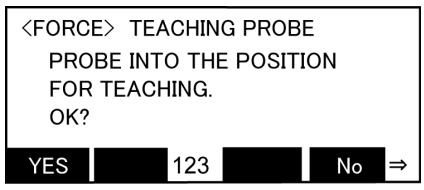
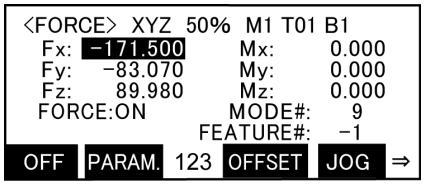
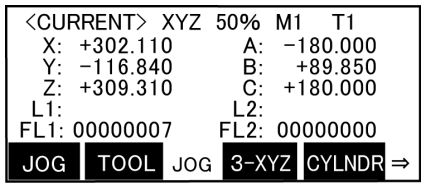
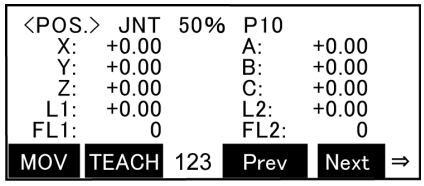
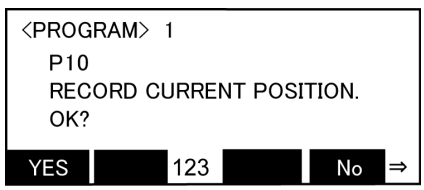
If the teaching operation is performed on the teaching box with the difference remains, since the "position displayed on the teaching box" will be taught to the position variables, add the offset amount by the force sense control before teaching.
(Refer to " Chapter7 7.1 Teaching Position Precautions" in the previous page.)

By executing this function, the "position displayed on the teaching box" can be replaced with the "actual position" with force sense control enabled.

* Even this function is not executed and the force sense control disabled, the "actual position" can be taught.

[Teaching position search → Teach current position]

Step	How to operate	T/B screen	Description of the operation method
1		<Instruction editing window>  	Create a new program on the teaching box, and open it. (The program number is 1 as an example.)
2	 	<JOG operation screen>  	Press the [JOG] key and display the JOG operation screen.
3	 	<JOG operation screen>  	Press the [FUNCTION] key and display "FORCE" as the function menu at the bottom of the screen. Press the [F3] key ("FORCE") and display the <FORCE> screen.

Step	How to operate	T/B screen	Description of the operation method
4		<FORCE screen> 	The current position of the force sensor data is displayed. Press the [FUNCTION] key and display "PROBE" as the function menu at the bottom of the screen. Press the [F3] key ("PROBE").
5		<Teaching probe execution confirmation screen> 	The "TEACHING PROBE" screen is displayed. Press the [F1] key ("Yes") and execute the teaching position search function.
6		<FORCE screen> 	When the position search is completed, the screen returns to the <FORCE> screen.
7		<JOG operation screen> 	Press the [F4] key ("JOG") to return to the JOG operation screen.
8		<Position editing window> 	Press the [JOG] button (release JOG mode) and display the <POS.> screen.
9		<JOG operation screen> 	Press the [F2] key ("Teach").

* For the operation of the R56TB, refer to "Appendix 4 Operation of the Teaching Box (R56TB) (6) Position search".

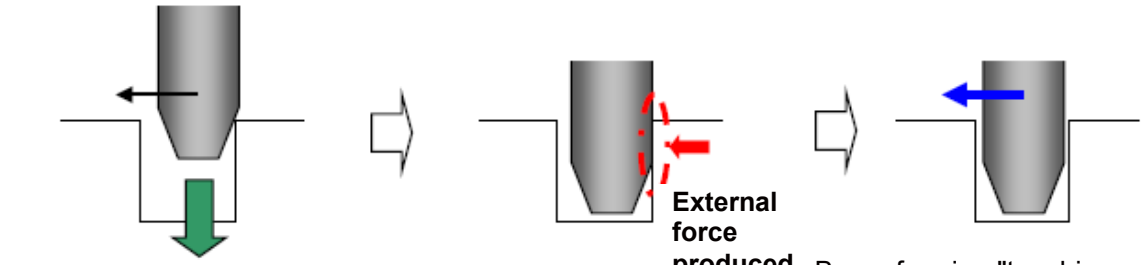
7.3 Precautions when using stiffness control

The spring center position when using stiffness control is the position displayed on the teaching pendant. The spring center position also moves when performing "teaching position search", and so if a stiffness coefficient of other than 0.0 is set, the robot moves a little. Utilizing this characteristic, a position on which no external force acts can be taught when using stiffness control as shown in the following example.

[Example]

If inserting pins while following the workpiece shape with stiffness control(stiffness coefficient ≠ 0), external force acts on one side of the pin. By performing "teaching position search" at such times, the robot can be moved in a direction in which no external force acts.

There may be cases in which the robot is unable to move to a position in which no external force acts by performing this function only once. In such a case, perform several times while keeping an eye on the force sensor data until the reaction force becomes sufficiently small.

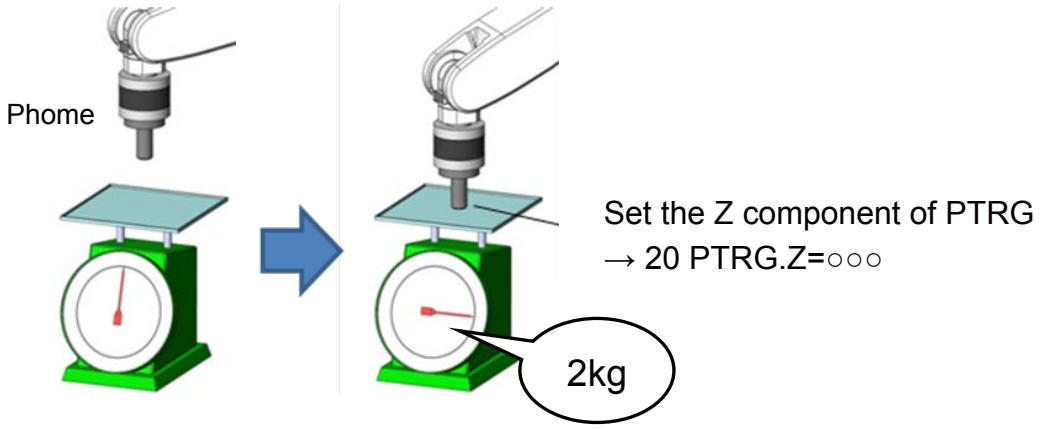


7.4 Practice

◆Practice 8: Teaching the force sense

* Learn how to teach the position command and force sense position command when the force sense control is enabled.

1) Teach a point above the scale for Phome and move it to the position where the scale pointer points at "2 kg" by JOG operation, and record the value of Z.
2) Input the recorded Z value to "PTRG.Z=" in the 20th line.
3) Execute program "8".
4) Check P1 to P5 by the program monitor.
5) Check that P_Curr is changed despite the position during the force sense control and after the force sense control are the same.



◆**Program "8"**

```
1 '-----------------------------------------------
2 ' Practice 8: Teaching the force sense
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)          'Force control mode (Z-axis
                                                                    enabled)
8   M_FsCod0 = 0                                                  'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10   P_FsGn0   = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)      'Force control gain [µm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)        'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set force/speed judgment value.
15 '*** <Control> ***
16   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
17   GoSub *INIT
18 *Main
19   PTRG=P_Fbc
20   PTRG.Z=260
21   Ovrd 5
22   Fsc On,0,0,1                                                  'Start force sense control
23   Mvs PTRG
24   Dly 5
25   P1=P_Cur                                          'Position command value during the force sense control
26   P2=P_FsCurP                 'Force sense position command value during the force sense control
27   P3=P_Fbc                                                      'Current position by feedback
28   Dly 2
29   Fsc Off
30   Dly 2
31   Ovrd M_NOvrd
32   P4=P_Cur                                                     'Position command value after the force
                                                                   sense control
33   P5=P_Fbc                                                     'Current position by feedback
34   Servo Off
35   Wait M_Svo=0
36   Hlt
37 End
```

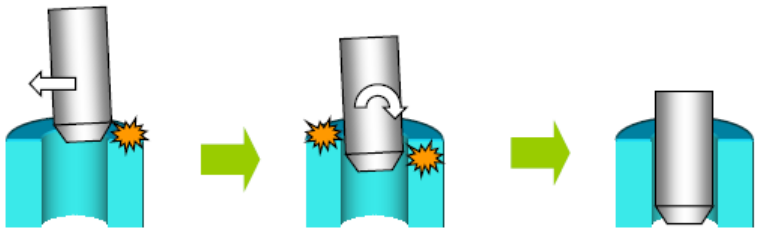
(Continue to the next page →)

(→ Continuation of program "8")

```
38 '----- Subroute -----
39 *INIT
40   P_FsBias0=P_Zero                          'Bias value with control mode 0
41   P_FsGrPos0=P_Zero          'Center of gravity position of hand tip with control mode 0
42   M_FsMass0=0                               'Hand tip weight with control mode 0
43   Loadset 1,1
44   OAdl On
45   Servo On
46   Wait M_Svo=1
47   Pnow=P_Fbc
48   If Pnow.Z < PHome.Z Then
49     Pnow.Z=PHome.Z
50     Mvs Pnow
51     Pnow2=Align(Pnow)
52     Mvs Pnow2
53     Dly 0.2
54   EndIf
55   Mov PHome
56   Dly 0.2
57 Return
58 '--------------------
```

<<MEMO>> *Please use this page for your memo.

◆Practice 9 Teaching the insert complete position with the force sensor (using the force control)



[Setting item] Set the value of "Control mode" and "Control characteristics" from the following table.

Control mode	Stiffness coefficient [N/mm]	P_FsStf0	+0.00, +0.00, +0.00, +0.10, +0.10, +0.10
	Damping coefficient	P_FsDmp0	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Force control mode (control all axes)	P_FsMod0	+1.00, +1.00, +1.00, +1.00, +1.00, +1.00
	Force sense control coordinate system (tool)	M_FsCod0	0
Control characteristics	Force sense control gain [μm/N]	P_FsGn0	+5.00, +5.00, +5.00, +5.00, +5.00, +5.00
	Force detection setting value [N]	P_FsFLm0	+2000.0, +2000.0, +2000.0, +200.0, +200.0, +200.0
	Force command value	P_FsFCd0	+0.00, +0.00, +5.00, +0.00, +0.00, +0.00
	Speed command value	P_FsSpd0	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Mode switching judgment value	P_FsSwF0	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
Hand	Tool	Tool	+0.00, +0.00, +185.00, +0.00, +0.00, +0.00

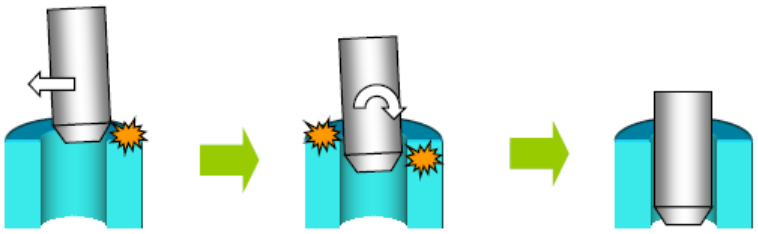
[Operation procedure]

1) Open the "Force Control Mode 2" window with RT ToolBox3 to set the force control for X, Y, Z, A, B, and C-axis.
2) Check that all items of "Stiffness coefficients" and "Damping coefficients" are "0".
3) Set "Coordinate system" to "Tool Coordinate System".
4) Open the **"Force Control Characteristics 2"** window and select the "Speed condition" tab. Then set all the values to "0".
5) Select the "Force condition" tab in the **"Force Control Characteristics 2"** window.
6) Set "Force Gain" to "5.00" for X, Y, Z, A, B, and C.
7) Set the Z-axis of "Force Cmd." to "5.00".
8) Set "Force detection" to "2000" for X, Y, and Z, "200" for A, B, and C. Then press the "Write" button.
9) Open the **"Control Characteristics 3"** window and input the same value as "Control Characteristics 2" but change the value of "Force Cmd." to "-5". Then press the "Write" button.
10) Move the robot above the insert position. After the aligning the hand, move the A and B-axis for approximately 0.5 degrees.
11) Select control mode 2 and control feature 2, then enable the offset cancel. Start the force sense control and wait until the insertion completes.
12) When the robot has stopped, press "PROBE" on the teaching box.
    Turn OFF the force sensor when the robot settles around the command value, and teach that position.
13) When an appropriate insert position has determined, set to **control mode 2** and **control characteristics 3**, and then turn ON the force sense. Then pull out the robot.

◇◆ Key learning points ◆◇

Learn the usefulness of preparing the control characteristics of inserting and pulling out in advance for precise inserting operation.

◆Practice 10 Teaching the insert complete position with the force sensor (using the stiffness control)



[Setting item] Set the value of "Control mode" and "Control characteristics" from the following table.

Control mode	Stiffness coefficient [N/mm]	P_FsStf0	+0.00,+0.00,+0.00,+0.10,+0.10,+0.10
	Damping coefficient	P_FsDmp0	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Force control mode (XYZ-axis force control, ABC-axis stiffness control)	P_FsMod0	+1.00, +1.00, +1.00, +2.00, +2.00, +2.00
	Force sense control coordinate system（tool）	M_FsCod0	0
Control characteristics	Force sense control gain [μm/N]	P_FsGn0	+5.00, +5.00, +5.00, +10.00, +10.00, +10.00
	Force detection setting value [N]	P_FsFLm0	+2000.0, +2000.0, +2000.0, +200.0, +200.0, +200.0
	Force command value	P_FsFCd0	+0.00, +0.00, +5.00, +0.00, +0.00, +0.00
	Speed command value	P_FsSpd0	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Mode switching judgment value	P_FsSwF0	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
Hand	Tool	Tool	+0.00, +0.00, +185.00, +0.00, +0.00, +0.00

[Operation procedure]

1) Open the **"Force Control Mode 2"** window with RT ToolBox3 to set the force control for X, Y, and Z-axis, and stiffness control for A, B, and C-axis.
2) Set "0.1" for A, B, and C-axis of "Stiffness coefficients", and "0" for all axes of "Damping coefficients".
3) Set "Coordinate system" to "Tool Coordinate System".
4) Open the **"Force Control Characteristics 2"** window and select the "Speed condition" tab. Then set all the values to "0".
5) Select the "Force condition" tab in the **"Force Control Characteristics 2"** window.
6) Set "Force Gain" to "5.00" for X, Y, and Z, "10.00" for A, B, and C.
7) Set the Z-axis of "Force Cmd." to "5.00".
8) Set "Force detection" to "2000" for X, Y, and Z, "200" for A, B, and C. Then press the "Write" button.
9) Open the **"Control Characteristics 3"** window and input the same value as "Control Characteristics 2" but change the value of "Force Cmd." to "-5". Then press the "Write" button.
10) Move the robot above the insert position. After the aligning the hand, move the A and B-axis for approximately "0.5 degrees".
11) Select **control mode 2** and **control feature 2**, then enable the offset cancel. Start the force sense control and wait until the insertion completes.
12) When the robot has stopped, press "PROBE" on the teaching box. Turn OFF the force sensor when the robot settles around the command value, and teach that position.
13) When an appropriate insert position has determined, set to **control mode 2** and **control characteristics 3**, and then turn ON the force sense. Then pull out the robot.

◇◆ Key learning points ◆◇

Learn that the probability of "twist" decreases by controlling A, B, and C-axis by the stiffness control rather than the force control for precise inserting operation. (Know-how)

Chapter 8 Force Sense Function (Interrupt Processing)

8.1 Control mode/Control characteristics

(1) Control characteristics Change Commands (FsGChg/FsCTrg)

The "control characteristics " (force sense control gain, force specification value/limit value, speed command value, mode switching judgment value, force detection setting value) settings can be changed while force sense control is enabled using the MELFA-BASIC language FsGChg and FsCTrg commands.

Changing the "control characteristics " during movement facilitates work with a great degree of freedom. (The "control mode" cannot be changed until the Fsc Off command has been executed.)

a) Changing the control characteristics during the movement (FsGChg)

FsGChg <Change start position>, <Change time>, <Control characteristics No. after change>

Program example

```
FsGChg 30, 500, -1
Change the control characteristics to -1 at 30% (switching time: 500 ms)
```

Changes the control characteristics of force sense control during movement.

<Change start position>

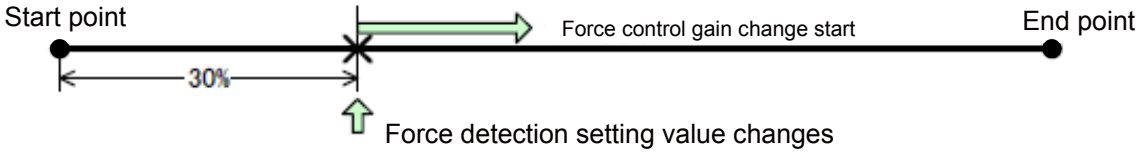
Specifies the position at which the change to the control characteristics setting is started.
Specify with a percentage for the next interpolation start point → end point
Setting range: 0 to 100 [%]

<Change time>

Specifies the time taken to change the control characteristics setting.
The mode switching judgment value and force detection setting value changes immediately, regardless of this setting.
Setting range: 1 to 1000 [ms]

<Control characteristics No. after change>

Specifies the control characteristics value for which the force control gain, force command value, and force detection setting value, speed command value and mode switching judgment value are set after the change.
Setting range: -1 to 9



Example: in case of the change start position set at 30%

b) Switching the control characteristics by Mo trigger (FsCTrg)

FsCTrg <Trigger No.>, <Change time>, <Control characteristic group No. after change>
[, <Timeout>, <Execution method> [, <Error specification>]]

Program example

```
Def MoTrg 1, P_FsCurD.Y>4.5     'Mo trigger #1 definition: force sensor data Fy > 4.5 [N] ·· 1)
Mvs PStart                      'Move to the start position
Dly 1                           'Wait until the robot completely stops
Fsc On, 0, 0, 1                 'Force sense enabled
FsCTrg 1, 10, -1, 30, 0 , 1     'Specify the control characteristics switching by Mo trigger #1·· 2)
```

1) Establish condition of Mo trigger #1 when Fy > 4.5 N is satisfied
2) Change the control characteristics from "0" to "-1" when condition of Mo trigger #1 is established

Sets the control characteristics change for force sense control with an Mo trigger.
* If using the FsCTrg command, it is necessary to set the Mo trigger conditions beforehand.
(For the Mo trigger, refer to "Chapter9 9.2 Mo Trigger".)

<Trigger No.>
Specifies the Mo trigger No. used to change the control characteristic with a constant.
Setting range: 1 to 3

<Change time>
Specifies the time taken to change the control characteristic.
The force detection setting value and mode switching judgment value change immediately, regardless of this setting.
Setting range: 1 to 1000 [ms]

<Control characteristic group No. after change>
Specifies the control characteristic group No. applied after the change.
Setting range: -1 to 9

<Timeout>
Specifies the Mo trigger timeout monitoring time with a constant.
Setting range: 0 to 60 [s]
If omitted, timeout processing is not performed.

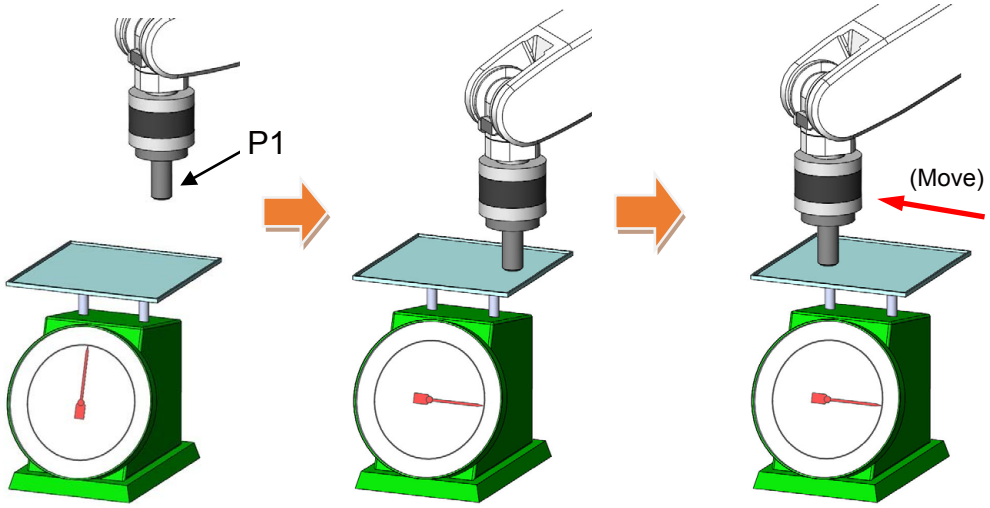
<Execution method>
Specifies the timeout monitoring execution method for this command with a constant.
0: Proceeds to next program without waiting for Mo trigger ON.
1: Does not proceed to next program until Mo trigger turns ON or timeout reached.

<Error specification>
Specifies whether an error occurs following a timeout.
0: An error occurs.
1: An error does not occur.

8.2 Practice

◆Practice 11: Changing the control characteristics

1) Execute program "11".
2) Teach the position approximately 10 mm above the scale for P1.
   (For P1, teach the position close to the robot, rather than the center of the scale.)
3) When the program is executed, the robot moves in the -Y direction. Check that the pushing force changes from the last half of the movement.
4) Also, check how the force changes by changing the argument of FsGChg.



◆**Program "11"**

```
1 '-----------------------------------------------
2 ' Practice 11: Changing the control characteristics
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)        'Force control mode (Z-axis
                                                                  enabled)
8   M_FsCod0 = 0                                                 'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10  P_FsGn0   = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [µm/N]
11  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force detection setting value [N]
12  P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)       'Force command
13  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set speed control mode speed.
14  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set force/speed judgment value.
15  '[Control characteristics (1)]
16  P_FsGn1   = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [µm/N]
17  P_FsFLm1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force detection setting value [N]
18  P_FsFCd1 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)      'Force command
19  P_FsSpd1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set speed control mode speed.
20  P_FsSwF1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set force/speed judgment value.
21 '*** <Control> ***
22  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
23  GoSub *INIT
24 *Main
25  Ovrd 5
26  Dly 1
27  Fsc On,0,0,1                                                 'Start force sense control
28  Dly 10
29  FsGChg 50,10,-1
30  Dly 0.5
31  Mvs P1+(+0.00,-120.00,+0.00)
32  Dly 0.5
33  Fsc Off
34  Mvs P_Curr+(+0.00,+0.00,+50.00,+0.00,+0.00,+0.00)
35  Hlt
36 End
```

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(→ Continuation of program "11")

```
37 '----- Subroute -----
38 *INIT
39   Loadset 1,1
40   OAdl On
41   Servo On
42   Wait M_Svo=1
43   Pnow=P_Fbc
44   If Pnow.Z < P1.Z Then
45     Pnow.Z=P1.Z
46     Mvs Pnow
47     Pnow2=Align(Pnow)
48     Mvs Pnow2
49     Dly 0.2
50   EndIf
51   Mov P1
52   Dly 0.2
53 Return
54 '--------------------
```

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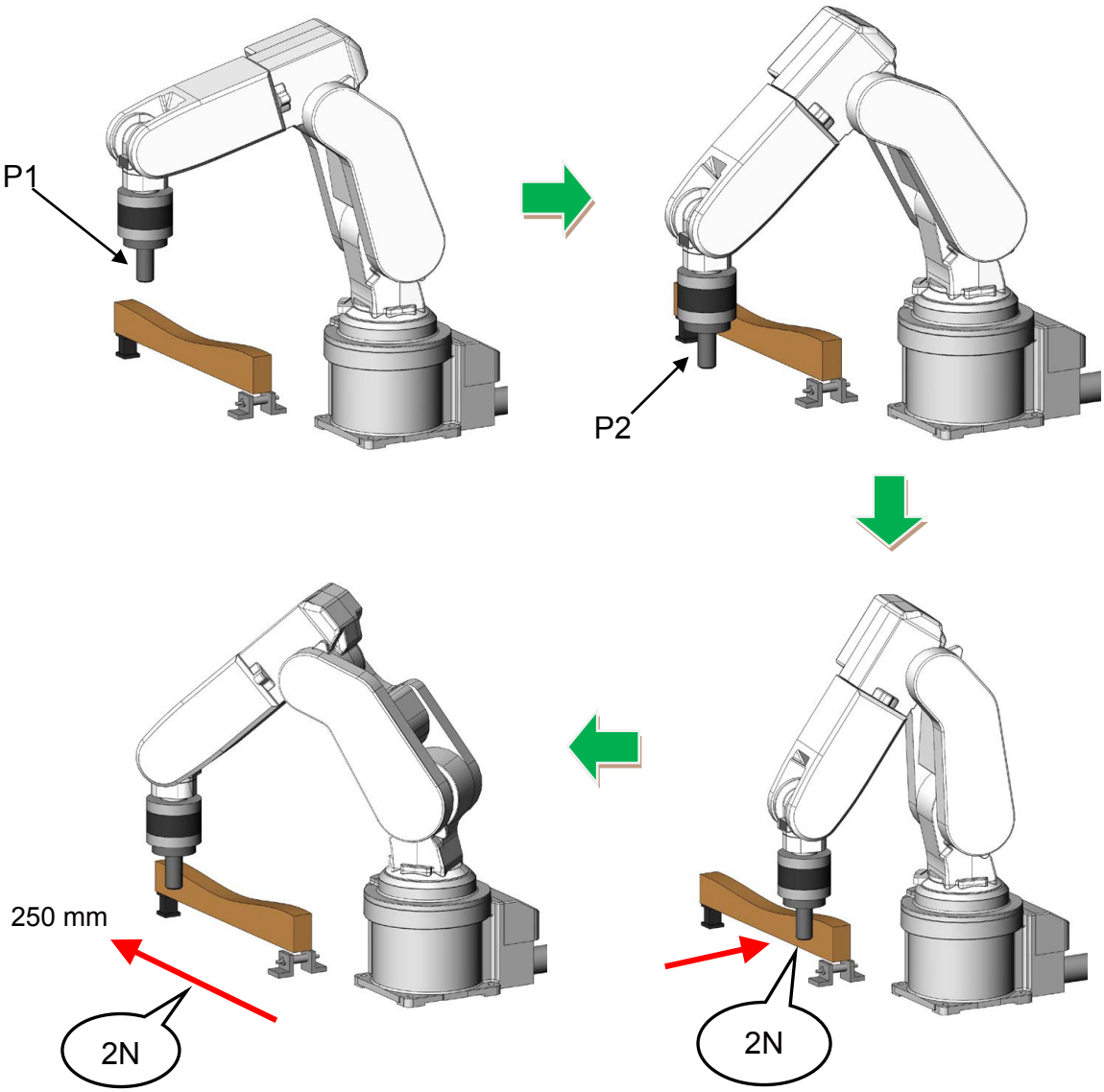
◆Practice 12: Changing the control characteristics

Learn the movement of the MoTrg command by using the side of the metal parts with a curve.

