

Mitsubishi Electric Industrial Robot

Collaborative Robot Safety Manual

RV-5AS-D

BASIC PRECAUTIONS AND IMPORTANT POINTS WHEN USING COLLABORATIVE ROBOTS

Collaborative robots have a variety of safety functions, so unlike conventional industrial robots, they can work in the same space as humans without being separated by a machine guard.

Even though collaborative robots are equipped with safety functions, it does not guarantee that they will not cause injury. To prevent injury, robot users, machine manufacturers who construct robot systems, and system builders such as system integrators must select and use functions correctly. Peripherals must be designed, manufactured, set, programmed, maintained, and inspected appropriately. Before working with collaborative robots, conduct risk assessments, check that no risk is present, and ensure all required documentation is in order.

It is vitally important that all the points mentioned above are fully understood in order to work with collaborative robots safely and without incident. When using collaborative robots, always keep in mind that they may move unexpectedly.

STRUCTURE OF THE COLLABORATIVE ROBOT SAFETY MANUAL

This manual describes the following items.

Section	Summary
Residual risk	Provides information about residual risks, which is necessary for users to understand before using the robot. Residual risk is the risk remaining if the robot is used as it is. To use the robot safely, understand the residual risks. Machine users must take appropriate actions to reduce these risks to an acceptable level. The information is necessary to conduct risk assessments and take safety precautions.
Precautions	Important precautions and notes.
Contents	Chapters and the corresponding pages.
1 FUNDAMENTAL CONCEPT OF SAFETY MEASURES	Describes the basics and information about safety precautions, which are necessary for robot users.
2 INFORMATION ON ROBOTS	Describes the information and basic usage of the robot to conduct risk assessments.
3 PROCEDURES AND SAFETY CONSIDERATIONS IN EACH OPERATION	Describes precautions, reference manuals, and other information separately for each stage of the product life cycle including transport and setup.
4 SAFEGUARDING	Describes check points regarding safety protection devices and ways to draw attention to potential hazards. Check the descriptions when implementing safeguarding measures.
5 SYSTEM DOCUMENTATION	Describes what should be included in instruction manuals of robot systems ^{*1} provided by the system manufacturers. Refer to this section to check whether the instruction manuals of the robot systems include necessary descriptions.
6 TRAINING	Those who teach, maintain, or repair robots or robot systems must be educated or trained so that they have the skills and appropriate knowledge beforehand in order to work safely. This section describes what must be done in the education and training.
7 DEGREE OF DANGER AND DAMAGE, AND INDICATIONS	Warning labels corresponding to the degree of danger or damage are attached to the robot and its controller. This section describes the details on the labels.
8 RISK ASSESSMENT AND SELECTING SAFETY FUNCTIONS	To use the robot system safely, make sure to conduct risk assessments. Reference documents for risk assessments are introduced. Simply introduces how to find dangerous areas in the system and what method should be used to reduce risks in these areas.
APPENDIX	Describes extracts from the related laws and regulations, structure examples of safety protection devices, meaning of terms, and symbols.

*1 Indicates the whole system including peripherals, not only the robot arm.

Read and understand all the instructions in manuals and instruction manuals before using the robot. To do the following, refer to the corresponding chapter in this manual.

Purpose	Reference
Conducting risk assessments	• Obtaining information about restrictions on the use of machinery ☞ Precaution ☞ 2 INFORMATION ON ROBOTS • Understanding residual risks ☞ Residual risk ☞ 3 PROCEDURES AND SAFETY CONSIDERATIONS IN EACH OPERATION

Purpose	Reference
Taking safety precautions	☞ 2 INFORMATION ON ROBOTS ☞ 4 SAFEGUARDING ☞ 6 TRAINING ☞ 8 RISK ASSESSMENT AND SELECTING SAFETY FUNCTIONS
Obtaining information about safety and risk assessments	☞ 1 FUNDAMENTAL CONCEPT OF SAFETY MEASURES
Learning the usage of robots	☞ Precaution ☞ 2 INFORMATION ON ROBOTS

The terms "safety precaution" and "precaution" are used in this manual, and the term "solution" is also used commonly. The difference in the meaning between "precaution" and "solution" is as follows.

Precaution: A measure taken in advance to prevent an incident.

Solution: A means of solving a problem after an incident occurs.

A safety precaution is a measure taken to prevent incidents or risks or to reduce impact from them beforehand. A safety solution is a measure taken to prevent the recurrence of incidents or reduce impact from them after the incidents or risks occur.