1) Execute program "12".
2) Set the position 10 mm ahead the parts as P2, and the position above P2 where it does not interfere with the surroundings as P1.
3) The robot moves toward the metal parts (-X direction) until "2 N" is applied. Check that when that force is applied, the robot moves -250 mm (-Y direction), applying "2 N" to the parts.



◆Program "12"

```
1 '-----------------------------------------------
2 ' Practice 12: Changing the control characteristics MoTrg
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
7   P_FsMod0 = (+1.00,+1.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Force control mode (X, Y-axis
                                                                    enabled)
8   M_FsCod0 = 0                                                   ' Force sense control coordinate system (tool)
9   '[Control characteristics (0)]
10   P_FsGn0   = (+10.00,+10.00,+0.00,+0.00,+0.00,+0.00)(0,0)  ' Force control gain [μm/N]
11   P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Force detection setting value [N]
12   P_FsFCd0 = (+2.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Set speed control mode speed.
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Set force/speed judgment value.
15   '[Control characteristics (-1)]
16   P_FsGn1   = (+10.00,+10.00,+0.00,+0.00,+0.00,+0.00)(0,0)  ' Force control gain [μm/N]
17   P_FsFLm1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Force detection setting value [N]
18   P_FsFCd1 = (+2.00,-2.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Force command
19   P_FsSpd1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Set speed control mode speed.
20   P_FsSwF1 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      ' Set force/speed judgment value.
21 '*** <Control> ***
22   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
23   GoSub *INIT
24 *Main
25   Mvs P2
26   Dly 0.2
27   Def MoTrg 1,P_FsCurD.X >2
28   Ovrd 5
29   Dly 1
30   Fsc On,0,0,1
31   FsCTrg 1,10,-1,30,0,1                                          'Start force sense control
32   *LBL02: If P_Fbc.Y > -250 Then *LBL02
33   Fsc Off
34   Mvs P_Fbc+(+10.00,+0.00,+0.00)
35   Hlt
```

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(→ Continuation of program "12")

```
36 End
37 '----- Subroute -----
38 *INIT
39   Loadset 1,1
40   OAdl On
41   Servo On
42   Wait M_Svo=1
43   Pnow=P_Fbc
44   If Pnow.Z < P1.Z Then
45     Pnow.Z=P1.Z
46     Mvs Pnow
47     Pnow2=Align(Pnow)
48     Mvs Pnow2
49     Dly 0.2
50   EndIf
51   Mov P1
52   Dly 0.2
53 Return
```

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Chapter 9 Force Sense Detection

9.1 Force Sense Detection

The force sense detection function detects the robot contact status using force sensor information. By using this function, the moving direction can be switched by detecting contact during the movement, and the work can be retried or error processing can be executed by detecting the work failure.

<Features>

1) Trigger conditions combining force data and position data can be set. (Mo trigger)
2) Interrupt processing for start-up and shut-down conditions can be performed for force sensor data force detection setting values (set with Fsc On command conditions group (control characteristics).
3) Sensor data and position data obtained when the force detection setting value is exceeded can be retained as status variables.

<Status variables for force sense detection function>

Class	Status Variable	Function Overview
Mo trigger	M_MoTrg	Checks the Mo trigger status.
Force detection status	M_FsLmtS	Checks whether the force sensor data force detection setting value has been exceeded.
	P_FsLmtR	Checks the status of the current force sensor data with respect to the force sensor data force detection setting value.
Data latch	P_FsLmtX	Checks/resets axes for which the force sensor data force detection setting value is exceeded.
	P_FsLmtP	Checks/resets the robot FB position when the force sensor data force detection setting value is exceeded.
	P_FsLmtD	Checks/resets the force sensor data when the force sensor data force detection setting value is exceeded.
Data referencing	P_FsMaxD	Checks/resets the force sensor maximum data value during force sense control.
	P_FsCurD	Checks the current force sensor data.
	P_FsCurP	Checks the current position command offset with force sense control.
	M_FsRsltF	Checks the current force sensor resultant force.
	M_FsRsltM	Checks the current force sensor resultant moment.
	M_FsCSts	Checks the force sense control enabled/disabled status.

* For the force detection setting value, refer to "Chapter5 5.4 (11) Specifying the force detection setting value (P_FsFLm0/P_FsFLm1, FSFLMT0#)".

9.2 Mo Trigger (DefMoTrg, SetMoTrg, M_MoTrg)

The Mo trigger function is used to issue trigger signals when conditions are established based on conditions defined by combining the following data with a comparison operation. The Mo trigger status is output to status variable M_MoTrg.

Data	Description
Each P_Curr component	Robot current position (linear data)
Each P_Fbc component	Robot FB position (linear data)
Each J_Curr component	Robot current position (joint data)
Each J_Fbc component	Robot FB position (joint data)
Each P_FsCurP component	Position command after offsetting with force control
Each P_FsCurD component	Force sensor data (values after updating offset cancel, converting tool/XYZ coordinates)
M_FsRsltF	Force sensor data resultant force (values after updating offset cancel, converting tool/XYZ coordinates)
M_FsRsltM	Force sensor data resultant moment (values after updating offset cancel, converting tool/XYZ coordinates)
M_In	Input signal ON/OFF status
M_Out	Output signal ON/OFF status

By using this function, complicated trigger conditions can be specified for use with work completion judgment/interrupt processing when abnormal work is performed (DEF ACT command), and for changing force sense control characteristics (FsCTrg command), and so on.

To use the Mo trigger, define trigger conditions with the following procedure, and then start condition monitoring.

<Mo trigger setting procedure flow>

(1) Define trigger conditions with the Def MoTrg command. Up to three types of conditions can be set.

(2) Enable the Mo trigger with the SetMoTrg command.

(3) Perform condition branching and interrupt processing using values output to status variable M_MoTrg.

* Procedures (2) and (3) are unnecessary if using FsCTrg command.

Program example

```
Def MoTrg 1, ((P_Fbc.Z <= 5) AND (P_FsCurD.Z > 18))     'Define work complete conditions for Mo trigger #1.
Def Act 1, M_MoTrg(1)=1 GoTo *XOK, F                    'Define Mo trigger #1 as interrupt condition.
Mvs PStart                          'Move the robot above the insert position.
Set MoTrg 1                         'Enable Mo trigger #1.
Fsc On, 0, 0, 1                     'Enable force sense control.
Act 1=1
• • • • • •
Fsc Off                             'Disable force sense control.
Act 1=0
Set MoTrg 0                         'Disable Mo trigger.
End
```

```
Def MoTrg 3, (P_Fbc.Z < 100)        'Work complete conditions defined for Mo trigger 3.
Fsc On, 0, 1, 1                     'Enable force sense control.
FsCTrg 3, 100, 2                    'Enable Mo trigger #3 and change the control characteristics
                                    from 1 to 2 when the trigger turns ON.
Mvs P1
• • • • • •
Fsc Off                                         'Disable force sense control.
End
```

9.3 Force Detection Status (M_FsLmtS, P_FsLmtR)

(1) M_FsLmtS

Status variable M_FsLmtS verifies whether the force has exceeded the force detection setting value (P_FsFLm0/P_FsFLm1) specified with the "control characteristics" group. It can be used for interrupt processing and so on when a collision occurs.

M_FsLmtS = 0 or 1

0: Force detection setting value not exceeded

1: Force detection setting value exceeded

Program example

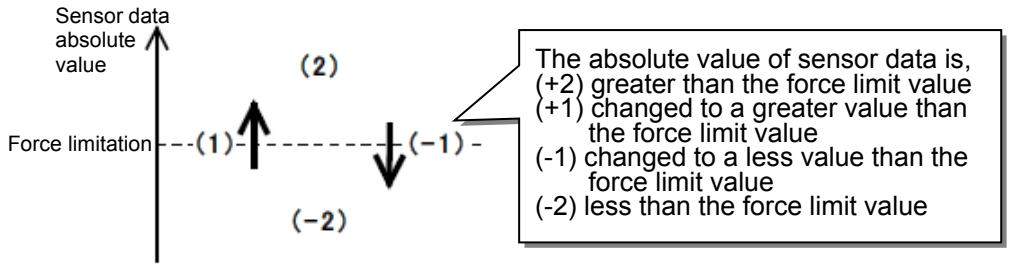
```
Def Act 1,M  FsLmtS=1 GoTo *XMOV,S
```

Execute interrupt processing when the force detection setting value is exceeded (P_FsFLm0/P_FsFLm1)

(2) P_FsLmtR

Status variable P_FsLmtR indicates the current status of the force sensor data against the force detection setting value (P_FsFLm0/P_FsFLm1) specified with the "control characteristics" group.

Each component of P_FsLmtR = (-2 or +1 or +2 or -1)



Program example 1

```
Mvs P2 Wthif P_FsLmtR.X = 1, Skip
```

When the force in the X-direction exceeds the force detection setting value, the next command is skipped with an interrupt.

Program example 2

```
M1=-1
Def Act 1, P_FsLmtR.Z=M1 GoTo *PCEN, S
```

When the force in the Z-direction becomes smaller than the force detection setting value, this status variable defines that interrupt processing is executed.

9.4 Data Latch (P_FsLmtX/P_FsLmtP/P_FsLmtD)

The axis data, position data, and force sense data at the point when they exceed the "force detection setting value" of the force sensor are latched, and the values are retained until they are reset in status variable P_FsLmtX( ), P_FsLmtP( ), P_FsLmtD( ).
Substitute position variable (any position variable value) to reset the value. By the reset operation, the values of P_FsLmtX, P_FsLmtP, and P_FsLmtD are also reset simultaneously.

When the force sensor is not connected, all axes are always 0.

(1) P_FsLmtX

Verifies/resets the axis that exceeds the force detection setting value of the force sensor.

Indicates whether the absolute value of the force sensor data exceeds the force detection setting value or not.

<Position variable>= P_FsLmtX
P_FsLmtX = <Position variable>

1: Axis element that has exceeded
0: Axis element that has not exceeded
(All axes are 0 by default.)

Program example

```
Def Act 1, P_FsLmtX.Z=1 GoTo *ESCP,S
```

Execute interrupt processing when Z-axis direction exceeds the force detection setting value

(2) P_FsLmtP

Verifies/resets the position that exceeds the force detection setting value of the force sensor.

<Position variable>= P_FsLmtP
P_FsLmtP = <Position variable>

Program example

```
PX(M1)=P_FsLmtP
```

Retain the position that exceeds the force detection setting value

(3) P_FsLmtD

Verifies/resets the force sensor data when exceeded the force detection setting value of the force sensor.

<Position variable>= P_FsLmtD
P_FsLmtD = <Position variable>

Program example

```
MFD=P_FsCurD.Z-P_FsLmtD.Z
```

Calculate the force displacement when exceeded the setting value (N)

9.5 Data Verification (P_FsMaxD / P_FsCurD)

The maximum value and current value of the force sensor data are stored.

All axes are 0 by default (at Power-ON). The value is set despite the force sense control function is enabled or disabled. The value is retained when the position variable is substituted (any position variable value), offset cancel is executed, or until reset is executed for the maximum value with the teaching box.

When the force sensor is not connected, all axes are always 0.

(1) P_FsMaxD

Indicates the maximum value (maximum absolute value) of the force sensor data. (The maximum value of each axis are retained.)

```
<Position variable>= P_FsMaxD
P_FsMax = <Position variable>
```

Program example

```
P1=P_FsMaxD      Retain the maximum value of force sensor data up to present to P1
P_FsMaxD=P1      Reset the maximum value
```

(2) P_FsCurD

Verifies the current force sensor data.

```
<Position variable>= P_FsCurD
P_FsCurD = <Position variable>
```

Program example

```
Def Act 1, P_FsCurD.Z > 10 GoTo *INTR1, S
    When the sensor data in Z-direction exceeds 10 N, define an interruption that executes interrupt processing *INTR1
```

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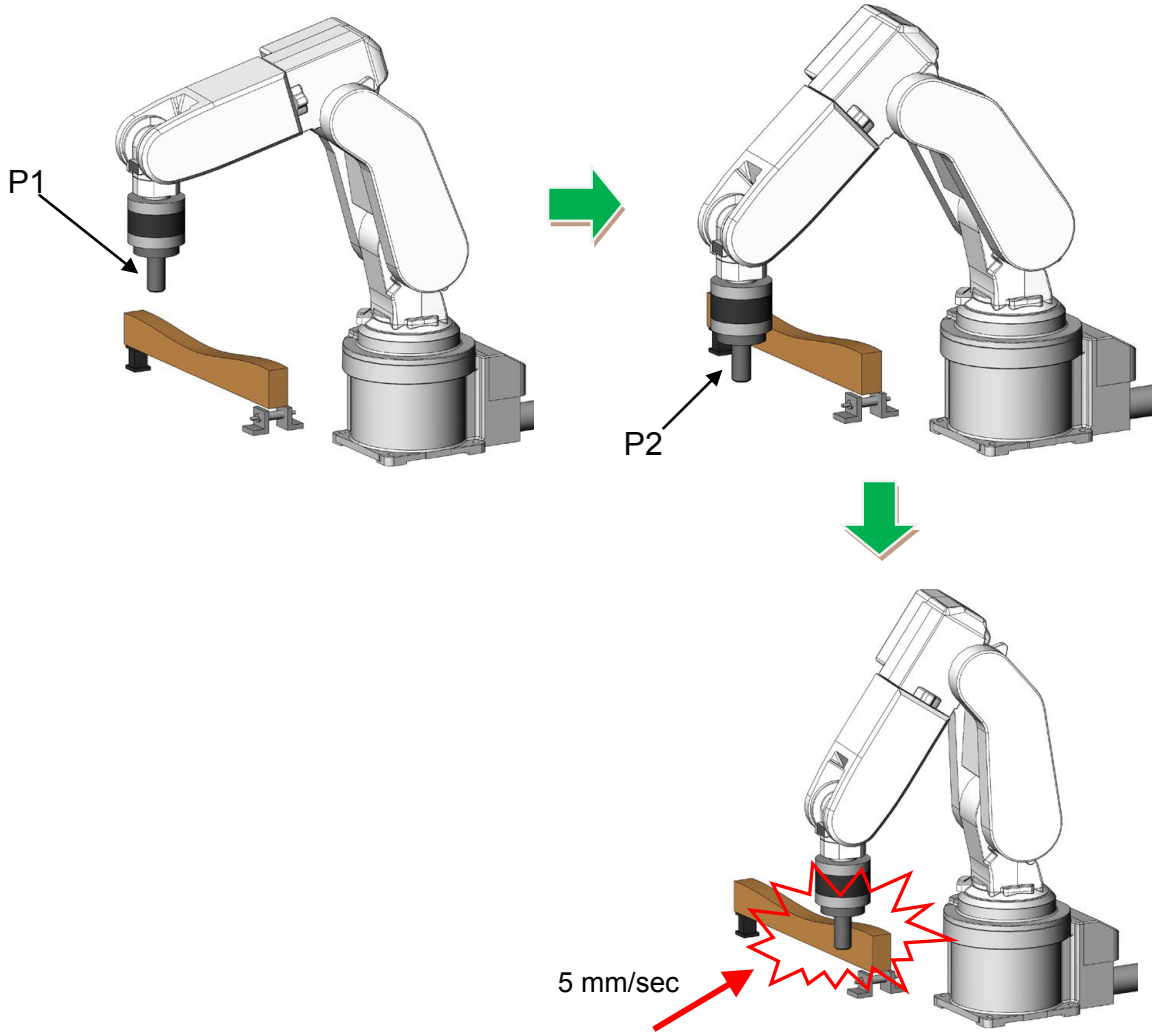
9.6 Practice

◆Practice 13: Interrupt processing

1) Execute program "13".
2) Use the side of the metal parts with a curve and output an error when exceeding the set limit. Set the speed to 5 mm/sec.



◆ **Program "13"**

```
1 '-----------------------------------------------
2 'Practice 13: Interrupt processing M_FsLmtS
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Force control mode (Z-axis
                                                                  enabled)
8   M_FsCod0 = 0                                  'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10   P_FsGn0   = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Force control gain [µm/N]
11   P_FsFLm0 = (+5.00,+5.00,+5.00,+1.00,+1.00,+1.00)(0,0)       'Force detection setting value [N]
12   P_FsFCd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set the speed of the speed
                                                                  control mode
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Set the force/speed judgment
                                                                  value
15 '*** <Control> ***
16   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
17   GoSub *INIT
18 *Main
19   Mvs P2
20   Dly 1
21   P3=P2+(-200.00,+0.00,+0.00)
22   '----- Speed -----
23   MSpd=5
24   Ovrd M_NOvrd
25   MSpeed=100 / M_OPovrd *MSpd          'Fix the speed despite the override
26   Spd MSpeed
27   '-----------------
28   Def Act 1,M_FsLmtS=1 GoTo *XERR
29   Act 1=1
30   Fsc On,0,0,1                                          'Start force sense control
31   Mvs P3
32   Dly 0.2
33   M1=Zone2(P_Fbc,P3,P3,2)
34   If M1<>1 Then Mvs P2
35   Fsc Off
36   Hlt
37 End
```

(Continue to the next page →)

(→ Continuation of program "13")

```
38 '----- Subroute -----
39 *INIT
40   Loadset 1,1
41   OAdl On
42   Servo On
43   Wait M_Svo=1
44   Ovrd M_NOvrd
45   Spd M_NSpd
46   Pnow=P_Fbc
47   If Pnow.Z < P1.Z Then
48     Pnow.Z=P1.Z
49     Mvs Pnow
50     Pnow2=Align(Pnow)
51     Mvs Pnow2
52     Dly 0.2
53   EndIf
54   Mov P1
55   Dly 0.2
56 Return
57 '---- XERR -----
58 *XERR
59   Act 1=0
60   Fsc Off
61   Mvs P2
62   Dly 0.2
63   Spd M_NSpd
64   Error 9100
65   Hlt
66 End
```

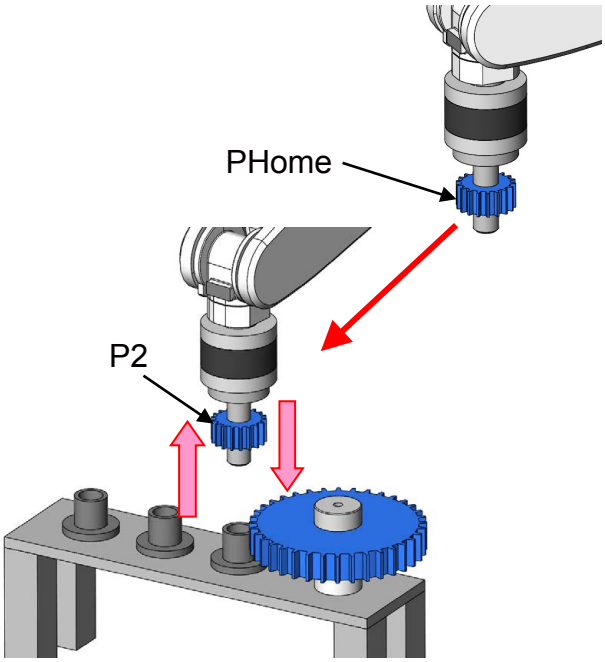
<<MEMO>> *Please use this page for your memo.

Chapter10 Exercise

Exercise 1: Phase focusing and assembly inspection

◇Exercise 1-1 Hand insertion and withdraw operation

1) Set "185.00" only for the Z-axis of the robot tool data.
   Teach the position above the cylinder where the gear is to P2.
   (When the hand cannot be inserted to the cylinder, teach the position again.)
2) Move the robot to P2, and insert the hand to the cylinder with the force sense function.
   Record the height of Z-axis at the point when completely inserted to a variable.
   (If the robot hand hits the gear of fixture at insertion, rotate it manually so that it is inserted.)
3) Lift the robot in Z-axis direction and pull out the hand.



◇Exercise 1-1 Program example

```
1 '-------------------------------------------
2 ' Exercise 1)-1 Hand insertion and pulling out operation
3 '-------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.10,+0.10,+0.10)(0,0)          'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
7   P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)          'Force control mode (XYZ-axis
                                                                    enabled)
8   M_FsCod0 = 0                    'Force sense control coordinate system (0/1: Tool/XYZ)
9 '[Control characteristics (0)]
10  P_FsGn0   = (+5.00,+5.00,+5.00,+8.00,+8.00,+8.00)(0,0)          'Force control gain [μm/N]
11  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Force detection setting value [N]
12  P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)          'Force command
13  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Set the speed of the speed
                                                                    control mode
14  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Set the force/speed judgment
                                                                    value
15 '*** <Force control> ***
16  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)                   'Tool setting
17  '----------- Preparation----------
18  '1) Teach position above the cylinder closest to the gear   P2
19  '2) Teach retract position                  PHome
20  '-------------------------------
21  Loadset 1,1
22  OAdl On
23  Ovrd M_NOvrd
24  Spd M_NSpd
25  Servo On
26  Wait M_Svo=1
27  '----- Retract position return -----
28  If P_Fbc.Z < PHome.Z Then
29     PNow=P_Fbc
30     PNow.Z=PHome.Z
31     Mvs PNow
32  EndIf
33  Mov PHome
34  '----------------------
35  '------ Insert P2 -------
36  PB=P2
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-1 Hand insertion and pulling out operation)

```
37   PB.Z=PHome.Z
38   Mov PB
39   Fine 0.1,P
40   Mvs P2
41   Fine 0
42   Dly 0.2
43   Fsc On, 0, 0, 1                                    'Start force sense control
44 *Loop1
45   M_Timer(2)=0
46   PB=P_Fbc
47 *Loop2
48   Dly 0.1
49   PNow=P_Fbc
50   M1=Zone2(PNow,PB,PB,0.2)
51   If ((M_Timer(2) > 5000) And (M1=1)) Then *Fin1
52   If M_Timer(2) <= 5000 Then *Loop2 Else *Loop1
53 *Fin1
54   Fsc Off
55   Dly 0.1
56   Mjudge=P_Fbc.Z              'Insert judgment condition (Z)
57   '------------------------
58   '----- Withdraw -----
59   P_FsFCd0 = (+0.00,+0.00,-10.00,+0.00,+0.00,+0.00)(0,0)      'Force command
60   Dly 0.2
61   Fsc On, 0, 0, 0                                    'Start force sense control
62 *Loop3
63   Dly 0.1
64   If P_Fbc.Z < P2.Z Then *Loop3
65   Fsc Off
66   Dly 0.1
67   Mvs P_Fbc+(+0.00,+0.00,+30.00)
68   Mov PHome
69   Hlt
70   End
PHome=(+270.00,+0.00,+320.00,+180.00,+0.00,+180.00,+0.00,+0.00)(7,0)
P2=(+351.07,+38.03,+107.52,-180.00,+0.00,-180.00)(7,0)
```

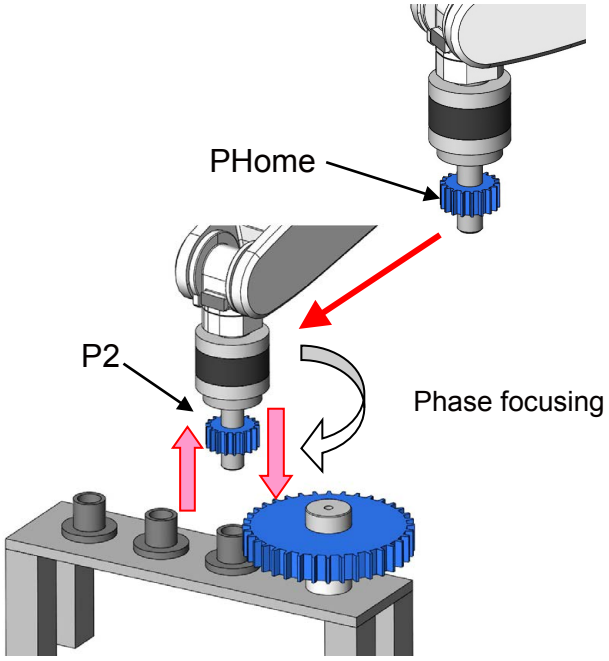
(// End of program example of Exercise 1-1 Hand insertion and pulling out operation)

<<MEMO>> *Please use this page for your memo.

Exercise 1: Phase focusing and assembly inspection

◇Exercise 1-2 Perform phase focusing for the gear at hand insertion, and pulling out operation

1) Set "185.00" only for the Z-axis of the robot tool data.
   Teach the position above the cylinder where the gear is to P2.
   (When the hand cannot be inserted to the cylinder, teach the position again.)
   } Same as Exercise 1-1
2) Add 2 mm to the Z-axis value at insertion that was recorded in Exercise 1-1. Set that height as the Z judgment value at insert completion.
3) Move the robot to P2 and use the force sense function to match the phase of the gear. Then insert the hand. If the phases are matched already, rotate the gear manually.
4) When the hand is inserted, lift the robot in Z-axis direction and pull out the hand.



◇Exercise 1-2 Program example

```
1 '-----------------------------------------------
2 ' Exercise 1)-2     Perform phase focusing for the gear at hand insertion, and pulling out operation
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.10,+0.10,+0.10)(0,0)          'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
7   P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)          'Force control mode (XYZ-axis
                                                                    enabled)
8   M_FsCod0 = 0                                'Force sense control coordinate system (0/1: Tool/XYZ)
9 '[Control characteristics (0)]
10  P_FsGn0   = (+5.00,+5.00,+5.00,+8.00,+8.00,+8.00)(0,0)         'Force control gain [μm/N]
11  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Force detection setting value [N]
12  P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)         'Force command
13  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Set the speed of the speed
                                                                    control mode
14  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Set the force/speed judgment
                                                                    value
15 '*** <Force control> ***
16  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)                       'Tool setting
17  '----------- Preparation ----------
18  '1) Teach position above the cylinder closest to the gear   P2
19  '2) Teach retract position                      PHome
20  '-------------------------------
21  Mjudge=67.6             'Insert judgment condition (Z: measure in 1) - 1)
22  Loadset 1,1
23  OAdl On
24  Ovrd M_NOvrd
25  Spd M_NSpd
26  Servo On
27  Wait M_Svo=1
28  '----- Retract position return -----
29  If P_Fbc.Z < PHome.Z Then
30     PNow=P_Fbc
31     PNow.Z=PHome.Z
32     Mvs PNow
33  EndIf
34  Mov PHome
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-2 Perform phase focusing for the gear at hand insertion, and pulling our operation)

```
'----------------------
'------ Insert P2 -------
PB=P2
PB.Z=PHome.Z
Mov PB
Fine 0.1,P
Mvs P2
Fine 0
Dly 0.2
P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)        'Force control mode (XYZ-axis enabled)
P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)       'Force command
Dly 0.2
Fsc On, 0, 0, 1                                              'Start force sense control
*Loop1
M_Timer(2)=0
PB=P_Fbc
*Loop2
Dly 0.1
PNow=P_Fbc
M1=Zone2(PNow,PB,PB,0.2)
If ((M_Timer(2) > 2000) And (M1=1)) Then *Fin1
If M_Timer(2) <= 2000 Then *Loop2 Else *Loop1
*Fin1
Fsc Off
Dly 0.1
If P_Fbc.Z < Mjudge+2 Then *UP                'Insert judgment condition (Z)
'-----------------------
'----- Phase focusing   -----
*ISOU
P_FsMod0 = (+1.00,+1.00,+1.00,+0.00,+0.00,+1.00)(0,0)        'Force control mode (XYZ-axis enabled)
P_FsGn0   = (+5.00,+5.00,+5.00,+8.00,+8.00,+16.00)(0,0)      'Force control gain [μm/N]
P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+1.00)(0,0)        'Force command
Dly 0.1
PB=P_Fbc
PTRG=PB*(+0.00,+0.00,+0.00,+0.00,+0.00,-30.00)
MCHK=PB.Z-0.5
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-2 Perform phase focusing for the gear at hand insertion, and pulling out operation)

```
71 *ISOU_Loop
72   Def Act 1,P_Fbc.Z < MCHK GoTo *ISOU_Fin1
73   Fsc On, 0, 0, 0                                          'Start force sense control
74   Act 1=1
75   Dly 30
76   Act 1=0
77   Fsc Off
78   Dly 0.1
79   PTRG=P_Fbc
80   Dly 0.1
81   Mvs PTRG+(+0.00,+0.00,+30.00)
82   Mvs PB+(+0.00,+0.00,+30.00)
83   Dly 0.1
84   Mvs PB+(+0.00,+0.00,+2.00)
85   Dly 0.2
86   GoTo *ISOU_Loop
87 *ISOU_Fin1
88   Act 1=0
89   Fsc Off
90   Dly 0.1
91   P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)    'Force control mode (XYZ-axis
                                                              enabled)
92   P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)   'Force command
93   Dly 0.1
94   PB=P_Fbc
95   Mvs PB
96   Dly 0.1
97   Fsc On,0,0,0
98 *Loop7
99   Dly 0.1
100   If P_Fbc.Z > Mjudge+2 Then *Loop7
101   Dly 1
102   Fsc Off
103   Dly 0.1
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-2 Perform phase focusing for the gear at hand insertion, and pulling out operation)

```
104   '-----   Withdraw -----
105   *UP
106   P_FsFCd0 = (+0.00,+0.00,-10.00,+0.00,+0.00,+0.00)(0,0)          'Force command
107   Dly 0.2
108   Fsc On, 0, 0, 0                                                 'Start force sense control
109 *Loop10
110   Dly 0.1
111   If P_Fbc.Z < P2.Z Then *Loop10
112   Fsc Off
113   Dly 0.1
114   Mvs P_Fbc+(+0.00,+0.00,+30.00)
115   Mov PHome
116   '------------------
117   Hlt
118 End
PHome=(+270.00,+0.00,+320.00,+180.00,+0.00,+180.00,+0.00,+0.00)(7,0)
P2=(+351.07,+38.03,+107.52,-180.00,+0.00,-180.00)(7,0)
```

(→ End of program example of Exercise 1-2 Perform phase focusing for the gear at hand insertion, and pulling out operation)

<<MEMO>> *Please use this page for your memo.

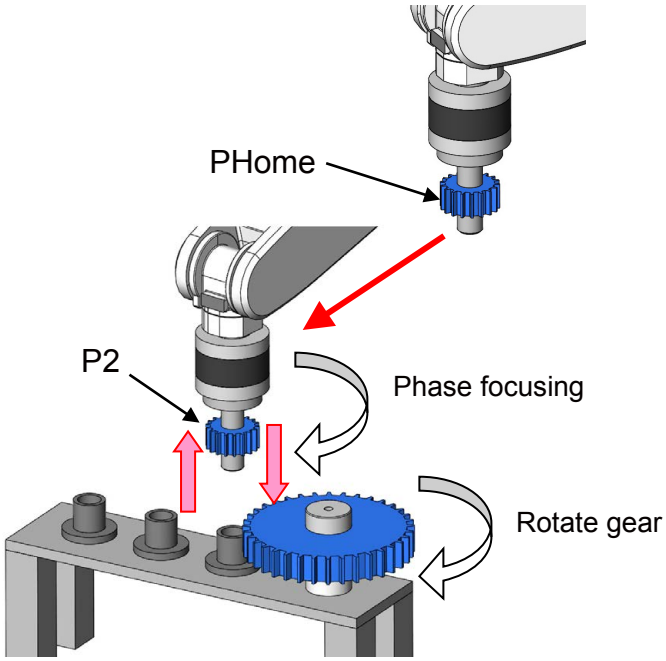
Exercise 1: Phase focusing and assembly inspection

◇Exercise 1-3 Hand insertion (phase focusing), gear rotation confirmation, pulling out operation

1) Set "185.00" only for the Z-axis of the robot tool data.
   Teach the position above the cylinder where the gear is to P2.
   (When the hand cannot be inserted to the cylinder, teach the position again.)
2) Add 2 mm to the Z-axis value at insertion that was recorded in Exercise 1-1.
   Set that height as the Z judgment value at insert completion.
3) Move the robot to P2 and use the force sense function to match the phase of the gear. Then insert the hand.

} Same as Exercise 1-2

4) Move up for 2 mm from the insert complete position, and rotate the gear on the hand for ±45 degrees.
5) When the hand is rotated, lift the robot in the Z-axis direction to pull out the hand.



◇Exercise 1-3 Program example

```
'-----------------------------------------------
' Exercise 1)-3   Hand insertion (phase focusing), gear rotation confirmation, pulling out operation
'-----------------------------------------------
'[Control mode (0)]
  P_FsStf0 = (+0.00,+0.00,+0.00,+0.10,+0.10,+0.10)(0,0)          'Stiffness coefficient [N/mm]
  P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
  P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)          'Force control mode
                                                                  (XYZ-axis enabled)
  M_FsCod0 = 0                                'Force sense control coordinate system (0/1: Tool/XYZ)
'[Control characteristics (0)]
  P_FsGn0   = (+5.00,+5.00,+5.00,+8.00,+8.00,+8.00)(0,0)         'Force control gain [μm/N]
  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Force detection setting value [N]
  P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)         'Force command
  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Set the speed of the speed
                                                                  control mode
  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Set the force/speed judgment
                                                                  value
'***<Force control> ***
  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)                   'Tool setting
  '---------- Preparation ----------
  '1) Teach position above the cylinder closest to the gear   P2
  '2) Teach retract position                  PHome
  '------------------------------
  Mjudge=67.6            'Insert judgment condition (Z: measure in 1) - 1)
  Loadset 1,1
  OAdl On
  Ovrd M_NOvrd
  Spd M_NSpd
  Servo On
  Wait M_Svo=1
  '----- Retract position return -----
  If P_Fbc.Z < PHome.Z Then
     PNow=P_Fbc
     PNow.Z=PHome.Z
     Mvs PNow
  EndIf
  Mov PHome
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-3 Hand insertion (phase focusing), gear rotation confirmation, pulling out operation)

```
35  '----------------------
36  '------ P2 Insert -------
37  PB=P2
38  PB.Z=PHome.Z
39  Mov PB
40  Fine 0.1,P
41  Mvs P2
42  Fine 0
43  Dly 0.2
44  P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)      'Force control mode (XYZ-axis enabled)
45  P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)        'Force command
46  Dly 0.2
47  Fsc On, 0, 0, 1                                                    'Start force sense control
48 *Loop1
49  M_Timer(2)=0
50  PB=P_Fbc
51 *Loop2
52  Dly 0.1
53  PNow=P_Fbc
54  M1=Zone2(PNow,PB,PB,0.2)
55  If ((M_Timer(2) > 2000) And (M1=1)) Then *Fin1
56  If M_Timer(2) <= 2000 Then *Loop2 Else *Loop1
57 *Fin1
58  Fsc Off
59  Dly 0.1
60  If P_Fbc.Z < Mjudge+2 Then *ROT2                'Insert judgment condition (Z)
61  '-----------------------
62  '----- Phase focusing -----
63  *ISOU
64  P_FsMod0 = (+1.00,+1.00,+1.00,+0.00,+0.00,+1.00)(0,0)        'Force control mode (XYZ-axis
                                                                   enabled)
65  P_FsGn0   = (+5.00,+5.00,+5.00,+8.00,+8.00,+16.00)(0,0)      'Force control gain [μm/N]
66  P_FsFCd0 = (+0.00,+0.00,+5.00,+0.00,+0.00,+1.00)(0,0)        'Force command
67  Dly 0.1
68  PB=P_Fbc
69  PTRG=PB*(+0.00,+0.00,+0.00,+0.00,+0.00,-30.00)
70  MCHK=PB.Z-0.5
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-3 Hand insertion (phase focusing), gear rotation confirmation, pulling out operation)

```
71 *ISOU_Loop
72   Def Act 1,P_Fbc.Z < MCHK GoTo *ISOU_Fin1
73   Fsc On, 0, 0, 0                                          'Start force sense control
74   Act 1=1
75   Dly 30
76   Act 1=0
77   Fsc Off
78   Dly 0.1
79   PTRG=P_Fbc
80   Dly 0.1
81   Mvs PTRG+(+0.00,+0.00,+30.00)
82   Mvs PB+(+0.00,+0.00,+30.00)
83   Dly 0.1
84   Mvs PB+(+0.00,+0.00,+2.00)
85   Dly 0.2
86   GoTo *ISOU_Loop
87 *ISOU_Fin1
88   Act 1=0
89   Fsc Off
90   Dly 0.1
91   P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+2.00)(0,0)    'Force control mode (XYZ-axis enabled)
92   P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)   'Force command
93   Dly 0.1
94   PB=P_Fbc
95   Mvs PB
96   Dly 0.1
97   Fsc On,0,0,0
98 *Loop7
99   Dly 0.1
100   If P_Fbc.Z > Mjudge+2 Then *Loop7
101   Dly 1
102   Fsc Off
103   Dly 0.1
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 1-3 Hand insertion (phase focusing), gear rotation confirmation, pulling out operation)

```
104   '------- Rotate ------
105   *ROT2
106      Dly 0.1
107      Mvs P_Fbc,-2
108      Dly 0.2
109      PB=P_Fbc
110      P_FsMod0 = (+1.00,+1.00,+1.00,+2.00,+2.00,+0.00)(0,0)      'Force control mode (XYZ-axis
                                                                    enabled)
111      P_FsFCd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Force command
112      Fsc On, 0, 0, 0                                            'Start force sense control
113      Mvs PB*(+0.00,+0.00,+0.00,+0.00,+0.00,+45.00)
114      Dly 0.5
115      Mvs PB*(+0.00,+0.00,+0.00,+0.00,+0.00,-45.00)
116      Dly 0.2
117      Fsc Off
118      Dly 0.2
119   '
120   '----- Withdraw -----
121   P_FsFCd0 = (+0.00,+0.00,-10.00,+0.00,+0.00,+0.00)(0,0)        'Force command
122   Dly 0.2
123   Fsc On, 0, 0, 0                                              'Start force sense control
124 *Loop10
125   Dly 0.1
126   If P_Fbc.Z < P2.Z Then *Loop10
127   Fsc Off
128   Dly 0.1
129   Mvs P_Fbc+(+0.00,+0.00,+30.00)
130   Mov PHome
131   '------------------
132   Hlt
133 End
PHome=(+270.00,+0.00,+320.00,+180.00,+0.00,+180.00,+0.00,+0.00)(7,0)
P2=(+351.07,+38.03,+107.52,-180.00,+0.00,-180.00)(7,0)
```

(// End of program example in Exercise 1-3 Hand insertion (phase focusing), gear rotation confirmation, pulling out operation)

<<MEMO>> *Please use this page for your memo.

Exercise 2 : Following operation

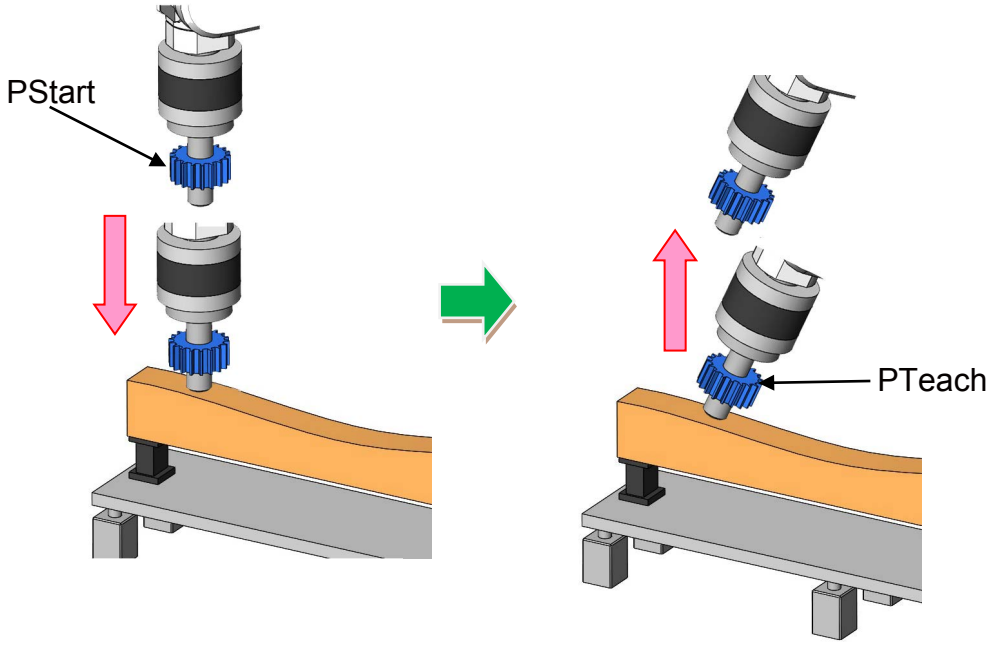
◇Exercise 2-1 Follow the curved surface

Vertically lower the robot that has performed the hand alignment from the Z-axis direction for the fixture with a curve. Follow the curved part and read the position where the robot has stopped to the position variable.
Then create a program to retract to the above position.

◇◆ Key learning points ◆◇

Learn how to teach the appropriate posture and position with the force sensor.

Check whether the robot reached the appropriate taught position in shortest time by a method that cannot be performed with the Dly command.



◇Exercise 2-1 Program example

```
1 '-----------------------------------------------
2 ' Exercise 2)-1 Following operation (follow the curved surface)
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.01,+0.00,+0.00)(0,0)        'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+2.00,+0.00,+0.00)(0,0)        'Force control mode (XYZ-axis
                                                                  enabled)
8   M_FsCod0 = 0                          'Force sense control coordinate system (0/1: Tool/XYZ)
9 '[Control characteristics (0)]
10  P_FsGn0   = (+0.00,+0.00,+5.00,+20.00,+10.00,+10.00)(0,0)    'Force control gain [µm/N]
11  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Force detection setting
                                                                  value [N]
12  P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)       'Force command
13  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set the speed of the speed
                                                                  control mode
14  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set the force/speed judgment value
15 '*** <Force control> ***
16  PStart=(+225.00,-193.00,+220.00,+180.00,+0.00,+180.00)(7,0)
17  '----- Move the robot to PStart position in advance!
18  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
19  Loadset 1,1
20  OAdl On
21  Spd M_NSpd                  'Set the speed to initial value. (*Valid only for CP control)
22  Ovrd M_Novrd                'Set the override to initial value.
23  Cnt 0                       'Set the continuous operation for interpolation to initial value.
24  Servo On
25  Wait M_Svo=1
26  GoSub *Home
27  Dly 0.5
28  Fsc On, 0, 0, 1                         'Start force sense control
29  PNow=P_Fbc*(+0.00,+0.00,-185.00)        'Store the center position of flange to Pnow
30  Dly 1
31  *Loop1
32  PNow2=P_Fbc*(+0.00,+0.00,-185.00)       'Store the center position of flange after one
                                             second to Pnow2
33  MChk1=Zone2(PNow2,PNow,PNow,0.2)        'Check that Pnow2 is inside 0.2 mm diameter
                                             sphere of Pnow
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 2-1 Following operation (follow the curved surface))

```
34  If MChk1=1 Then *Loop1_Fin                  'Exit loop when Pnow2 is in the sphere
35  PNow=PNow2          'Change Pnow to Pnow2 (← Compare the one second-before position)
36  Dly 1
37  GoTo *Loop1                                 'Loop
38  *Loop1_Fin
39  Dly 1
40  Fsc Off
41  PTeach=P_Fbc          'Teach position where the force sensor indicated to PTeach
42  PNow2=PTeach
43  PNow2.Z=PStart.Z
44  Mvs PNow2
45  Mov PStart
46  Dly 0.5
47  Servo Off
48  Wait M_Svo=0
49  Hlt
50 End
51 '----- Home -----
52 *Home
53  PNow=P_Fbc                                  'Acquire current position
54  MChk=Zone2(PNow,PStart,PStart,0.5)    'Check whether the current position exists in 0.5 mm
                                                diameter sphere
55  If MChk<>1 Then                           'If not
56    PNow.Z=PStart.Z                         'Adjust height
57    Mvs Pnow                          'Move to position where only the height is adjusted with
                                        the posture maintained
58    Mov PStart                              'Move to PStart
59  EndIf
60 Return
```

(// End of program example in Exercise 2-1 Following operation (follow the curved surface))

<<MEMO>> *Please use this page for your memo.

Exercise 2: Following operation

◇Exercise 2-2 Move by following the curved surface

Apply the program from Exercise 2-1 and create the robot movement that follows the curved surface.

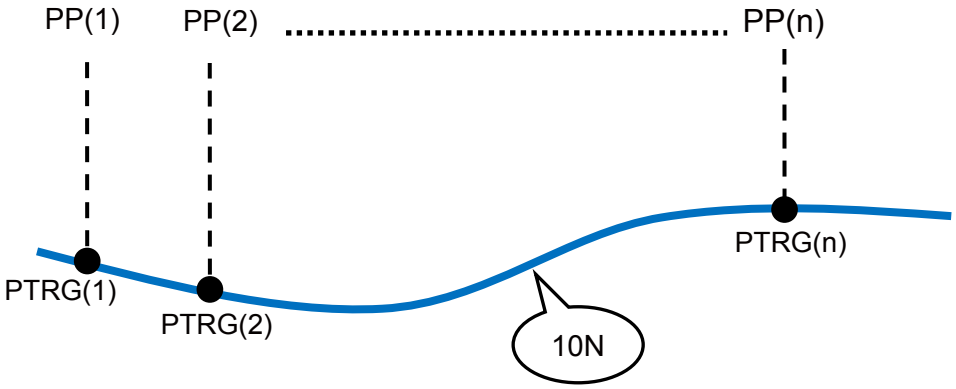
Acquire multiple points on the curved surface by following program from Exercise 2-1, and perform the following operation by passing through those acquired points.

However, 10 N is always applied to the metal surface.

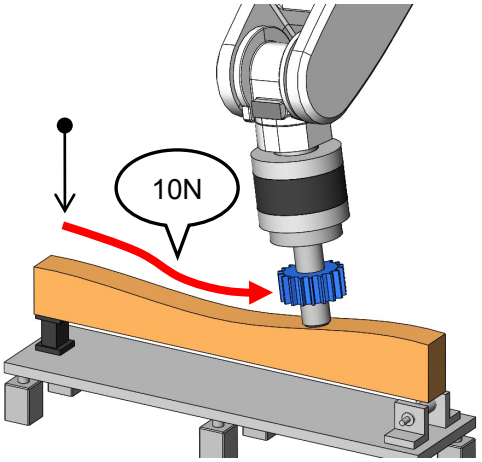
◇◆ Key learning points ◆◇

Learn how to teach a position for following the curved surface.