The term "safeguarded space" is used in this manual. Guards (safety fences) separate workspaces for humans and industrial robots. Safeguarded spaces have almost the same function as guarded areas. In collaborative operation, even if guards are not used, robots are allowed to be operated in workspaces where humans work. This means guards are not always used in every robot system.

The term "safeguarded space" used in this manual has the following meanings: workspaces separated by guards for humans and robots, and areas or spaces monitored by safety protection devices such as laser scanners, light curtains, or safety mats. A safeguarded space is not always the maximum space for robot operation. A safeguarded space may indicate an area larger than the maximum space. That is because a certain time is required for safety sensors to detect humans and then for robots to become safe even if a collision occurs. Safety sensors must detect humans before they reach areas where a collision may occur.

RESIDUAL RISK MAP FOR WHICH MACHINE USERS MUST TAKE PROTECTIVE MEASURES

PRODUCT NAME: MITSUBISHI ELECTRIC INDUSTRIAL ROBOT

Created on 04/10/2020

Mitsubishi Electric Corporation

Read and fully comprehend the information in instruction manuals before using the product. This manual is reference material. Do not use this product if you do not understand the information in the instruction manuals.

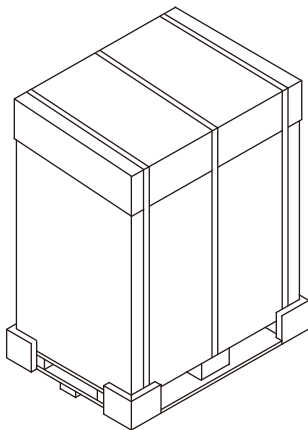
In this manual, residual risks are classified as follows.

 DANGER	Indicates that death or severe injury is likely to occur if protective measures are not taken.
 WARNING	Indicates that death or severe injury may occur if protective measures are not taken.
 CAUTION	Indicates that minor injury may occur if protective measures are not taken.

"No." indicated in the tables corresponds to the protective measure number described in the list of residual risks for this product. Refer to the following for details on residual risks.

 Page 10 LIST OF RESIDUAL RISKS FOR WHICH MACHINE USERS MUST TAKE PROTECTIVE MEASURES
PRODUCT NAME: MITSUBISHI ELECTRIC INDUSTRIAL ROBOT

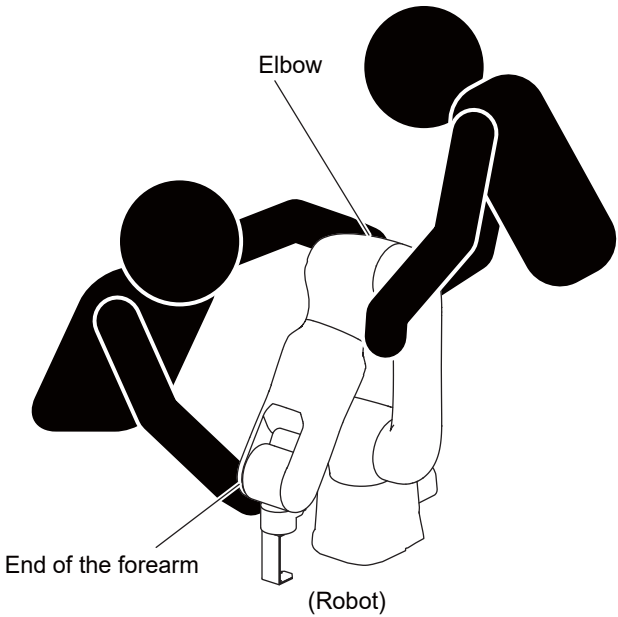
- Unpacking



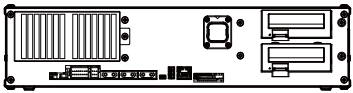
Part A	 CAUTION	No. 1
--------	--	-------