Create a program that repeats (2-1), and create a movement that connects the imported points.



* Circular interpolation is used for moving between each point.



◇Exercise 2-2 Program example

```
1 '-----------------------------------------------
2 ' Exercise 2)-2 Following operation
3 '-----------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.01,+0.00,+0.00)(0,0)          'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+2.00,+0.00,+0.00)(0,0)      'Force control mode (XYZ-axis
                                                                  enabled)
8   M_FsCod0 = 0                          'Force sense control coordinate system (0/1: Tool/XYZ)
9 '[Control characteristics (0)]
10  P_FsGn0   = (+0.00,+0.00,+5.00,+20.00,+10.00,+10.00)(0,0)      'Force control gain [µm/N]
11  P_FsFLm0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)          'Force detection setting
                                                                    value [N]
12  P_FsFCd0 = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)         'Force command
13  P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Set the speed of the speed
                                                                  control mode
14  P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Set the force/speed judgment
                                                                  value
15  Dim PP(13),PTRG(13)
16 '*** <Force control> ***
17  PStart=(+235.00,+0.00,+220.00,+180.00,+0.00,+180.00)(7,0)
18  '----- Move the robot to PStart position in advance!
19  Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
20  Loadset 1,1
21  OAdl On
22  Spd M_NSpd                  'Set the speed to initial value. (*Valid only for CP control)
23  Ovrd M_Novrd                'Set the override to initial value.
24  Cnt 0                       'Set the continuous operation for interpolation to initial value.
25  Servo On
26  Wait M_Svo=1
27  GoSub *Home
28  'GoTo *Mark
29  For M1=1 To 13
30     Mvs PP(M1)
31     Dly 0.5
32     Fsc On, 0, 0, 1                                  'Start force sense control
33     PNow=P_Fbc*(+0.00,+0.00,-185.00)
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 2-2 Move by following the curved surface)

```
34      Dly 1
35      *Loop1
36      PNow2=P_Fbc*(+0.00,+0.00,-185.00)
37      MChk1=Zone2(PNow2,PNow,PNow,0.2)
38      If MChk1=1 Then *Loop1_Fin
39      PNow=PNow2
40      Dly 1
41      GoTo *Loop1
42      *Loop1_Fin
43      Dly 1
44      Fsc Off
45      PTRG(M1)=P_Fbc
46      PNow2.Z=PStart.Z
47      Mvs PNow2
48      Mov PP(M1)
49    Next M1
50    *Mark
51    Mov PStart
52    Dly 0.1
53    MSpd1=100 / M_OPovrd *10
54    Mvs PTRG(1),-30
55    Fsc On, 0, 0, 1
56    Spd MSpd1
57    Mvs PTRG(1)
58    Dly 0.5
59    For M100=1 To 11 Step 2
60      PS=PTRG(M100)
61      PM=PTRG(M100+1)
62      PE=PTRG(M100+2)
63      Mvr PS,PM,PE
64    Next M100
65    Fsc Off
66    Dly 0.5
67    Mvs P_Fbc+(+0.00,+0.00,+50.00)
68    Spd M_NSpd
69    Mov PStart
70    Dly 0.5
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 2-2 Move by following the curved surface)

```
71   Servo Off
72   Wait M_Svo=0
73   Hlt
74 End
75 '----- Home -----
76 *Home
77   PNow=P_Fbc                          'Acquire current position
78   MChk=Zone2(PNow,PStart,PStart,0.5)   'Check whether the current position exists in 0.5 mm
                                          diameter sphere
79   If MChk<>1 Then                     'If not
80     PNow.Z=PStart.Z                   'Adjust height
81     Mvs Pnow                          'Move to position where only the height is adjusted with
                                          the posture maintained
82     Mov PStart                        'Move to PStart
83   EndIf
84 Return
PE=(225.010,-333.010,151.270,-175.110,0.000,180.000,0.000,0.000)(7,0)
PM=(225.000,-313.140,148.060,-168.610,0.000,179.990,0.000,0.000)(7,0)
PNow=(225.000,-317.600,335.630,-175.220,0.000,180.000)(7,0)
PNow2=(225.000,-317.420,220.000,-175.170,0.000,180.000)(7,0)
PS=(225.000,-293.170,144.190,-169.550,0.000,179.990,0.000,0.000)(7,0)
PStart=(235.000,0.000,220.000,180.000,0.000,180.000)(7,0)
PP(1)=(225.000,-93.000,176.000,-180.000,0.000,180.000)(7,0)
PP(2)=(225.000,-113.000,176.000,-180.000,0.000,180.000)(7,0)
PP(3)=(225.000,-133.000,176.000,-180.000,0.000,180.000)(7,0)
PP(4)=(225.000,-153.000,176.000,-180.000,0.000,180.000)(7,0)
PP(5)=(225.000,-173.000,176.000,-180.000,0.000,180.000)(7,0)
PP(6)=(225.000,-193.000,176.000,-180.000,0.000,180.000)(7,0)
PP(7)=(225.000,-213.000,176.000,-180.000,0.000,180.000)(7,0)
PP(8)=(225.000,-233.000,176.000,-180.000,0.000,180.000)(7,0)
PP(9)=(225.000,-253.000,176.000,-180.000,0.000,180.000)(7,0)
PP(10)=(225.000,-273.000,176.000,-180.000,0.000,180.000)(7,0)
PP(11)=(225.000,-293.000,176.000,-180.000,0.000,180.000)(7,0)
PP(12)=(225.000,-313.000,176.000,-180.000,0.000,180.000)(7,0)
PP(13)=(225.000,-333.000,176.000,-180.000,0.000,180.000)(7,0)
```

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(→ Continuation of program example in Exercise 2-2 Move by following the curved surface)

```
PTRG(1)=(225.010,-93.100,153.470,-168.690,0.010,179.990)(7,0)
PTRG(2)=(225.010,-113.150,157.500,-168.700,0.010,179.980)(7,0)
PTRG(3)=(225.010,-132.990,160.670,-175.790,0.000,179.990)(7,0)
PTRG(4)=(225.000,-153.000,160.970,-179.940,0.000,180.000)(7,0)
PTRG(5)=(225.000,-173.010,160.360,175.750,-0.000,-180.000)(7,0)
PTRG(6)=(224.980,-192.730,156.030,164.830,-0.010,-179.990)(7,0)
PTRG(7)=(224.970,-212.420,148.680,160.220,-0.010,-179.990)(7,0)
PTRG(8)=(224.990,-232.930,143.410,170.600,-0.000,-179.990)(7,0)
PTRG(9)=(225.000,-253.050,141.440,179.160,-0.000,-180.000)(7,0)
PTRG(10)=(225.010,-273.010,141.930,-177.050,0.000,180.000)(7,0)
PTRG(11)=(225.000,-293.170,144.190,-169.550,0.000,179.990)(7,0)
PTRG(12)=(225.000,-313.140,148.060,-168.610,0.000,179.990)(7,0)
PTRG(13)=(225.010,-333.010,151.270,-175.110,0.000,180.000)(7,0)
```

(// End of program example of Exercise 2-2 Move by following the curved surface)

<<MEMO>> *Please use this page for your memo.

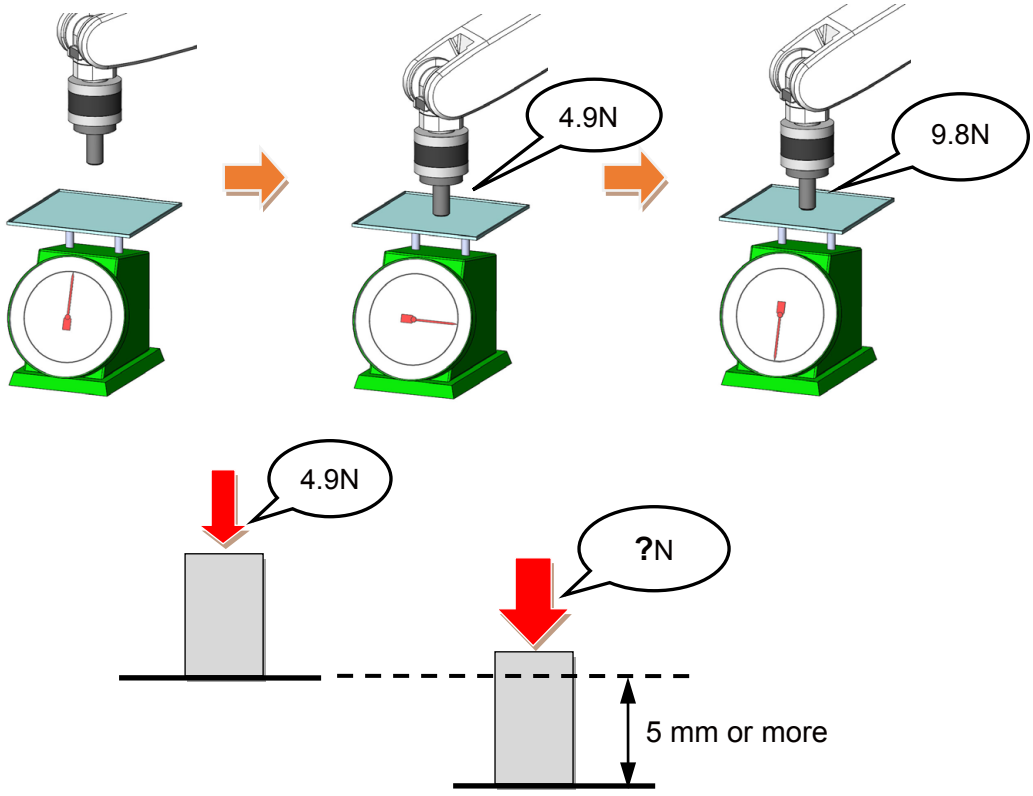
Exercise 3: Interrupt processing, data latch

◇Exercise 3: Interrupt processing, data latch

1) Teach starting point P1 above the scale.
2) Push the scale plate in the Z-axis direction until the force sensor detects "4.9 N" (500 g).
3) Teach the point to P2 where the force sensor detects "4.9 N".
4) Then press the scale plate with "9.8 N" (1 kg) and find a point where the Z-axis position stays for 2 seconds or more.

   (Position where the Z-axis position stays within ±0.2 mm for 2 seconds with 0.5 seconds interval.)

5) If the reaction force that has been specified is applied, and the difference of start position P1 Z component and end position P2 Z component is 5 mm or more, it is OK. If not, find a force (N) that will be OK.



◇Exercise 3-1 Program example

```
1 '-------------------------------------------------------------
2 ' Exercise 3) Interrupt processing, data latch
3 '-------------------------------------------------------------
4 '[Control mode (0)]
5   P_FsStf0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Stiffness coefficient [N/mm]
6   P_FsDmp0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient
7   P_FsMod0 = (+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)        'Force control mode (Z-axis
                                                                 enabled)
8   M_FsCod0 = 0                                                 'Force sense control coordinate
                                                                  system (tool)
9 '[Control Feature (0)]
10   P_FsGn0   = (+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)          ' Force control gain [µm/N]
11   P_FsFLm0 = (+20.00,+20.00,+25.00,+1.00,+1.00,+1.00)(0,0)         'Force detection setting
                                                                       value [N]
12   P_FsFCd0 = (+0.00,+0.00,+4.90,+0.00,+0.00,+0.00)(0,0)            'Force command
13   P_FsSpd0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set the speed of the speed
                                                                  control mode
14   P_FsSwF0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Set the force/speed judgment
                                                                  value
15 '*** <Control> ***
16   Tool (+0.00,+0.00,+185.00,+0.00,+0.00,+0.00)
17   GoSub *INIT
18 *Main
19   '----- 1st Try -----
20   Fsc On,0,0,1
21   *Loop_001:If P_FsCurD.Z <= 5 Then *Loop_001
22   Dly 0.2
23   If P_FsCurD.Z <5 Then *Loop_001
24   Fsc Off
25   Dly 0.2
26   P2=P_Fbc
27   '--------------------
28   Mvs P1
29   Dly 0.2
30   '--------------------
31   P_FsFCd0 = (+0.00,+0.00,+9.80,+0.00,+0.00,+0.00)(0,0)        'Force command
32   '--------------------
33   M3=0
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 3-1 Interrupt processing, data latch)

```
37   Fsc On,0,0,1
38   *Loop_002
39   M_Timer(2)=0                                    'Start force sense control
40   PCHK=P_Fbc
41   *Loop_003
42   Dly 0.05
43   PNow=P_Fbc
44   M10=Zone2(PNow,PCHK,PCHK,0.2)
45   If M_Timer(2) >= 15000 Then *XERR
46   If M10=1 Then *Loop_003 Else *Loop_002
47 *Loop_End1
48   Act 1=0
49   Fsc Off
50   M3=P2.Z-P_Fbc.Z
51   MTRGF=5
52   If M3>=5 Then *Finish                           'OK
53   '-------------------
54   '-----
55   P_FsMod0 = (+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Force control mode (all axes
                                                                disabled)
56   Def MoTrg 1 ,P_FsCurD.Z > 30
57   Def Act 1,M_MoTrg=1 GoTo *XERR
58   SetMoTrg 1
59   Act 1=1
60   '-----
61   PNow=P_Fbc
62   PNow.Z=PNow.Z-(5-M3)
63   Cnt 0
64   Fine 0.1
65   Fsc On,0,0,0
66   Spd MSpeed
67   Mvs PNow
68   Dly 0.05
69   Fine 0
70   Fsc Off
71   Spd M_NSpd
72   Act 1=0
73   SetMoTrg 0
74   MTRGF=P_FsCurD.Z
75 *Finish
76   PTRG=P  Fbc
```

(Continue to the next page →)

(→ Continuation of program example in Exercise 3-1 Interrupt processing, data latch)

```
77   Dly 0.5
78   Mvs P1
79   Hlt
80 End
81 '----- Subroute -----
82 *INIT
83   Loadset 1,1
84   OAdl On
85   Servo On
86   Wait M_Svo=1
87   Ovrd M_NOvrd
88   Spd M_NSpd
89   PNow=P_Fbc
90   If PNow.Z < P1.Z Then
91      PNow.Z=P1.Z
92      Mvs PNow
93      Pnow2=Align(PNow)
94      Mvs Pnow2
95      Dly 0.2
96   EndIf
97   Mov P1
98   Dly 0.2
99    '----- Speed -----
100  MSpd=5
101  Ovrd M_NOvrd
102  MSpeed=100 / M_OPovrd *MSpd
103  'Spd MSpeed
104  '-----------------
105 Return
106 '-----
107 *XERR
108   Act 1=0
109   SetMoTrg 0
110   Error 9105
111   Hlt
112 ReturnP2=(0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)(,)
P1=(-60.84,-282.07,+300.47,+180.00,+0.00,+179.98)(7,0)
PCHK=(0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)(,)
PNow=(0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)(,)
PTRG=(0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)(,)
Pnow2=(0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00)(,)
```

(// End of program example in Exercise 3-1 End of Exercise 3-1 Interrupt processing, data latch program example)

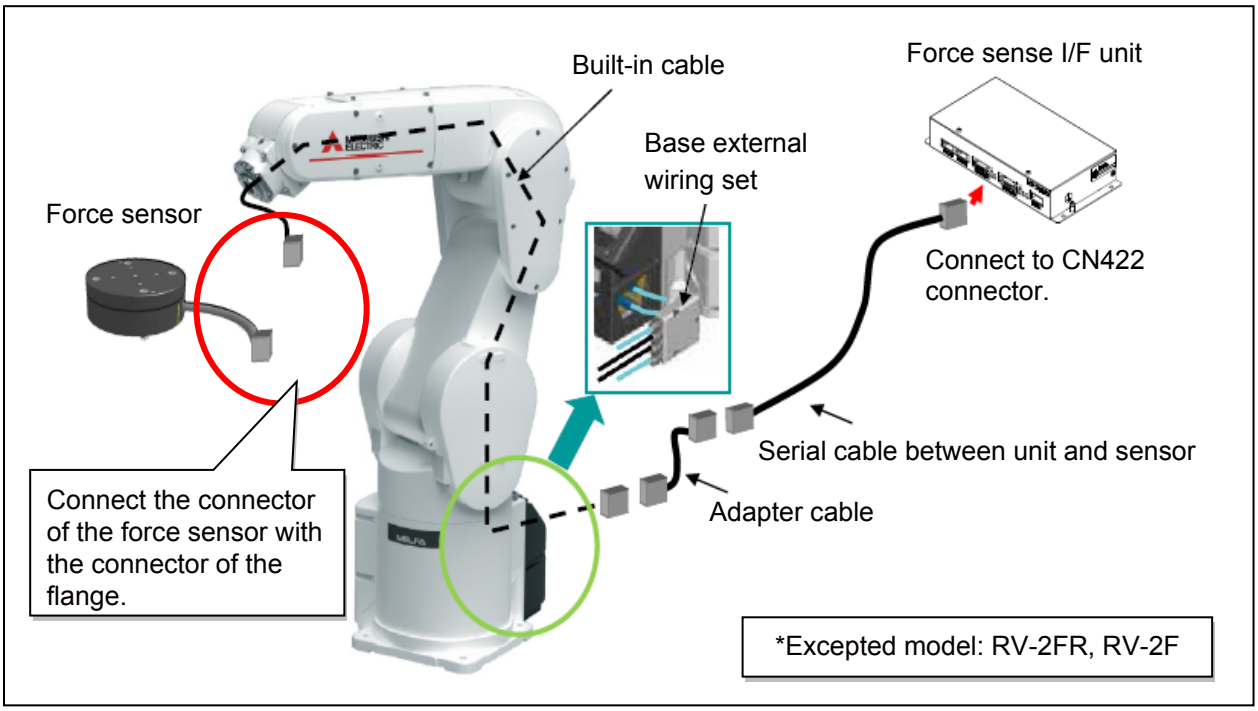
Appendix 1 Connecting the Force Sensor

Appendix 1.1 Connecting the Force Sensor and the Force Sense Interface Unit

This section describes how to connect the force sense interface unit and force sensor.

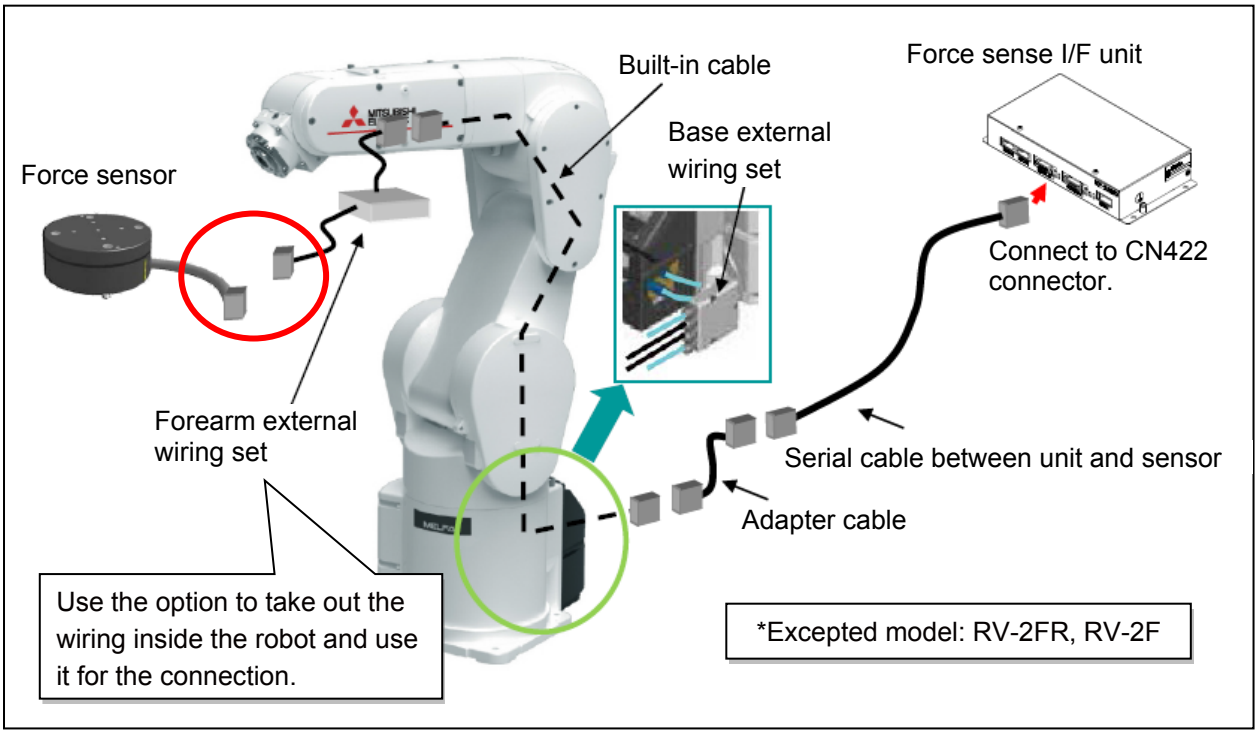
(1) Robot with internal wiring (-SH**)

Connect the force sensor with the cable that comes from the flange of the internal wiring model robot (SH02/03/04). (RV-2FR and RV-2F are excepted.)

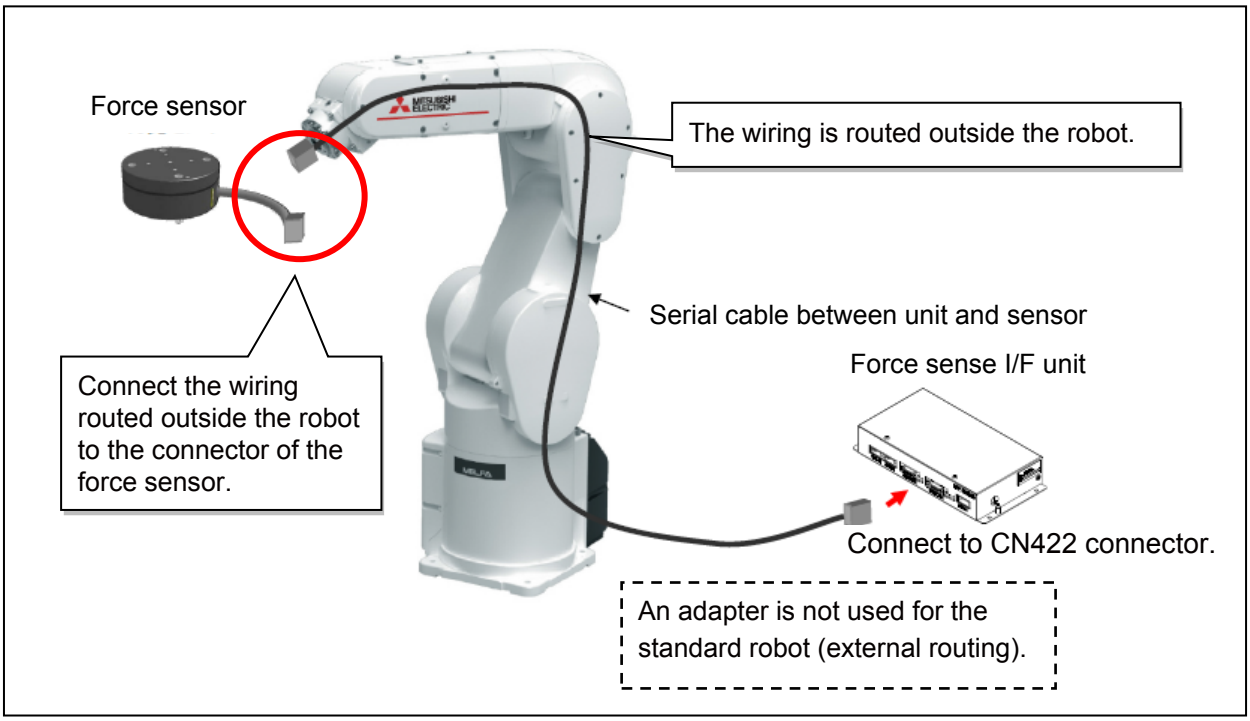


(2) Standard robot + option (forearm external wiring set)

Use the option (forearm external wiring set) and take out the wiring inside the robot for the connection. (RV-2FR and RV-2F are excepted.)



(3) Standard robot + external wiring (external routing)



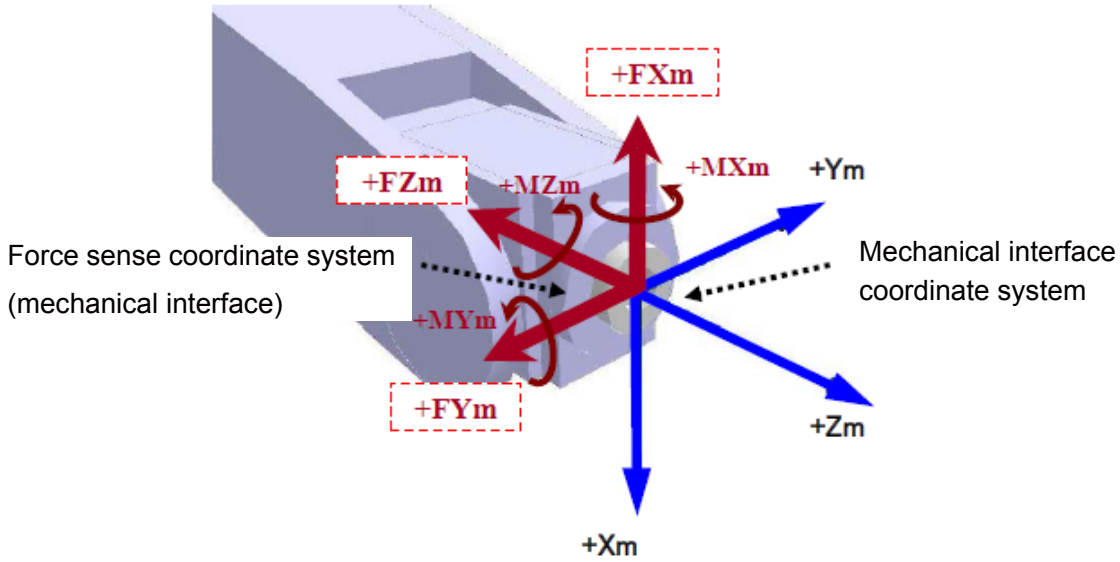
Appendix 2 Coordinate System Definition

List of the force and moment coordinate systems used with the force sense function

Coordinate System Name	Description
Force sense coordinate system (mechanical interface)	Coordinate system that forms reference for calibration (For calibration, refer to "Chapter4 4.4 (2) Calibration".)
Force sense coordinate system (tool)	Coordinate system for force sense function (when tool selected)
Force sense coordinate system (XYZ)	Coordinate system for force sense function (when XYZ selected)
Force sensor coordinate system	Coordinate system for force sensor

Appendix 2.1 Force Sense Coordinate System (Mechanical Interface)

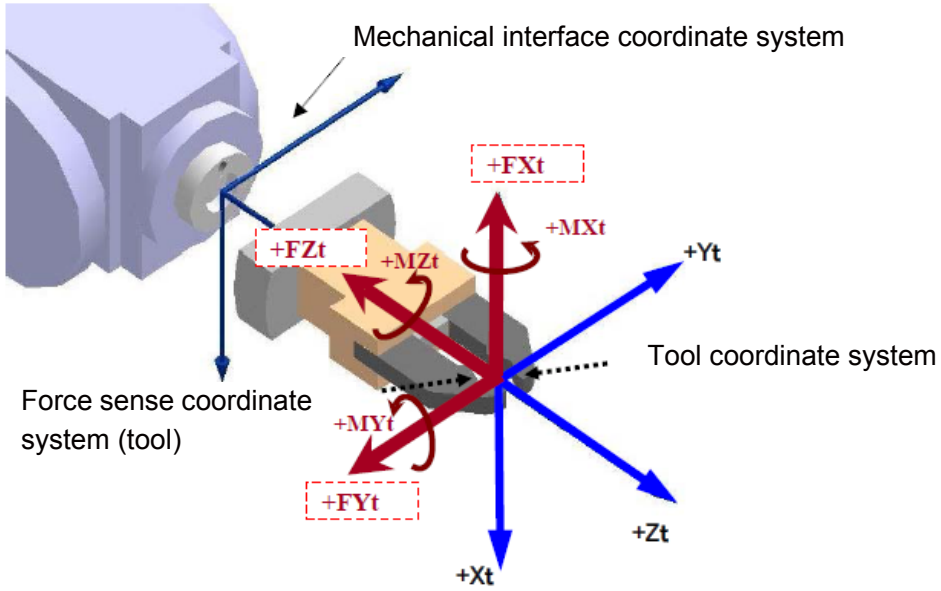
The force sense coordinate system (mechanical interface) is defined as follows.



The force sense coordinate system (mechanical interface) is the plus direction coordinate system for the direction receiving the reaction force when the robot is moved in the mechanical interface coordinate system plus direction. The coordinate system origin point overlaps with that of the mechanical interface coordinate system. (In this coordinate system, the mechanical interface coordinate system symbols are reversed.)

Appendix 2.2 Force Sense Coordinate System (Tool)

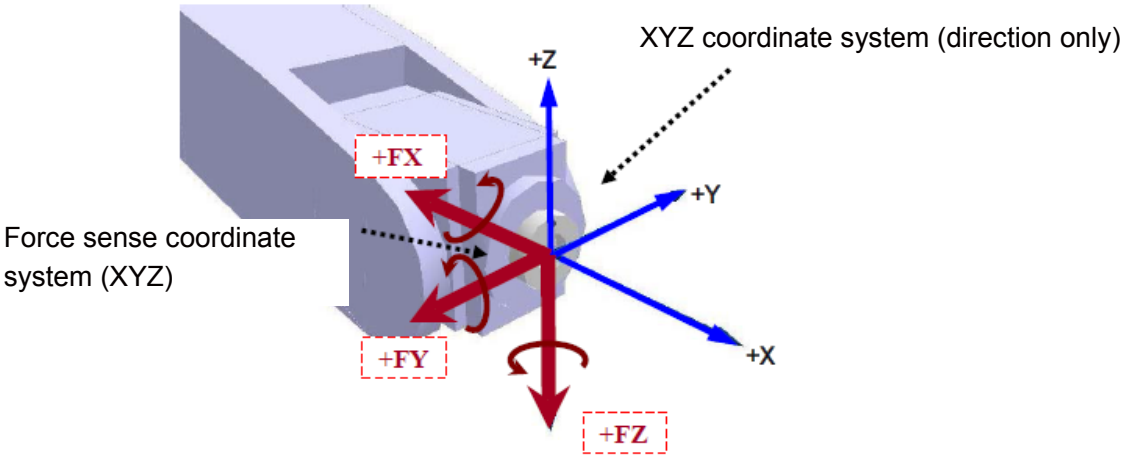
If the tool coordinate system is set, the force sense coordinate system (tool) is defined as follows based on the set tool coordinate system.



The force sense coordinate system (tool) is the plus direction coordinate system for the direction receiving the reaction force when the robot is moved in the tool coordinate system plus direction. The coordinate system origin point overlaps with that of the tool coordinate system. (In this coordinate system, the tool coordinate system symbols are reversed.)

Appendix 2.3 Force Sense Coordinate System (XYZ)

The assumed force sense coordinate system (XYZ) used in force sense function processing is defined as follows.



The force sense coordinate system (XYZ) is the plus direction coordinate system for the direction receiving the reaction force when the robot is moved in the XYZ coordinate system plus direction. The coordinate system origin point overlaps with that of the mechanical interface coordinate system.

Appendix 3 Contact Detection

(1) Using the contact detection

If the force sense data exceeds the selected "control characteristics" force detection setting value while force sense control is enabled, JOG operation is automatically stopped. Furthermore, the buzzer sounds and the force sensor data display field on the teaching pendant changes colour to notify the user that the force detection setting value has been exceeded.

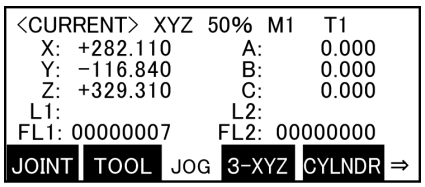
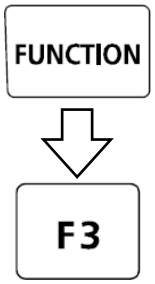
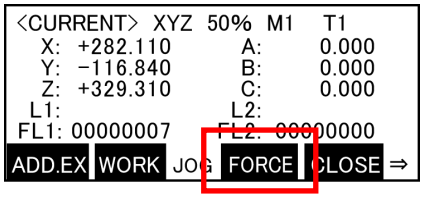
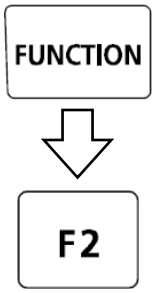
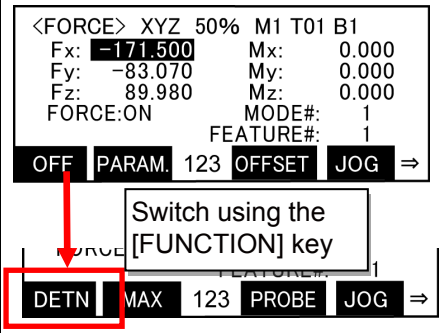
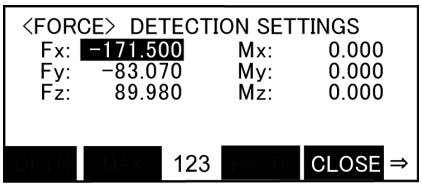
1) Set the threshold value used to detect the contact status for the "control characteristics" force detection setting value.
   (For details, refer to "Chapter5 5.4 (11) Specifying the force detection setting value (P_FsFLm0/P_FsFLm1, FSFLMT0#)".)
2) Enable force sense control.
3) If the force sensor data exceeds the force detection setting value during JOG operation, operation is stopped and the buzzer sounds.
4) The currently selected force detection setting value appears on the teaching pendant. (Refer to the next page.)

Pick Up!

Contact detection precautions

- When the robot is stopped by contact detection, the robot moves from the point the force is detected until the robot stops, and therefore a larger force than the force detection setting value may act.
- If JOG operation is stopped when the force detection setting value is exceeded, check the force sensor data value and then move the robot in the direction that the acting force becomes smaller.
- If the force detection setting value is greatly exceeded while force sense control is enabled, it will no longer be able to perform JOG operation. (Slight movement is possible.) In such a case, disable force sense control, and then move the robot by JOG operation. When doing so, take caution not to move in a direction in which a large force acts.

(2) Displaying the force detection setting value in the teaching box

Step	How to operate	T/B screen	Description of the operation method
1		<JOG operation screen> 	Press the [JOG] key and display the JOG operation screen.
2		<JOG operation screen> 	Press the [FUNCTION] key and display "FORCE" as the function menu at the bottom of the screen. Press the [F3] key ("FORCE") and display the <FORCE> screen.
3		<FORCE screen> 	The current position of the force sensor data is displayed. Enable the force control, press the [FUNCTION] key, and display "DETN" as the function menu at the bottom of the screen. Press the [F1] key ("DETN").
4		<FORCE screen> 	The force detection setting value is displayed.

(3) Usage example (contact detection/force sense monitor)

■Operation details

JOG operation is stopped automatically if unnecessary force acts on the workpiece. Check the maximum value for force applied to the workpiece.

JOG operation is stopped if unnecessary force is applied.

■Operation procedure

(1) Parameter settings

- When inserting, stiffness control (stiffness coefficient = 0) is specified only in the X- and Y-directions to ensure that the robot can move freely in response to the reaction force.
- Set the "force detection setting value" so that the robot stops following contact detection when a force of 5 N or more acts in the FXt, Fyt, or FZt directions, and a moment of 0.1 N·m or more acts in the MXt, MYt, or MZt directions. (See table below.)

Control mode	Force sense control coordinate system	FSCOD01	0
	Force control mode	FSFMD01	+2.00, +2.00, +0.00, +0.00, +0.00, +0.00
	Stiffness coefficient	FSSTF01	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Damping coefficient	FSDMP01	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
Control characteristics	Force command value	FSFCMD01	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Speed command value	FSSPD01	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Mode switching judgment value	FSSWF01	+0.00, +0.00, +0.00, +0.00, +0.00, +0.00
	Force sense control gain	FSFGN01	+1.00, +1.00, +0.00, +0.00, +0.00, +0.00
	Force detection setting value	FSFLMT01	+5.00, +5.00, +5.00, +0.10, +0.10, +0.10

(* In this example, settings are specified with parameters, however, setting is also possible with status variables.)

(2) Offset cancel operation

Perform force sensor zero point offset.

* Perform offset cancel with no external forces acting other than gravity.

(3) Control mode/control characteristics selection

Set the "control mode" and "control characteristics" numbers. (In this example, control mode 1 and control feature 1 are used.)

(4) Force sense control enable operation

Turn the servo ON after enabling force sense control, and then use JOG operation to move the robot to the insertion complete position.

JOG operation is stopped automatically if unnecessary force acts on the workpiece. (The buzzer also sounds.)

(5) Force sense monitor

Check the force sense data maximum value with the force sense monitor.

<<MEMO>> *Please use this page for your memo.

Appendix 4 Operation of the Teaching Box (R56TB)

Appendix 4.1 Editing Parameter

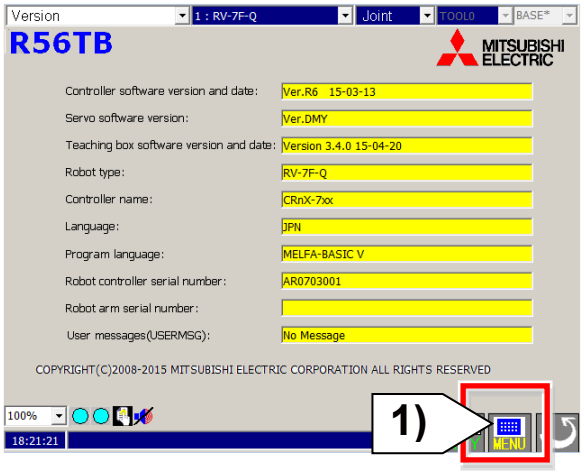
1) Tap the [MENU] key on the initial screen to display the menu panel.

2) Tap the [Parameter] key on the menu panel to display the parameter editing screen.

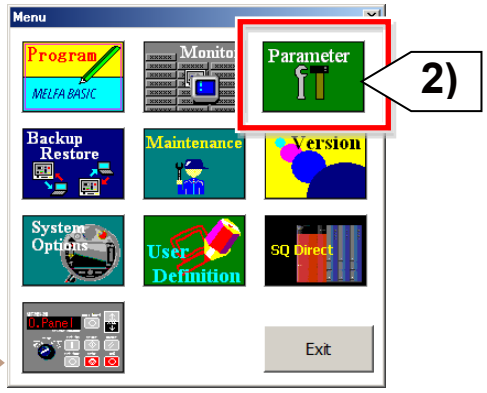
3) Tap the parameter displayed on the list or input the parameter name, and then tap [Read]. The specified parameter in the robot controller is displayed.

4) Change the parameter and confirm it. Then, tap the [Write] key to write the changed parameter to the robot controller.

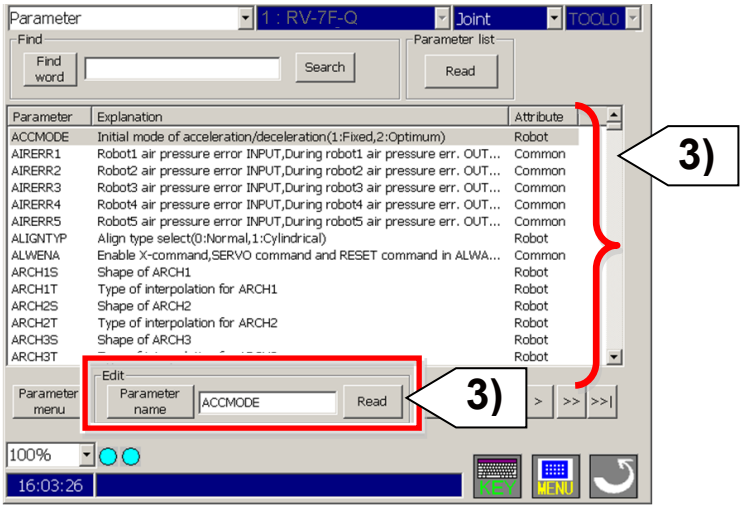
Initial screen



Menu panel

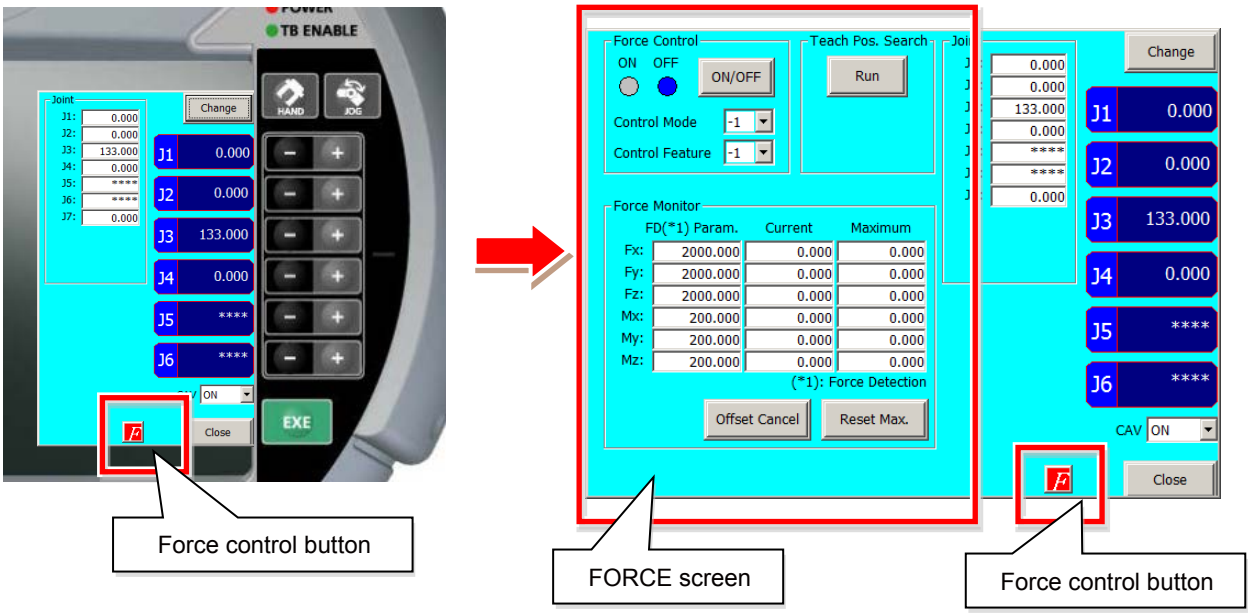


Parameter editing screen



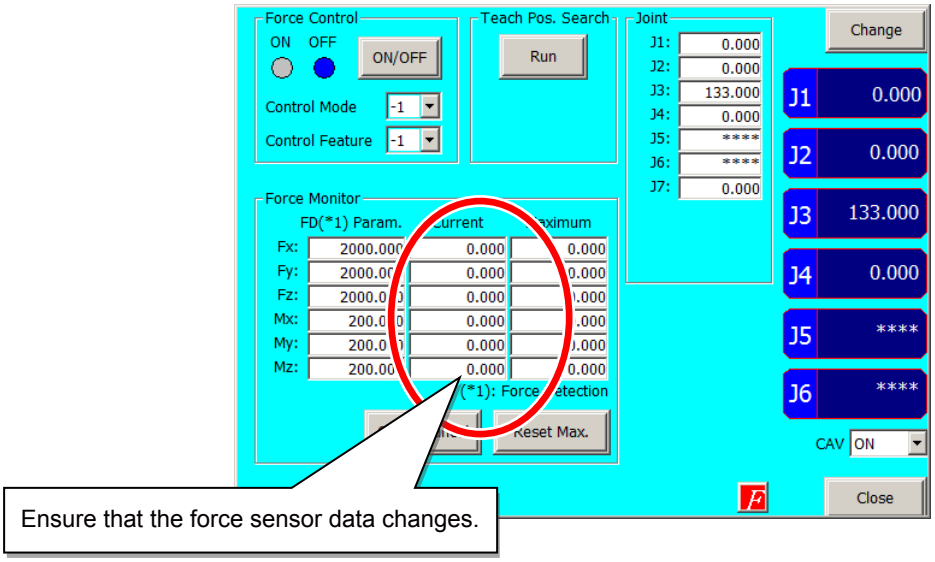
Appendix 4.2 Force Control Operation

When the force control function is used, the force control button (F button) is displayed at the bottom of the JOG operation screen.
Pressing this button displays the screen for the force control on the left side of the JOG screen.
On the FORCE screen, specifying enable/disable of the force control, checking the current status, and monitoring the force sensor are possible. (When the F button is not displayed, check the parameter setting of "Chapter4 4.4 (1) Robot number (AXMENO), axis number (AXJNO)".)



(1) Checking the force sensor data communication

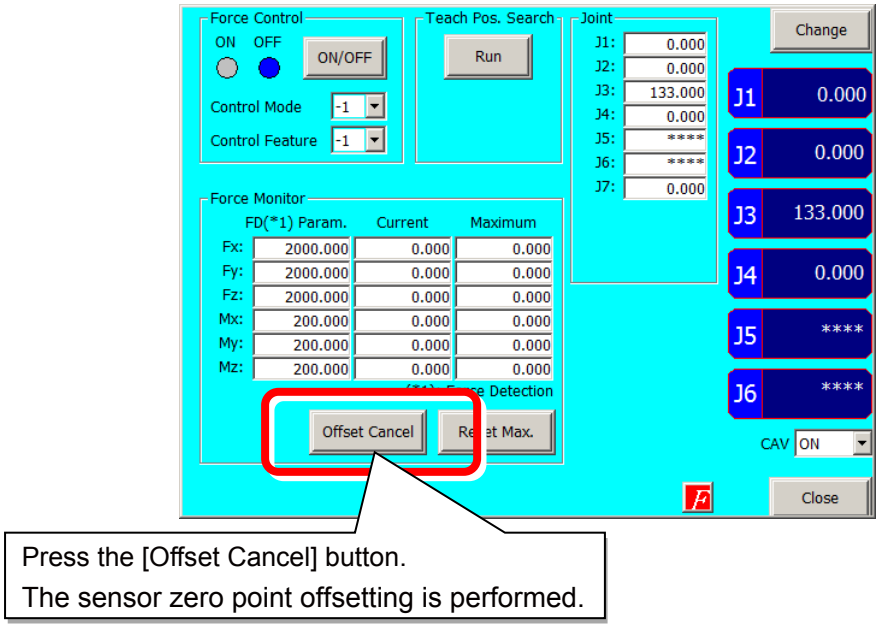
Display the force sense control screen of the teaching box and ensure that the force sensor data is displayed correctly.
If the data does not change even when force is applied to the force sensor, the device connection or parameter settings is possibly incorrect.



(2) Offset Cancel Operation

If the force sensor data zero point is offset, force sense control will not function properly. Always perform the offset cancel operation (sensor zero point offset) before use. The offset cancel operation can only be performed when force sense control is disabled.

1) Move the robot to a position at which no external force acts on the sensor (position at which no contact is made with hand, etc.)
2) Check that the robot has completely stopped, then perform the offset cancel operation.



Pick Up!

Offset cancel operation precautions

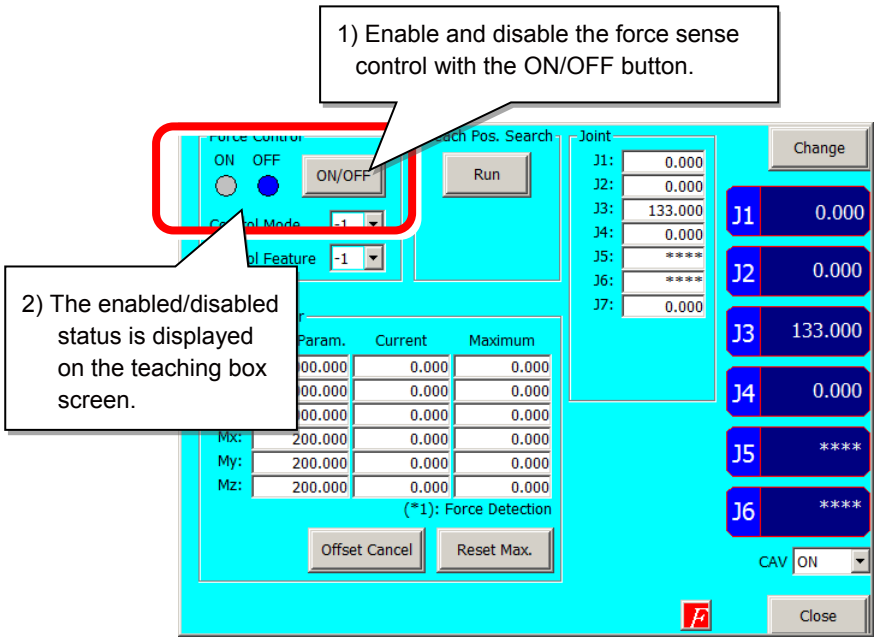
- The offset cancel status is reset by rebooting the controller. If the controller is rebooted, perform the offset cancel operation again.
- The effects of gravity are contained in the sensor offset component, and therefore if the robot arm posture is changed significantly, it is necessary to perform the offset cancel operation again.
- The offset amount may change if used for long periods of time due to changes in sensor temperature (temperature drift). In such a case, perform the offset cancel operation again.

(3) Selecting the Control Mode/Control characteristics

Before enabling force sense control, it is necessary to set the force sense control "control mode" and "control characteristics " beforehand.
(For details, refer to "Chapter5 5.4 Control Mode and Control Characteristics Details".)

1) Specify the used "control mode" and " control characteristics " number.

2) Ensure that the numbers used have been set correctly before enabling force sense control.

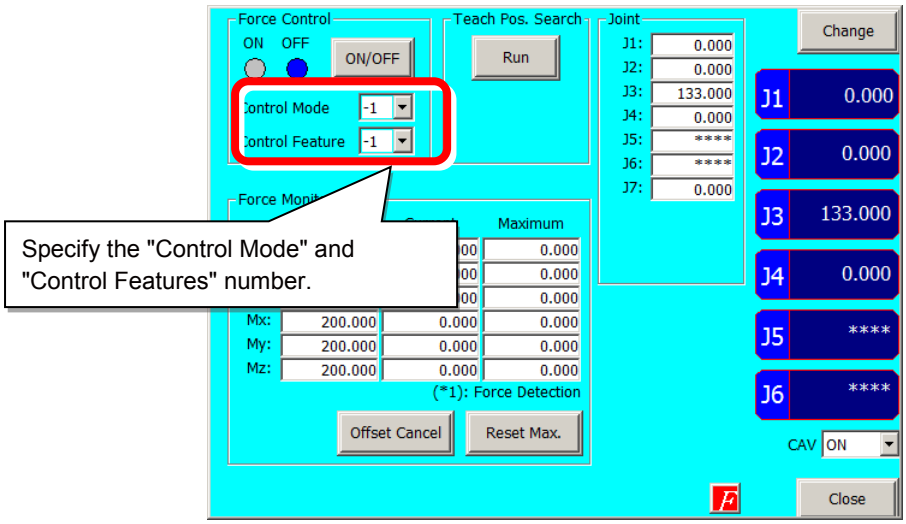


(4) Force Sense Control Enable/Disable Selection

Enable or disable force sense control. If performing JOG operation using force sense control, select "Enable", and if performing normal JOG operation, select "Disable".

1) Enable/disable force sense control with the ON/OFF button.

2) The enabled/disabled status is displayed on the T/B screen.

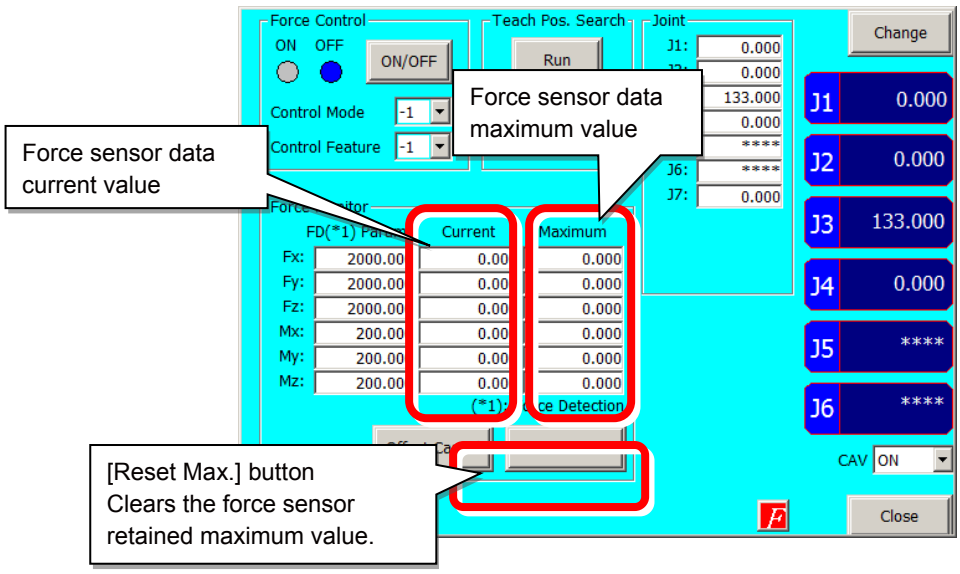


(5) Force Sense Monitor

Displays the force sensor current and maximum values. Retained maximum values can also be cleared.

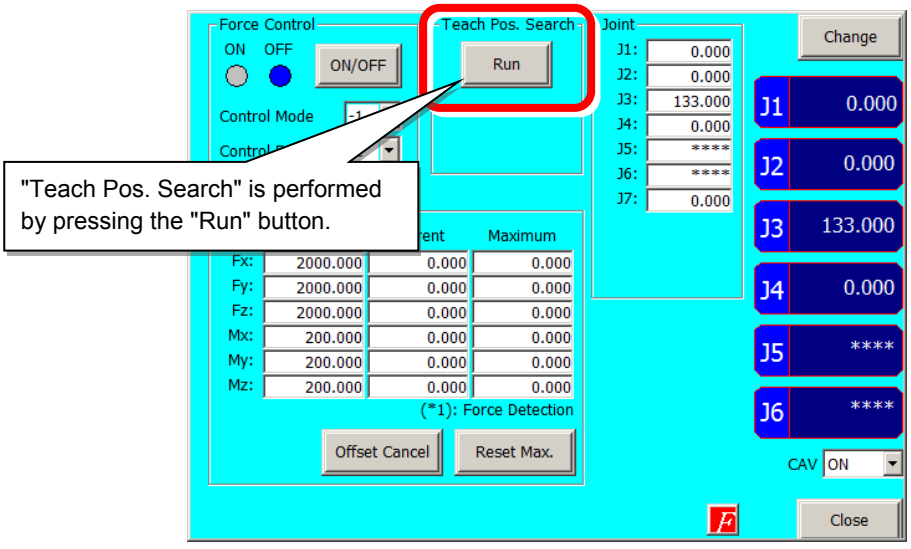
The force sensor data current and maximum values are shown below.

The coordinate system for the displayed sensor data is based on the force sensor coordinate system set for the "control mode".



(6) Position search

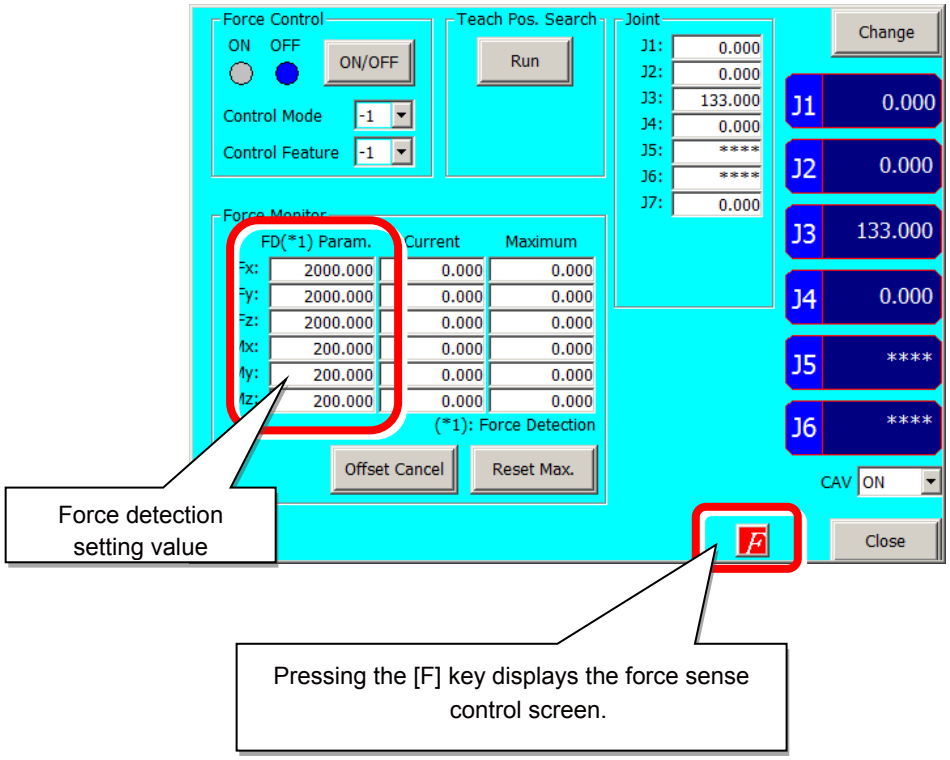
The "teaching position search" function is used to assist position teaching when force sense control is enabled.
While force control is enabled, a position offset with force sense control is added to the normal position command (position taught with T/B), resulting in a difference between the actual robot position and position displayed on the teaching pendant. By performing the teaching operation, the position displayed on the teaching
pendant is registered, and so it is necessary to eliminate this difference before performing the teaching operation.
By executing this function, the "position displayed on the teaching pendant" can be replaced with the "actual position" with force sense control still enabled.



(7) Contact Detection

If the force sense data exceeds the selected "control characteristics” force detection setting value while force sense control is enabled, JOG operation is automatically stopped. Furthermore, the buzzer sounds and the force sensor data display field on the teaching pendant changes colour to notify the user that the force detection setting value has been exceeded.

1) Set the threshold value used to detect the contact status for the "control characteristics” force detection setting value.
2) Enable force sense control.
3) If the force sensor data exceeds the force detection setting value during JOG operation, operation is stopped and the buzzer sounds.
4) The currently selected force detection setting value appears on the teaching pendant.



Pick Up!

Contact detection precautions

- When the robot is stopped by contact detection, the robot moves from the point the force is detected until the robot stops, and therefore a larger force than the force detection setting value may act.
- If JOG operation is stopped when the force detection setting value is exceeded, check the force sensor data value and then move the robot in the direction that the acting force becomes smaller.
- If the force detection setting value is greatly exceeded while force sense control is enabled, it will no longer be able to perform JOG operation. (Slight movement is possible.) In such a case, disable force sense control, and then move the robot by JOG operation. When doing so, take caution not to move in a direction in which a large force acts.

Appendix 5 Force Sense Log File

Force sense log files created in the robot controller can be transferred to a personal computer (FTP server).

Appendix 5.1 Force Sense Log File FTP Transfer

FsOutLog ＜Log File No.＞

Log File No.: Setting range: 1 to 999999999

(1) FTP parameter

Parameter	Parameter Name	No. of Elements	Description	Default Factory Setting
Log data transfer	FTPID	1 character string	Sets the user ID used with FsOutLog command FTP communication. 1st element: user ID Setting rang: Up to 8 single-byte alphanumeric characters (upper/lower case)	ftpuser
	FTPPASS	1 character string	Sets the password used with FsOutLog command FTP communication. 1st element: password [Setting range] Up to 16 single-byte alphanumeric characters (upper/lower case), or single-byte symbols (! # $ % & = - @ . ? _)	ftppassword
	FTPSVRIP	1 character string	Sets the FTP server IP address used with FsOutLog command FTP communication. 1st element: IP address [Setting range] "0.0.0.0" to "255.255.255.255"	192.168.0.99
Log function	FSLOGFN	3 integers	Specifies settings for the force sense log function. 1st element: Enables/disabled the log function. [Setting range] 0 (disable), 1 (enable) 2nd element: Selects the collected force sensor data type. [Setting range] 0: Raw data (with offset cancel) 1: Raw data (without offset cancel) 2: Data after coordinate conversion (offset cancel designation updated) 3rd element: Specifies whether to use/not use FTP. [Setting range] 0 (Do not use), 1 (Use)	0, 2, 0

(2) FTP connection/setting

The following preparations are required before executing the FsOutLog command.

1) Connect the robot controller and the personal computer that is the target for FTP with the Ethernet cable.

2) Set parameters.

Sets parameters FTPID, FTPPASS, FTPSVRIP, and FSLOGFN.

For details on the parameters, refer to "Chapter6 6.1 Force Log Parameters".

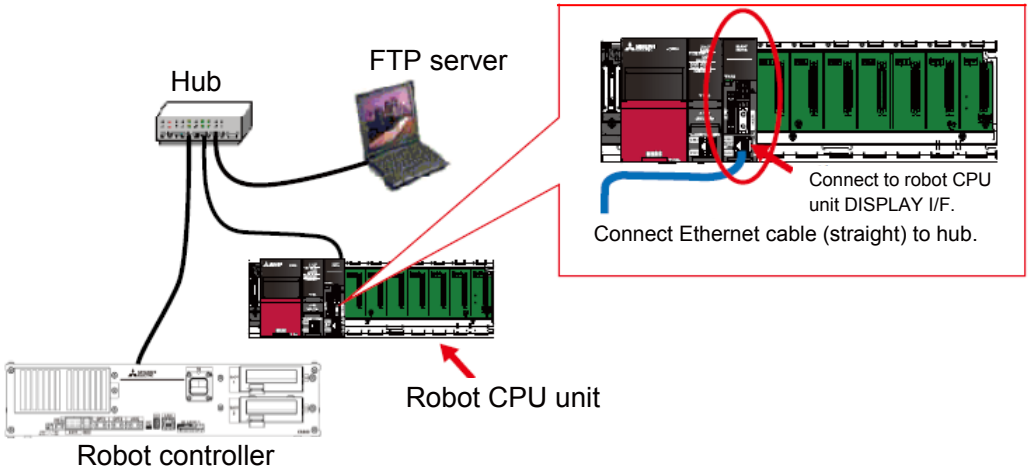
3) Start up the FTP server.

Set the FTP server on the target computer.

For the setting example of the FTP server, refer to "Force Sense Function Appendix 14.1 FTP Server Setting Example (Microsoft Internet Information Services)" in the instruction manual.

<CR800-R Series connection example>

With the CR800-R Series robot controller, FTP communication uses the robot CPU unit "DISPLAY I/F". Prepare a hub and Ethernet cable and connect to the network as shown below.

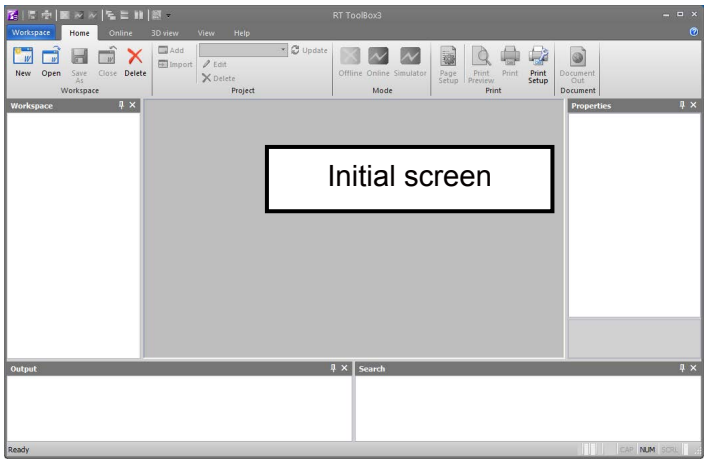


Appendix 5.2 RT ToolBox3 Creating a project for the oscillograph

(1) Starting RT ToolBox3

Double-click the shortcut of RT ToolBox3 on the desktop.

Shortcut icon



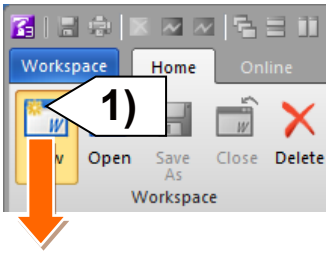
(2) Project creation and communication setting

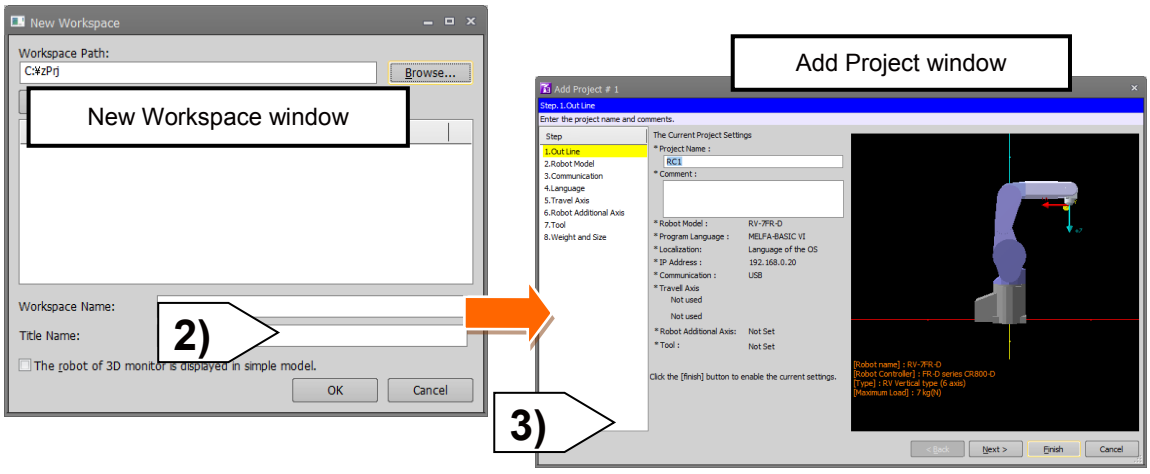
(2-1) Create a workspace and project.

1) Click [Workspace] → [NEW] in the menu bar.

2) The New Workspace window is displayed.
After inputting the workspace location, name, and title, click the [OK] button.

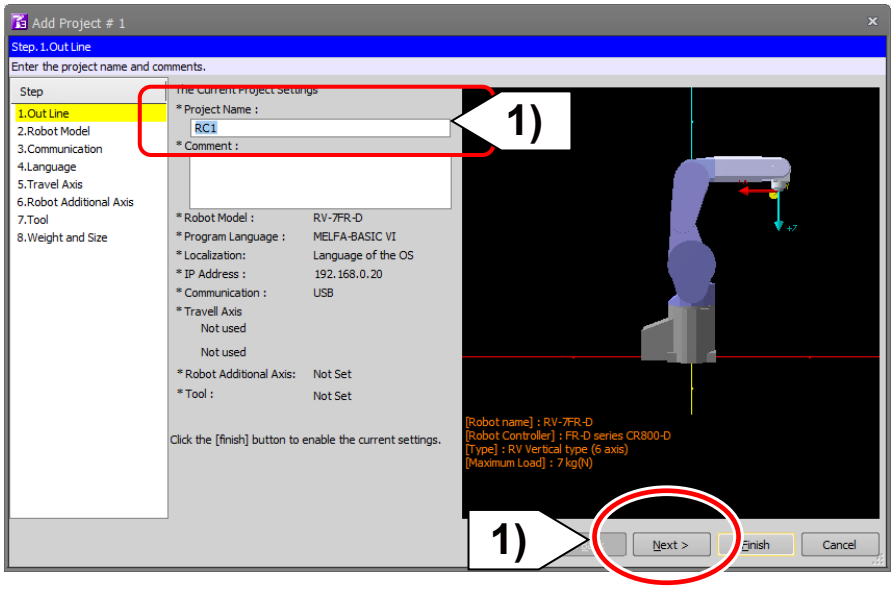
3) The "Add Project" window is displayed. (Set the robot model and communication method.)





(2-2) Step 1: Overview (project name and comment)

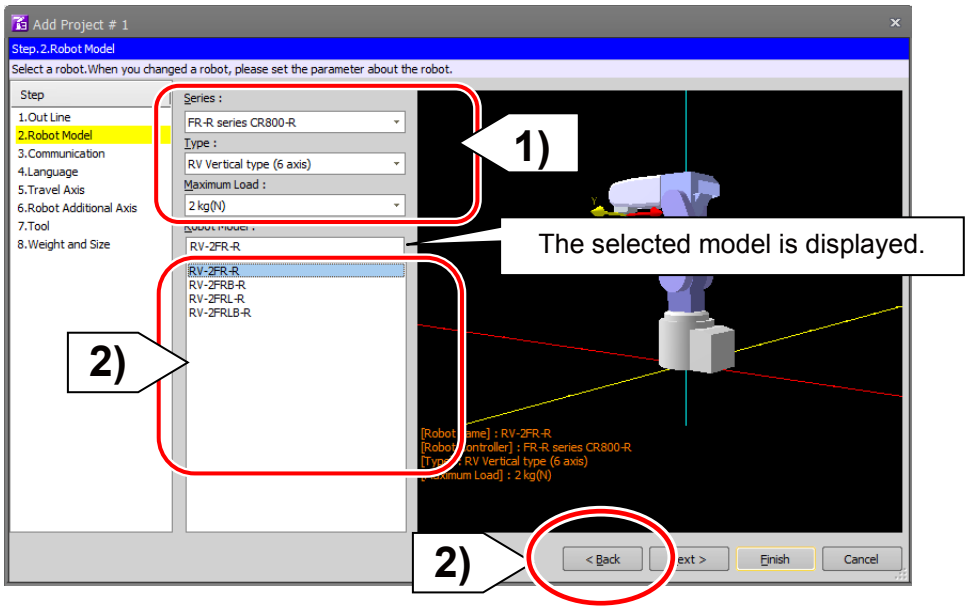
1) Enter the project name and click "Next".
RC1, RC2, or similar is input as a default value (leaving a default value is acceptable).



(2-3) Step 2: Robot model

1) Select the series and robot model of the robot controller to use in the project.
→This selection is effective only for the simulation.

2) Narrow the model with the select boxes Series, Type, and Maximum load, select a desired model, and then click "Next".

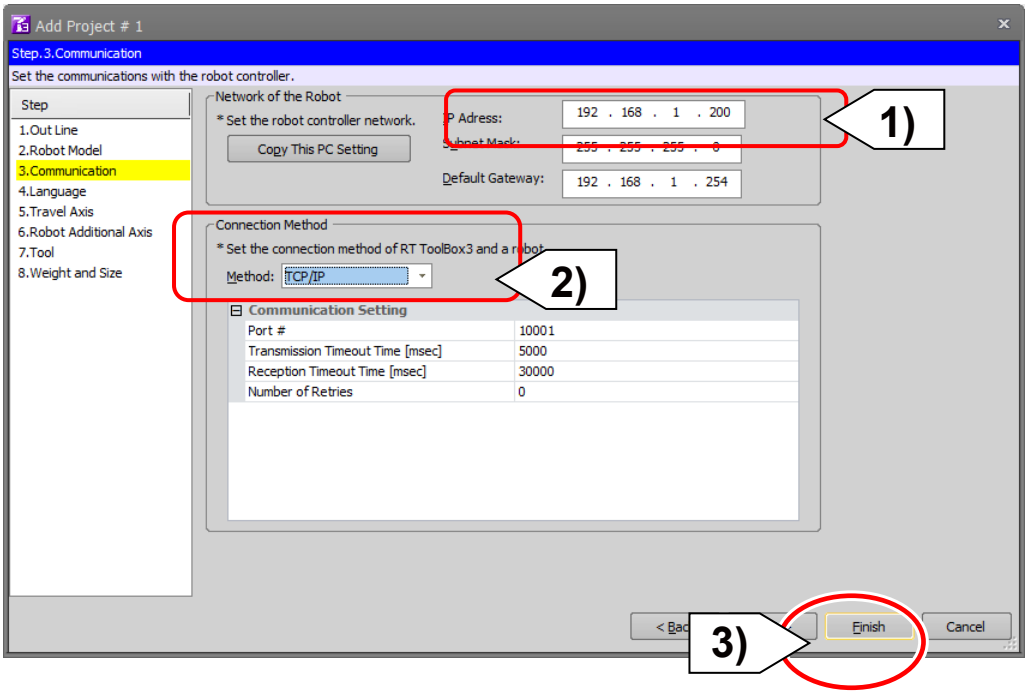


(2-4) Step 3: Communication setting

1) Input the information of the robot controller to "Network of the robot".
   For this practice, set "192.168.1.200" to "IP Address". (*)

2) Select "TCP/IP" in "Connection method".

3) Click "Finish".

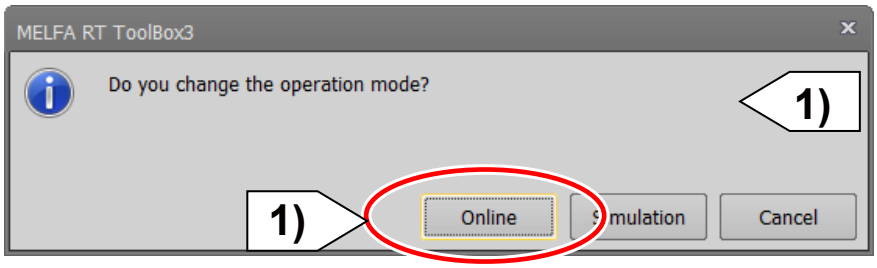


* Input "network of the robot" (IP address, subnet mask, and default gateway) according to the actual setting of the robot controller.

(2-5) Completing the project creation

1) Click "Online" when the window for the operation mode change appears.

2) The operation mode change window closes, the project setting is completed, and the project opens in "Online" mode.



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Appendix 6 Reference Case

Appendix 6.1Program Example

(1) Part Assembly Work (Force Control)

■Operation details

Assembles parts so that no unnecessary force acts on the parts when following the part fitting shape.

- The robot is controlled using force control so that the force acting in the X- and Y- directions is 0.0 N.
- The work complete condition is defined in the Mo trigger, and work is completed by interrupt processing.

■Program example