• Transportation

Part B	 DANGER	No. 2, 3, 6, 7
--------	---	----------------



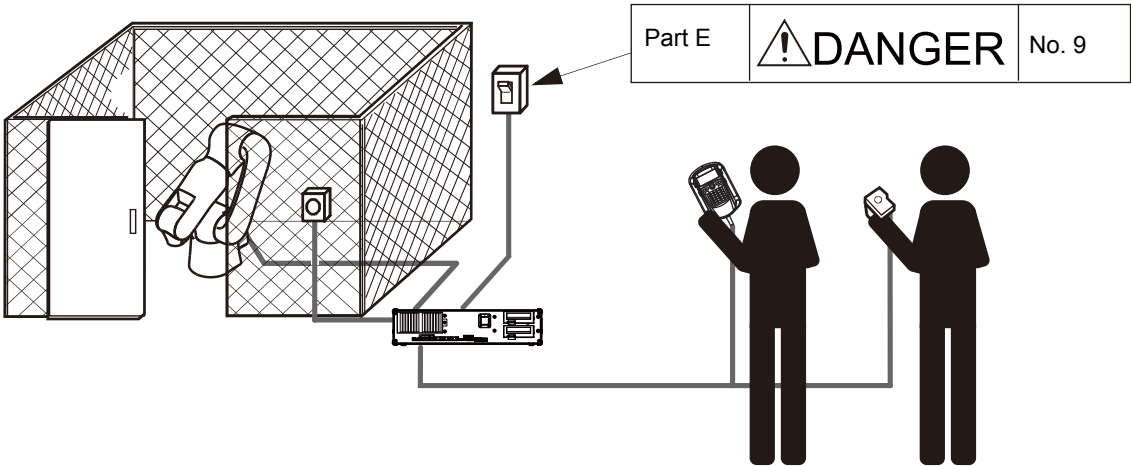
Part C	 CAUTION	No. 4
--------	---	-------



(Robot controller)

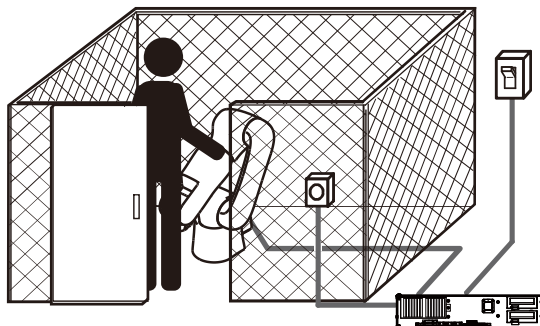
• Teaching and automatic operation

Part D	 DANGER	No. 5, 8, 12, 13, 14, 15, 16, 19, 22
	 CAUTION	No. 10, 11, 17, 18, 20, 21, 23



- Maintenance and inspection

Part F	 DANGER	No. 25, 26, 27
	 CAUTION	No. 24



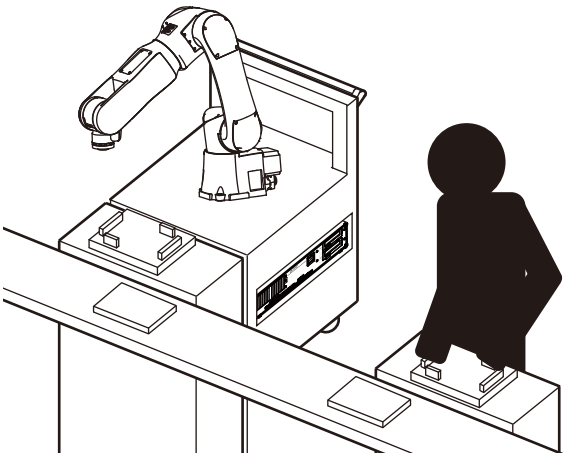
- Teaching and automatic operation

Part G	 DANGER	No. 8, 12, 13, 14, 15, 16, 19, 33, 34, 35, 42
	 CAUTION	No. 10 11, 17, 18, 20, 21, 23



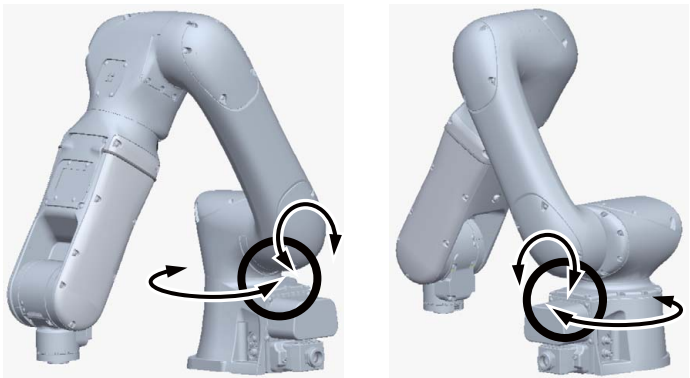
- Collaborative operation

Part H	 DANGER	No. 8, 12, 13, 14, 15, 16, 19, 25, 26, 27, 31, 32, 33, 34, 35, 42
	 CAUTION	No. 10, 11, 17, 18, 20, 21, 23, 24, 28