```
1 '------------------------------------------------------------
2 ' Appendix 6 Reference Case (1) Part assembly work (force control)
3 '------------------------------------------------------------
4 '[Control mode (0)]
5 P_FsStf0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Stiffness coefficient [N/mm]
6 P_FsDmp0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Damping coefficient
7 P_FsMod0=(+1.00,+1.00,+1.00,+0.00,+0.00,+0.00)(0,0)      'Force control mode (X,Y,Z-axis force control)
8 M_FsCod0=0                                               'Force sense control coordinate system (tool)
9 '[Control Feature (0)]
10 P_FsGn0 =(+3.00,+3.00,+3.00,+0.00,+0.00,+0.00)(0,0)     'Force control gain [μm/N]
11 P_FsFLm0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Force detection setting value [N]
12 P_FsFCd0=(+0.00,+0.00,+5.00,+0.00,+0.00,+0.00)(0,0)     'Force control (X,Y-axis: 0.0 N, Z-axis: 5.0 N)
13 P_FsSpd0=(+0.00,+0.00,+10.00,+0.00,+0.00,+0.00)(0,0)    'Sets speed control mode speed. (Z-axis: 10 mm/s)
14 P_FsSwF0=(+0.00,+0.00,+4.00,+0.00,+0.00,+0.00)(0,0)     'Sets force/speed judgment value.
15 '*** <Assembly work> ***
16 Def MoTrg 1, ((P_Fbc.Z <= 151) AND (P_FsCurD.Z > 4.8))  'Work complete conditions defined for Mo trigger 1.
17 Def Act 1,M_MoTrg(1)=1 GoTo *XOK,F                      'Mo trigger 1 defined as interrupt condition.
18 Mvs PStart 'The robot moves to just above the insertion position.
19 SetMoTrg 1 'Enables Mo trigger #1.
20 Fsc On, 0, 0, 1                                         'Force sense control is enabled. (Insertion started with
                                                           force control.)
21 Act 1=1                                                 'Interrupt processing 1 is enabled.
```

(Continue to the next page →)

(→ Continuation of (1) Part assembly work (force control))

```
22 M_Timer(1)=0                                  'Timer clear
23 *LBL1:If M_Timer(1) < 5000 Then Goto *LBL1
24 Fsc Off                                       'Force sense control is disabled.
25 Error 9100                                    'Error occurs if insertion work not complete within 5 seconds.
26 End
27 '*** <Work completed> ***
28 *XOK                                          'Insertion work complete interrupt processing
29 Act 1=0
30 SetMoTrg 0
31 Fsc Off                                       'Force sense control is disabled.
32 HOpen 1
33 P2=P_Fbc                                      'Feedback position acquisition
34 P2.Z=P2.Z+100                                 'Target position determined as position +100 mm in
                                                 Z-direction from current position.
35 Mvs P2
36 End
```

■Description

1）With force control, the robot is set to push with a force of 0.0 N in the X- and Y-directions, and 5.0 N in the Z-direction. Furthermore, if the reaction force in the Z-direction is less than 4 N, the robot moves at a speed of 10 mm/s in speed priority mode.

2）Work complete conditions are defined for Mo trigger 1 with the Def MoTrg command. (In this example, when Z ≤ 151 mm and Fzt > 4.8 N, it is judged that insertion work is complete.)

3）After moving to the assembly start position, by enabling Mo trigger 1 followed by force sense control, insertion work is started automatically.

4）If insertion work is not completed within 5 seconds of work starting, a 9100 error is output and insertion work is stopped.

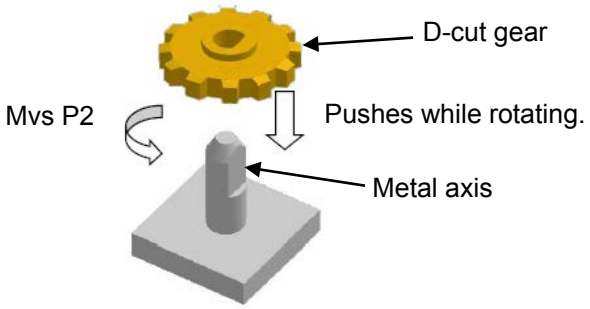
5）If insertion work is completed successfully, M_MoTrg(1)=1 and interrupt processing (label: *XOK) is performed.

(2) Phase Focusing Push

■Operation details

The robot inserts into a metal axis while searching for a d-cut gear phase.

- The robot rotates in the C-axis direction while pushing softly in the Z-direction with robot stiffness softened by stiffness control.
- When the gear and metal axis phases match, the moment around the Z-axis (Mz) increases.
- The Mz increase is detected and push work is started.



■Program example

```
1 '-------------------------------------------------------
2 ' Appendix 6 Reference Case (2) Phase focusing push
3 '-------------------------------------------------------
4 '[Control mode (0)]
5 P_FsStf0=(+0.00,+0.00,+3.00,+0.00,+0.00,+0.50)(0,0)      'Stiffness coefficient [N/mm]
6 P_FsDmp0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)      'Damping coefficient
7 P_FsMod0=(+2.00,+2.00,+2.00,+0.00,+0.00,+2.00)(0,0)      'Force control mode (X,Y,Z,C: stiffness control)
8 M_FsCod0 = 0                                             'Force sense control coordinate system (tool)
9 '[Control characteristics (0)]
10 P_FsGn0 =(+2.50,+2.50,+2.50,+0.00,+0.00,+2.50)(0,0)     'Force control gain [μm/N]
11 P_FsFLm0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.05)(0,0)     'Force detection setting value [N] (Mz=0.05[Nm])
12 P_FsFCd0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Force control
13 P_FsSpd0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Sets speed control mode speed.
14 P_FsSwF0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Sets force/speed judgment value.
15 '[Control characteristics (-1)]
16 P_FsGn1 =(+2.50,+2.50,+0.00,+0.00,+0.00,+3.00)(0,0)     'Force control gain [μm/N] (Z axis=0.0[μm/N])
17 P_FsFLm1=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Force detection setting value [N]
18 P_FsFCd1=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Force control
19 P_FsSpd1=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Sets speed control mode speed.
20 P_FsSwF1=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)     'Sets force/speed judgment value.
21 '*** <Assembly work> ***
22 Mvs PStart                                              'Robot moves over insertion position.
23 Dly 1
```

(Continue to the next page →)

(→ Continuation of (2) Phase focusing push)

```
24 Ovrd 5
25 Fsc On, 0, 0, 1                      'X,Y,Z,C-axes set to stiffness control.
26 Mvs P1                               'Robot moves to pos. pushed approx. 1 mm from assembly
27 Mvs P2 Wthif P_FsLmtR.C>0, Skip      'C-axis is rotated and skip occurs when Mz≥0.5 N·m.
28 If M_SkipCq = 0 Then *LERR           'Proceeds to failure processing if skip processing not
29 FsGChg 0, 10, -1                     '"Control characteristics " changed to "-1".
30 Mvs ,10                              'Tool moved 10 mm in +Z-direction.
31 HOpen 1
32 Fsc Off
33 Mvs PStart
34 End
35 *LERR                                'Error processing
36 Error 9100
37 End
```

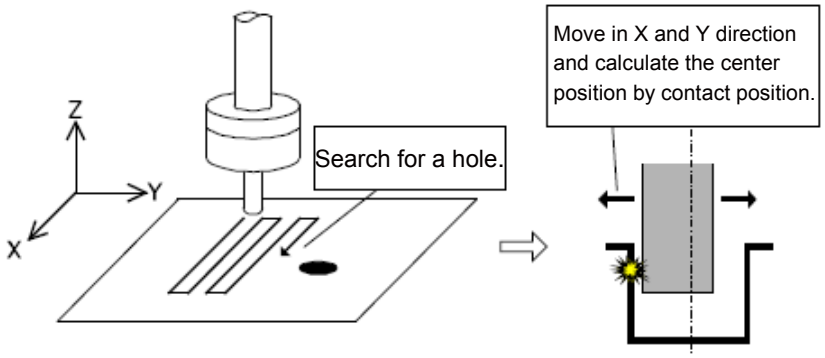
■Description

1) The robot is set to control the X-, Y-, Z-, and C-axes softly with stiffness control. The force detection setting value is Mz = 0.05 N·m.
2) Force control is enabled, and the robot moves to a position approximately 1 mm below of the insertion start position. (MvsP1)
3) The C-axis is rotated with the Mvs command. If a moment of Mz ≥ 0.05 N·m is detected during operation using a Wthif sub-clause, operation is stopped and skip processing is performed at the next step.
4) The gear is twisted in the C-axis direction while pushing in the Z-direction, and therefore when the D-cut gear and metal axis phases match, Mz increases. Wthif sub-clause conditions are established, and therefore rotation is stopped and skip processing is performed for the next command. (If skip processing is not performed, the system determines that phase detection has failed and error processing is performed.)
5) Control characteristics "0" is changed to "-1" using the FsGChg command so that the Z-axis control gain becomes 0.0. (If the control gain is 0, the robot is not controlled softly even if stiffness control is selected. Control will be the equivalent of position control.)
6) The robot moves 10 mm in the tool coordinate system Z-direction and assembly work is completed.

(3) Coordinate calculation

■Operation details

Search for a hole on the XY plane. If a hole is found, the XY coordinates of the center of the hole are figured.



■Program example

```
1 '-----------------------------------------------
2 ' Appendix 6 Reference Case (3) Coordinate calculation
3 '-----------------------------------------------
4 'Control Mode ( 0 ) setting
5 P_FsStf0=(+0.00,+0.00,+1.00,+0.00,+0.00,+0.00)(0,0)        'Stiffness coefficient (Specify Z-axis component as 1 [N/mm].)
6 P_FsDmp0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)        'Damping coefficient (Not specified.)
7 P_FsMod0=(+0.00,+0.00,+2.00,+0.00,+0.00,+0.00)(0,0)    'Force sense control type (Specify stiffness control in Z-axis
                                                              direction.)
8 M_FsCod0=1                                              'Force sense coordinate system (Specify XYZ coordinate system.)
9 '
10 ' Control Feature ( 0 ) setting
11 P_FsGn0=(+0.00,+0.00,+40.00,+0.00,+0.00,+0.00)(0,0)       'Gain (Specify Z-axis direction as 40 [10-3 mm/N].)
12 P_FsFLm0=(+20.00,+20.00,+5.00,+5.00,+5.00,+5.00)(0,0)     'Force detection setting value (Specify Z-axis direction as
                                                              5 [N].)
13 P_FsFCd0=(+0.00,+0.00,+0.00,+0.00,+0.00,+0.00)(0,0)       'Force control (Not specified.)
14 '
15 Def Act 1,P_FsLmtR.Z=1 GoTo *PCEN,S                       'Define so that interrupt processing is performed if the Z-axis
16 'direction becomes smaller than force detection setting value.
17 P2=P1
18 P2.X=P2.X+100                                            'Search for the width of 100 mm in X-direction.
19 Fsc On,0,0,1        'Enable the force sense control with control Mode=0, Control Feature =0, and offset cancel is enabled.
20 Mvs P1                  'Move the axis to search start position (Move it to an approximately 10 mm lower position in the
                            Z-axis direction from the search plane, and then pushes in the Z-direction).
21 '
22 Spd 5
23 Act 1=1
24 For M1=1 To 10        'Search in 5 mm intervals in the Y-direction. Force is lost in the Z-axis direction if the robot axis
                          drops into a hole, and therefore an interrupt is entered.
25 Mvs P1
```

(Continue to the next page →)

(→ Continuation of (3) Coordinate calculation)

```
26 Mvs P2
27 P1.Y=P1.Y+5
28 P2.Y=P1.Y
29 Mvs P2
30 Mvs P1
31 P1.Y=P1.Y+5
32 P2.Y=P1.Y
33 Next M1
34 Act 1=0
35 Fsc Off
36 End
37 '
38 ' Interrupt processing
39 *PCEN
40 Dim PX(2),PY(2)
41 P0=P_Curr              'The position where the robot axis falls into the hole and stops is used as a reference.
42 PX(1)=P0
43 PX(2)=P0
44 PY(1)=P0
45 PY(2)=P0
46 PX(1).X=P0.X+10        'The position ±10 mm in the XY-direction from the reference position is calculated.
47 PX(2).X=P0.X-10
48 PY(1).Y=P0.Y+10
49 PY(2).Y=P0.Y-10
50 '
51 Fsc Off
52 P_FsFLm0=(+2.00,+2.00,+5.00,+5.00,+5.00,+5.00)(0,0)          'Change the X, Y-axis direction force
                                                                 detection setting value to 2 [N].
53 Fsc On,0,0,1
54 MFLG=0
55 '
56 For M1=1 To 2
57 Mvs PX(M1) WthIf P_FsLmtR.X=1,Skip        'Move the axis ±10 mm in the X-axis direction and skip if the
                                              force detection setting is exceeded.
58 If M_SkipCq=1 Then
59 PX(M1)=P_FsLmtP   'If skipped, the position where the force detection setting value is exceeded is retained.
60 MFLG=MFLG+1
61 EndIf
62 Mvs P0
63 Fsc Off                                  'Force sense control is temporarily enabled to reset P_FsLmtP.
64 Fsc On,0,0,1
65 Next M1
66 '
67 For M1=1 To 2
68 Mvs PY(M1) WthIf P_FsLmtR.Y=1,Skip        'Move the axis ±10 mm in the Y-axis direction and skip if the
                                              force detection setting is exceeded.
```

(Continue to the next page →)

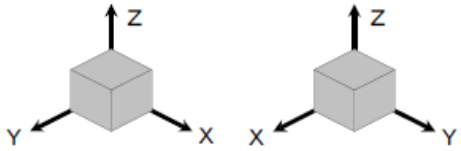
(→ Continuation of (3) Coordinate calculation)

```
69 If M_SkipCq=1 Then
70 PY(M1)=P_FsLmtP                'If skipped, the position where the force detection setting value is
                                   exceeded is retained.
71 MFLG=MFLG+1
72 EndIf
73 Mvs P0
74 Fsc Off                        'Force sense control is temporarily enabled to reset P_FsLmtP.
75 Fsc On,0,0,1
76 Next M1
77 '
78 If MFLG=4 Then                 '4 points are found.
79 PTMP=(PX(1)+PX(2))/2
80 P0.X=PTMP.X                    'The X-axis direction center position is set for P0.
81 PTMP=(PY(1)+PY(2))/2
82 P0.Y=PTMP.Y                    'The Y-axis direction center position is set for P0.
83 Else                           '4 points are not found.
84 Error 9100                     'Elicit error L9100.
85 EndIf
86 End
```

<<MEMO>> *Please use this page for your memo.

Appendix 7 Parameter

Appendix 7.1 Setting Parameters and Status Variables for Force Sense Control Conditions

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Set axis No.	AXJNO	16 integers	Sets the force sense interface unit or additional axis number for the element corresponding to the servo control axis number being used. <If using force sense interface unit> Servo control axis No.: Set "9" for axis No.1.	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Mechanical No. designation	AXMENO	16 integers	Enter a mechanical number corresponding to the servo control axis number being used. Always set "0" for axes that are not being used. <If using force sense interface unit> Servo control axis No.: Set "1" for axis No.1.	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Force sensor coordinate system selection	FSHAND	1 integer	Selects the force sensor coordinate system hand system (left-hand system/right-hand system). The force sensor coordinate system hand system differs depending on the sensor attachment direction, and therefore it is necessary to change the setting based on the attachment direction. Set the left-hand system for recommended attachment. 0: Force sensor coordinate system left-hand system 1: Force sensor coordinate system right-hand system <Left-hand system> <Right-hand system>  	0
Force sensor attachment position	FSXTL	6 real numbers	Sets the positional relationship for the mechanical interface coordinate system and force sensor coordinate system. 1st element: X-axis direction coordinate system origin offset [mm] 2nd element: Y-axis direction coordinate system origin offset [mm] 3rd element: Z-axis direction coordinate system origin offset [mm] 4th element: Coordinate axis rotation angle around X-axis [deg] 5th element: Coordinate axis rotation angle around Y-axis [deg] 6th element: Coordinate axis rotation angle around Z-axis [deg]	0.0, 0.0, 0.0, 0.0, 180.0, 0.0 (vertical multi-joint robots) 0.0, 0.0, 0.0, 0.0, 0.0, 180.0 (horizontal multi-joint robots)

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sensor tolerance	FSLMTMX	6 real numbers	Sets the force sensor tolerance. If sensor data exceeding the force and moment set at this parameter is detected, an error (H7660) occurs and the robot is stopped. (Force sense control will be disabled.) 1st element: Force sensor data Fx tolerance [N] 2nd element: Force sensor data Fy tolerance [N] 3rd element: Force sensor data Fz tolerance [N] 4th element: Force sensor data Mx tolerance [N·m] 5th element: Force sensor data My tolerance [N·m] 6th element: Force sensor data Mz tolerance [N·m]	0.0, 0.0, 0.0, 0.0, 0.0, 0.0
Force sense control offset limit	FSCORMX	2 real numbers	Sets the maximum position offset for force sense control. 1st element: Position maximum offset [mm] 2nd element: Posture maximum offset [deg.] [Setting range] 1st element: 0 to +200.0 2nd element: 0 to +150.0	10.0, 10.0
Force sensor data filter	FSFLCTL	1 real number	Sets the force sensor data filter time constant. [Unit]: ms [Setting range]: 0 to +1000.0	1.7
Force sensor minimum force control	FSMINCTL	6 real number	Sets the minimum control force of the force sensor. 1st element: Minimum control force of force sensor Fx [N] 2nd element: Minimum control force of force sensor Fy [N] 3rd element: Minimum control force of force sensor Fz [N] 4th element: Minimum control force of force sensor Mx [Nm] 5th element: Minimum control force of force sensor My [Nm] 6th element: Minimum control force of force sensor Mz [Nm]	0.3, 0.3, 0.3, 0.03, 0.03, 0.03
Force sensor Calibration data	FSEST01 - 09	12 real number	Sets the robot's posture and the force sensor data used for the force sensor calibration execution. 1st element: Robot position X [mm] 2nd element: Robot position Y [mm] 3rd element: Robot position Z [mm] 4th element: Robot posture A [deg] 5th element: Robot posture B [deg] 6th element: Robot posture C [deg] 7th element: Force sensor data Fx [N] 8th element: Force sensor data Fy [N] 9th element: Force sensor data Fz [N] 10th element: Force sensor data Mx [Nm] 11th element: Force sensor data My [Nm] 12th element: Force sensor data Mz [Nm] (The value is updated at the FsGetDat command is executed.)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Force sense control coordinate system	FSCOD01-09	1 integer	Specifies the force sense coordinate system. 0: Tool coordinate system 1: XYZ coordinate system [Setting range]: 0, 1	0
Force sense control mode	FSFMD01-09	8 integers	Selects the force sense control mode for each coordinate system axis. 0: Position control 1: Force control 2: Stiffness control 3: Limited stiffness control [Setting range]: 0, 1, 2, 3	0, 0, 0, 0, 0, 0, 0, 0
Stiffness coefficient	FSSTF01-09	8 integers	Sets the stiffness coefficient for force sense control (stiffness control). [Setting range]: 0.0 - 1000.0 [Setting unit]: X, Y , Z axes = N/mm A, B, C axes = N·m/deg (This setting is not required for axes for which stiffness control is not selected.)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
Damping coefficient	FSDMP01-09	8 real numbers	Sets the damping coefficient (responsiveness) for force sense control. [Setting range]: 0.0 - 1.0 [Setting unit]: X, Y , Z axes = N/(mm/s), A, B, C axes = N·m/(deg/s)	
Force sensor bias value	FSBIAS01-09	6 real numbers	Sets the bias value used for gravity offset cancel. 1st element: Force sensor data Fx bias value [N] 2nd element: Force sensor data Fy bias value [N] 3rd element: Force sensor data Fz bias value [N] 4th element: Force sensor data Mx bias value [N·m] 5th element: Force sensor data My bias value [N·m] 6th element: Force sensor data Mz bias value [N·m] (These values because these are set automatically by the force calibration function, so you do not need to be set again.)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Center of gravity position of hand tip	FSGRP01-09	6 real numbers	Sets the load center of gravity position used for gravity offset cancel. 1st element: Load center of gravity position X [mm] 2nd element: Load center of gravity position Y [mm] 3rd element: Load center of gravity position Z [mm] 4th element: Rotation angle of load center of gravity A [deg] 5th element: Rotation angle of load center of gravity B [deg] 6th element: Rotation angle of load center of gravity C [deg] (These values because these are set automatically by the force calibration function, so you do not need to be set again.)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0
Hand tip weight	FSMASS01-09	1 real number	Sets the load mass used for gravity offset cancel. [Setting unit]: kg (These values because these are set automatically by the force calibration function, so you do not need to be set again.)	0.0
Force command value Limit value	FSFCMD01-09	8 real numbers	The value has different roles in the force control and the limited stiffness control. [In the case of force control] Sets the force command for force sense control (force control). [Setting range]: - force sensor tolerance value to + force sensor tolerance value [Setting unit]: X, Y, Z component = N A, B, C component = N·m (This setting is not required for axes for which force control is not selected.) [In the case of the stiffness control with limit] Sets the limit value for the limited stiffness control. [Setting range]: 0 to + force sensor tolerance value [Setting unit]: X, Y, Z, L1 component = N (L1 component sets the limit value for the resultant force.) A, B, C, L2 component = N·m (L2 component sets the limit value for the resultant moment.) (The value is not required in the axis that is not applying the limited stiffness control.)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
Speed command value	FSSPD01-09	8 real numbers	Sets the speed command value for force sense control (force control). [Setting range]: 0.0 - 50.0 [Setting unit]: X, Y, Z component = mm/s A, B, C component = deg/s (This setting is not required for axes for which force control is not selected.)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Mode switching judgment value	FSSWF01-09	8 real numbers	Sets the mode switching judgment value for force sense control (force control). [Setting range]: - force sensor tolerance value to + force sensor tolerance value [Setting unit]: X, Y, Z component = N A, B, C component = N·m (This setting is not required for axes for which force control is not selected.)	
Force sense control gain	FSFGN01-09	8 real numbers	Sets the force sense control gain (response sensitivity) for force sense control. [Setting range]: 0.0 - 300.0 [Setting range]: X, Y, Z axis component = 10^{-3} mm/N A, B, C axis component = 10^{-3} deg/(N·m)	0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
Force detection setting value	FSFLMT01-09	6 real numbers	Sets the force detection setting for interrupt signals and data retention trigger for each coordinate axis. [Setting range]: 0.0 - force sensor tolerance value [Setting range]: X, Y, Z axis component = N A, B, C axis component = N·m	2000.0, 2000.0, 2000.0, 200.0, 200.0, 200.0
Filter time constant for offset cancel	FSFLOFST	1 real number	Sets the filter time constant used for gravity offset cancel. It is not required to change this value in normal use. [Setting range]: 0 or more [Setting unit]: ms	30.0
Log function	FSLOGFN	3 integers	Specifies settings for the force sense log function. 1st element: Enables/disabled the log function. [Setting range] 0 (disable), 1 (enable) 2nd element: Selects the collected force sensor data type. [Setting range] 0: Raw data (with offset cancel) 1: Raw data (without offset cancel) 2: Data after coordinate conversion (offset cancel designation updated) 3rd element: Specifies whether to use/not use FTP. [Setting range] 0 (Do not use), 1 (Use)	0, 2, 0

Parameter	Parameter Name	No. of Elements	Description	Factory Default Setting
Log data transfer	FTPID	1 character string	Sets the user ID used with FsOutLog command FTP communication. 1st element: user ID [Setting range]: Up to 8 single-byte alphanumeric characters (upper/lower case)	ftpuser
	FTPPASS	1 character string	Sets the password used with FsOutLog command FTP communication. 1st element: password [Setting range] Up to 16 single-byte alphanumeric characters (upper/lower case), or single-byte symbols (! # $ % & = - @ . ? _)	ftppassword
	FTPSVRIP	1 character string	Sets the FTP server IP address used with FsOutLog command FTP communication. 1st element: IP address [Setting range] "0.0.0.0" - "255.255.255.255"	192.168.0.99

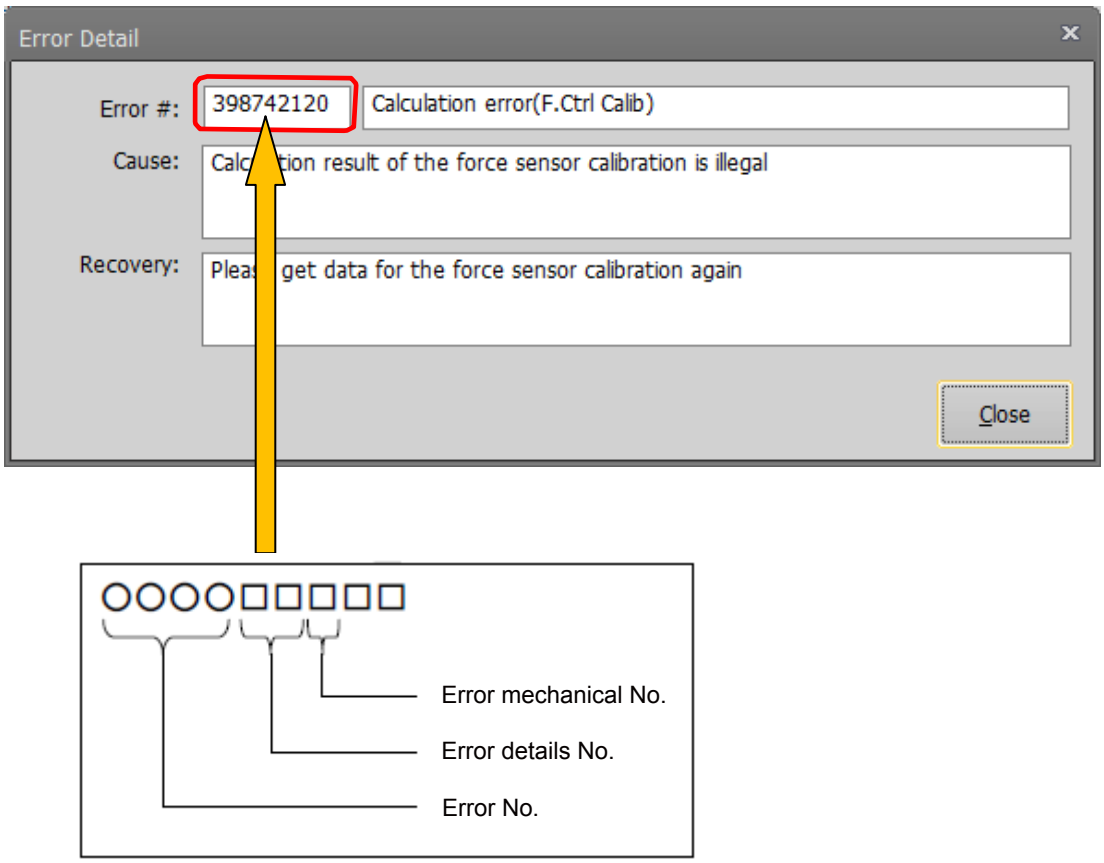
Appendix 8 Troubleshooting

Appendix 8.1 Behaviour when Force Sense Control Errors Occur

If any of the following types of error occurs, force sense control is disabled and the servo turns OFF.

Type	Error No.	Error Details
Force sense position command	H2760	Offset limit over
	H3988	Force sense position command calculation not possible
	H2770	Outside joint movement range
	H2780	Speed over
Force sense I/F unit	H8920	Force sense interface unit error
Force sensor data	H7660	Sensor tolerance over

The force sense control error number consists of 4 digits + 5 digits.
The first 4 digits appear on the operation panel and teaching pendant. The last 5 digits can be checked at the RT ToolBox3 error details display. (See below.)



Appendix 8.2 Force Sense Function Related Error List

This section describes only errors related to the force sense function.
(* Errors that may occur depending on the conditions and error detection timing are excluded.)
For the errors not described in the list, refer to the following manuals.
• CR800 Series Controller INSTRUCTION MANUAL Troubleshooting (BFP-A3480)
• CR750/CR751/CR760 Series Controller INSTRUCTION MANUAL Troubleshooting (BFP-A8871)

(★) The force sense control is disabled if an error occurs while the force sense control is enabled.

Error No.	Error Details
L_1864_00000	The FTP communication parameters are incorrect.
L_2750_01000	Unable to disable force sense control while tracking.
H_2760_00000	The force sense control offset value was approaching the limit value. (★)
H_2770_00000	The force sense control offset position is outside the movement range. (★)
H_2780_00000	The force sense control offset position exceeded the speed limit. (★)
L_3110_76000	A value outside the range was set for the force sense control command argument.
L_3110_77000	A value outside the range was set for the force sense control status variable argument.
L_3110_78000	A value outside the range was set for a force sense control related argument.
L_3110_80000	A value outside the range was set for the Mo trigger No.
L_3110_81000	A value outside the range was set for the Def MoTrg command argument.
L3770_00000	An attempt was made to use an undefined Mo trigger.
L_3870_17000	An invalid value was set for the force sense control status variable mechanical No.
L_3870_22000	The mechanical No. specified with the Def MoTrg command is invalid.
L_3986_01000	Unable to enable force sense function. (Force sensor not connected)
L_3986_02000	Unable to enable force sense function. (Compliance control function enabled)
L_3986_04000	Unable to enable compliance control function. (Force sense control function enabled)
L_3986_05000	Unable to enable collision detection function. (Force sense control function enabled)
L_3986_07000	Unable to enable force sense function. (Initialization failure)
L_3986_08000	Unable to move the singular point adjacent area. (Force sense control function enabled)
L_3986_09000	The force sense control enabled/disabled status differs from that when operation is interrupted.
L_3986_10000	This force sense control function cannot be used.
L_3986_11000	Unable to change tool conversion data. (Force sense control function enabled)

Error No.	Error Details
L_3986_12000	Unable to change base conversion data. (Force sense control function enabled)
L_3986_13000	Unable to execute Jrc command. (Force sense control function enabled)
L_3986_14000	Unable to perform JOG operation. (Force sense control function enabled)
L_3986_16000	Unable to perform offset cancel. (Force sense control function enabled)
L_3987_01000	The force sense control function is disabled.
L_3987_02000	An attempt was made to enable force sense control while enabled.
L_3987_04000	An attempt was made to execute an FsGChg command during force sense control gain change processing.
L_3987_07000	Failed to output a force sense log file to the FTP server.
L_3987_08000	The specified force sense log file does not exist.
L_3987_10000	Unable to change force sense control status variable settings. (Force sense control function enabled)
L_3987_11000	Unable to create/output another file while creating/outputting a force sense log file.
L_3987_12000	Unable to create force sense log file.
L_3987_14000	Unable to execute Fsc On command while changing the gain.
L_3987_16000	Unable to execute Fsc On command while registering log data.
L_3987_26000	Unable to change force sense control parameter settings. (Force sense control function enabled)
L_3987_27000	Unable to enable Mo trigger. (The FsCTrg command Mo trigger executed first is enabled.)
L_3987_28000	Mo trigger timeout. The Mo trigger did not turn ON within the specified time.
L_3987_29000	Unable to executed FsCTrg command. (Changing control characteristics)
L_3987_30000	Unable to executed FsCTrg command. (The FsCTrg command Mo trigger executed first is enabled.)
L_3987_31000	Unable to specify control characteristics change. A control characteristics change has been set with another command.
L3987_40000	FsHndEst command is not executed
L3987_41000	Input data error(F.Ctrl Calib)
L3987_42000	Calculation error(F.Ctrl Calib)
H_3988_00000	Unable to convert linear position data to joint angle after offsetting with force control. (★)
H_7650_00000	The force sensor quantity setting is incorrect.

Error No.	Error Details
H_7651_00000	Unable to initialize force sense interface unit.
H_7652_00000	This is a force sense interface unit for an unsupported revision.
H_7660_02000	The force acting on the sensor exceeded the tolerance value. (★)
H_8920_00000	Force sense interface unit error (★)
C_8921_00000	Force sense interface unit warning

Appendix 8.3 Force Sense Function Related Error Details

[Types of the first alphabets of the error No. → H: High level error, L: Low level error, C: Caution (Warning) "n" at the end of the error No. in this list indicates the axis number (1 to 8).]

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
L1864	00000	Err. message	FTP parameter setting error (**) *) "**" is substituted with the "parameter name".
		Cause	The FTP communication parameter setting lies outside the range.
		Remedy	Check the setting and correct.
L2750	01n00 n=Mech. No.	Err. message	Unable to disable force sense control. (Tracking being performed)
		Cause	Unable to disable force sense control while tracking function being executed.
		Remedy	Try again after disabling the tracking function.
H.2760	00n00 n= Mech. No.	Err. message	The force sense control offset limit was reached.
		Cause	The robot attempted to move beyond the force sense control offset limit.
		Remedy	Check whether there is a problem with robot movement while force sense control is enabled. (The offset limit is the value set in parameter FSCORMX.)
H.2770	xxn00 xx= Axis No. n= Mech. No.	Err. message	Outside offset position movement range (**) *) "**" is substituted with "±Jn" (n is axis No.)
		Cause	The position after force sense control offset lies outside the range. The robot may have been moved near the movement range limit.
		Remedy	Review the movement position or force sense control settings, and ensure that the offset position does not exceed the movement range.
H.2780	0xn00 x= Axis No. n= Mech. No.	Err. message	Offset position speed over (**) *) "**" is substituted with "Jn" (n is axis No.)
		Cause	The speed of movement to the position after offsetting with force sense control exceeded the speed limit. The movement speed may be too fast, or the robot may have been moved at the singular point adjacent.
		Remedy	Review the movement speed and movement position, or the force sense control settings.
L.3110	76n00 n= Mech. No.	Err. message	The force sense control command argument lies outside the range.
		Cause	A value outside the range was set for the force sense control command argument.
		Remedy	Check the argument range and set a correct value.
L.3110	77n00 n= Mech. No.	Err. message	The force sense control status variable argument lies outside the range.
		Cause	A value outside the range was set for the force sense control status variable argument.
		Remedy	Check the argument range and set a correct value.

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
L.3110	78n00 n= Mech. No.	Err. message	The force sense control related argument lies outside the range.
		Cause	A value outside the range was set for the force sense control related argument.
		Remedy	Check the argument range and set a correct value.
L.3110	80n00 n= Mech. No.	Err. message	The Mo trigger No. lies outside the range.
		Cause	A value outside the range was set for the Mo trigger No.
		Remedy	Check the setting range and set a correct value.
L.3110	81n00 n= Mech. No.	Err. message	Def MoTrg command argument error
		Cause	An unusable variable or different mechanical No. was set.
		Remedy	Set a usable variable or same mechanical No.
L.3770	00n00 n= Mech. No.	Err. message	This is an undefined Mo trigger.
		Cause	An attempt was made to use an undefined Mo trigger.
		Remedy	Define the specified Mo trigger before use.
L.3870	17000	Err. message	The force sense control status variable mechanical No. is an invalid value.
		Cause	An invalid variable was set for the force sense control status variable mechanical No.
		Remedy	Set a correct mechanical No.
L.3870	22000	Err. message	The mechanical No. specified with the Def MoTrg command is an invalid value.
		Cause	The mechanical No. specified with the Def MoTrg command is an invalid value.
		Remedy	Set a correct mechanical No.
L.3986	01n00 n= Mech. No.	Err. message	Unable to enable force sense control. (Sensor)
		Cause	Unable to execute because the force sensor is not connected.
		Remedy	Connect the force sensor, or delete the command that cause the error.
L.3986	02n00 n= Mech. No.	Err. message	Unable to enable force sense control. (Cmp command)
		Cause	It is not possible to enable force sense control function while the compliance control function is enabled.
		Remedy	The force sense control function and compliance control function cannot be enabled simultaneously. If using the force sense control function, disable the compliance control function.
L.3986	04n00 n= Mech. No.	Err. message	Unable to execute the Cmp command. (Force sense control)
		Cause	It is not possible to enable the compliance control function while the force sense control function is enabled.
		Remedy	The force sense control function and compliance control function cannot be enabled simultaneously. If using the compliance control function, disable the force sense control function.

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
L.3986	05n00 n= Mech. No.	Err. message	Unable to enable the collision detection function. (Force sense control)
		Cause	It is not possible to enable the collision detection function while force sense control function is enabled.
		Remedy	The force sense control function and collision detection function cannot be enabled simultaneously. If using the collision detection function, disable the force sense control function.
L.3986	07n00 n= Mech. No.	Err. message	Unable to enable force sense control. (Initialization)
		Cause	It is not possible to perform initialization when starting force sense control.
		Remedy	Check the parameter settings.
L.3986	08n00 n= Mech. No.	Err. message	This is the singular point adjacent area. (Force sense control)
		Cause	It is not possible to move the singular point adjacent area while the force sense control function is enabled.
		Remedy	If moving the singular point adjacent area, disable the force sense control function.
L.3986	09n00 n= Mech. No.	Err. message	The force sense control status is different.
		Cause	The force sense control enabled/disabled status when resuming program operation differs from that during program operation.
		Remedy	Set the force sense control enabled/disabled status to the correct status. (This occurs only once when resuming program operation.)
L.3986	10n00 n= Mech. No.	Err. message	This function cannot be used.
		Cause	This model is not compatible with the executed force sense control function.
		Remedy	Do not use this force sense control function. Contact the maker for details on the latest compatibility status.
L.3986	11n00 n= Mech. No.	Err. message	Unable to change tool conversion data. (Force sense control)
		Cause	It is not possible to change tool conversion data while the force sense control function is enabled.
		Remedy	If changing tool conversion data, disable the force sense control function.
L.3986	12n00 n= Mech. No.	Err. message	Unable to change base conversion data. (Force sense control)
		Cause	It is not possible to change base conversion data while the force sense control function is enabled.
		Remedy	If changing base conversion data, disable the force sense control function.
L.3986	13n00 n= Mech. No.	Err. message	Unable to execute the Jrc command. (Force sense control)
		Cause	It is not possible to execute the Jrc command while the force sense control function is enabled.
		Remedy	To execute the Jrc command, disable the force sense control function.

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
L.3986	14n00 n= Mech. No.	Err. message	Disable force sense control.
		Cause	JOG operation cannot be performed on your model while the force sense control function is enabled.
		Remedy	Disable the force sense control function.
L.3986	16n00 n= Mech. No.	Err. message	Unable to perform offset cancel. (Force sense control)
		Cause	It is not possible to perform offset cancel while the force sense control function is enabled.
		Remedy	If performing offset cancel, disable the force sense control function.
L.3987	01n00 n= Mech. No.	Err. message	Force sense control is disabled.
		Cause	Force sense control is disabled, and so unable to execute the command.
		Remedy	Enable the force sense control function.
L.3987	02n00 n= Mech. No.	Err. message	Force sense control is enabled.
		Cause	It is not possible to enable force sense control again while already enabled.
		Remedy	First disable the force sense control function, and then enable again.
L.3987	04n00 n= Mech. No.	Err. message	Unable to execute the FsGChg command.
		Cause	It is not possible to execute the FsGChg command when force control gain change is not complete.
		Remedy	Review the program so that the FsGChg command is executed after force control gain change is complete.
L.3987	07n00 n= Mech. No.	Err. message	Unable to output log file.
		Cause	FTP processing was not properly performed.
		Remedy	Check the FTP related parameter setting. Check the Ethernet cable connection. Check the FTP server settings at the computer.
L.3987	08n00 n= Mech. No.	Err. message	The specified log file does not exist.
		Cause	The log file for the No. specified with the FsOutLog command does not exist.
		Remedy	Check whether the log file No. is incorrect.
L.3987	10n00 n= Mech. No.	Err. message	Unable to change the force sense status variable.
		Cause	The status variable setting is currently being used by the force sense control function and so cannot be changed.
		Remedy	If changing the setting, disable the force sense control function.
L.3987	11n00 n= Mech. No.	Err. message	Force sense log commands executed simultaneously.
		Cause	It is not possible to create/output another file while creating (FsLog Off command) or outputting (FsOutLog command) a force sense log file.
		Remedy	Process after force sense log file creation/output is complete.

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
L.3987	12n00 n= Mech. No.	Err. message	Unable to create log file.
		Cause	Unable to create a force sense log file.
		Remedy	Check the amount of available record space in the robot controller.
L.3987	14n00 n= Mech. No.	Err. message	Unable to execute the Fsc ON command.
		Cause	It is not possible to execute the Fsc On command while changing the force control gain.
		Remedy	Execute the Fsc On command after force control gain change is complete.
L.3987	16n00 n= Mech. No.	Err. message	Unable to perform log data related processing.
		Cause	It is not possible to execute FsLog On command file while recording force sense control log data.
		Remedy	Execute the FsLog On command after log data recording is complete.
L.3987	26n00 n= Mech. No.	Err. message	Force sense control is enabled.
		Cause	The parameter setting is currently being used by the force sense control function and so cannot be changed.
		Remedy	If changing the parameter, disable the force sense control function once.
L.3987	27n00 n= Mech. No.	Err. message	Unable to enable the Mo trigger.
		Cause	The Mo trigger for the FsCtrg command executed first is enabled.
		Remedy	Execute after changing the control characteristics.
L.3987	28n00 n= Mech. No.	Err. message	Mo trigger timeout
		Cause	The Mo trigger did not turn ON within the specified time.
		Remedy	Review the Mo trigger conditions and robot program.
L.3987	29n00 n= Mech. No.	Err. message	Unable to execute the FsCTrg command.
		Cause	The control characteristics is currently being changed.
		Remedy	Execute after changing the control characteristics.
L.3987	30n00 n= Mech. No.	Err. message	Unable to execute the FsCTrg command.
		Cause	The Mo trigger for the FsCTrg command executed first is enabled.
		Remedy	Execute after changing the control characteristics.
L.3987	31n00 n= Mech. No.	Err. message	Unable to specify the control characteristics change.
		Cause	The control characteristics change has been set with another command.
		Remedy	Change the program so that the command is not executed at the same time as another command.
L.3987	40n00 n= Mech. No.	Err. message	FsHndEst command is not executed
		Cause	Cannot execute without FsHndEst On command
		Remedy	Please execute FsHndEst command and then execute FsGetDat

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
L.3987	41n00 n= Mech. No.	Err. message	Input data error(F.Ctrl Calib)
		Cause	Input data for the force sensor calibration is illegal
		Remedy	Please confirm data for the force sensor calibration
L.3987	42n00 n= Mech. No.	Err. message	Calculation error(F.Ctrl Calib)
		Cause	Calculation result of the force sensor calibration is illegal
		Remedy	Increase the rotation angle of the calibration operation then get data for the force sensor calibration again.
H.3988	00n00 n= Mech. No.	Err. message	Unable to create a position command.
		Cause	It is not possible to convert linear position data to joint angle after offsetting with force control. The position after offsetting lies outside the movement range or is a singular point.
		Remedy	Review the movement and, settings so that adjacents outside the movement range and singular point adjacents are avoided.
H.7650	00n00 n= Mech. No.	Err. message	The force sensor quantity setting is incorrect.
		Cause	Only 1 force sensor can be used for a single robot.
		Remedy	Check the parameter (AXJNO, AXMENO) settings to see whether multiple force sensors have been set.
H.7651*	00n00 n= Mech. No.	Err. message	Force sense I/F unit initialization error
		Cause	The force sense I/F unit was not recognized, and therefore it was not possible to successfully complete initialization.
		Remedy	Check the force sense I/F unit wiring and whether the power supply is ON.
H.7652*	00n00 n= Mech. No.	Err. message	Force sense I/F unit revision illegal
		Cause	This force sense I/F unit revision is not supported.
		Remedy	Contact the maker.
H.766x	02n00 n= Mech. No. x=Sensor axis	Err. message	The force sensor data exceeded the tolerance value.
		Cause	The force acting on the force sensor exceeded the set tolerance value.
		Remedy	Check whether too large a force is acting on the force sensor. Check whether an appropriate value has been set for parameter FSLMTMX. * For details on the error recovery method, refer to "Chapter4 4.4 (4) Tolerance value (FSLMTMX)".
H8920	00n00 n= Mech. No.	Err. message	Sensor I/F unit error (**) *) "**" is substituted with the "sensor I/F unit error No." (2 hexadecimal digits)
		Cause	An error occurred at the force sensor interface unit.
		Remedy	Refer to this table "Force Sense Function Related Error Details" with the error No. in the Err. Message.

Error No.		Error Cause and Remedy	
First 4 Digits	Last 5 Digits		
C8921	00n00 n= Mech. No.	Err. message	Sensor I/F unit warning (**) *) "**" is substituted with the "sensor I/F unit warning No." (2 hexadecimal digits)
		Cause	A warning occurred at the force sensor interface unit.
		Remedy	Refer to this table "Force Sense Function Related Error Details" with the warning No. in the Err. Message.

Appendix 8.4 Force sense interface unit errors

Error No. (Name)	Cause	Remedy
12 (memory error)	Force sense interface unit internal part fault	Replace the unit.
13 (S/W processing error)		
21 (sensor initial communication error)	(1) The force sensor connection cable is disconnected. (2) The force sensor connection cable is damaged. (3) Noise contamination occurred. (4) The F3 fuse (0.3 A) in the force sense interface unit is blown.	(1) Connect the cable. (2) Replace the cable. (3) Perform noise countermeasures. (4) When the LED located on the front of the force sense interface unit is off, the fuse is blown. Replace the F3 fuse (model: LM03) inside the force sense interface unit.
25 (sensor communication error)		
34 (communication data error)	(1) The SSCNET III cable is disconnected. (2) The SSCNET III cable end face is dirty. (3) The SSCNET III cable is damaged. (4) Noise contamination occurred.	(1) Connect after turning OFF the power. (2) Wipe any dirt from the end face. (3) Replace the cable. (4) Perform noise countermeasures.
36 (communication error)		
37 (parameter error)		
38 (communication frame error)		
39 (communication axis information error)		

Appendix 8.5 Q&A

	Cause	Measures
The robot vibrates during the force sense control.	Force sense control gain is high.	Decrease the force sense control gain. (Chapter5 5.4 (8) Specifying the force sense control gain)
	The response sensitivity of the sensor is high.	Increase the filter time constant of the force sensor data. (Chapter4 4.4 (5) Filter time constant)
	The minimum control force is small.	Increase the minimum control force of the force sensor. (Chapter4 4.4 (6) Force Sensor Minimum Control Force)
The robot moves to an unintended direction during the force sense control.	Incorrect setting of a calibration parameter.	Confirm the setting of a calibration parameter. (Chapter4 4.4 (2) Calibration)
	The offset cancel operation (sensor zero point offset) of the sensor is not performed.	Perform the offset cancel operation. (Chapter5 5.4 (12) Offset cancel designation)
	The offset cancel operation is performed before the robot is completely stopped.	Use the Dly command etc., and wait until the robot complete stop and the sensor data become stabilizing, and then perform the offset cancel operation of the sensor. (Chapter5 5.4 (12) Offset cancel designation)
	The offset cancel operation is performed when the external force is applied to the sensor.	Perform the offset cancel operation without the external force applied to the sensor. (Chapter5 5.4 (12) Offset cancel designation)
	The force from a cable etc. is applying.	Do not attach in such a way as to prevent movement of moveable parts of the force sensor. Confirm the cable fixation place. (Chapter2 2.2 Install the Force Sensor)
	Incorrect attachment of the sensor.	Confirm followings. - Contact between the sensor attachment surface and sensor attachment adapter. - Tightening torque of the built-in bolt of sensor. (Chapter2 2.2 Install the Force Sensor)
The robot moves like a bouncing on contact during the force sense control.	Force sense control gain is high.	Decrease the force sense control gain. (Chapter5 5.4 (8) Specifying the force sense control gain)
	Operating speed on contact is high.	When a contact object is hard, decrease the operating speed at the time of contact. (Chapter5 5.4 (9) Specifying the speed command value)

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