- Teaching and automatic operation

Part I	 DANGER	No. 36
--------	---	--------



Part J	 DANGER	No. 37
--------	---	--------

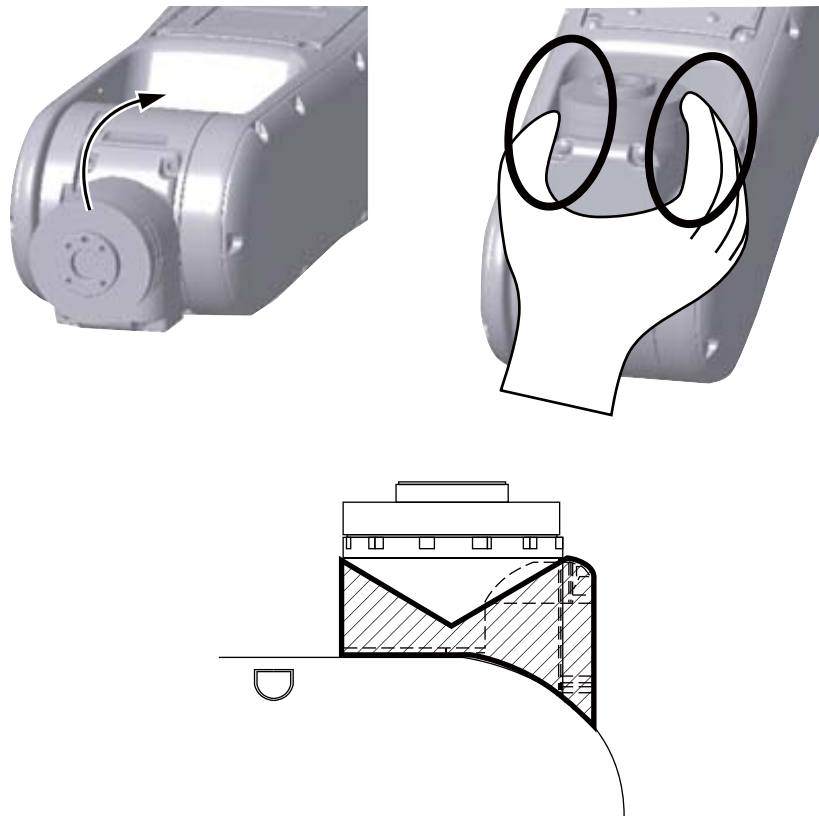


Fig. 1: Pinch point (shaded area)

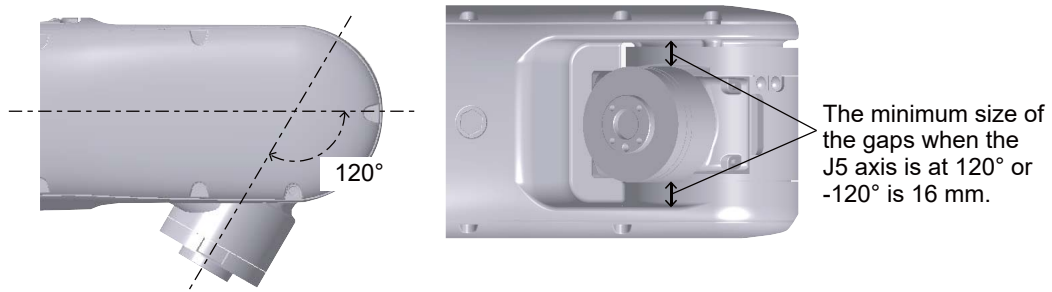
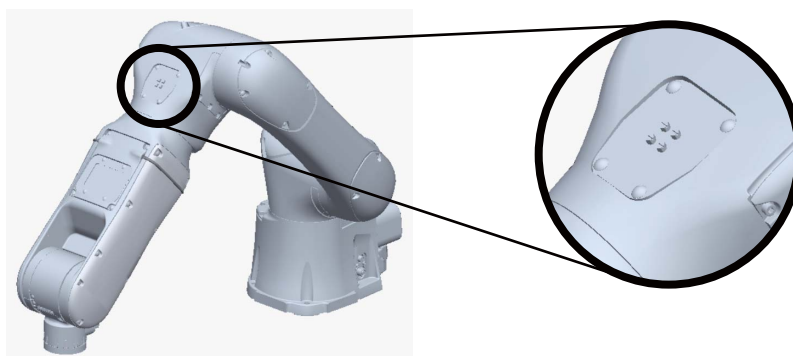


Fig. 2: Wrist: Minimum gaps

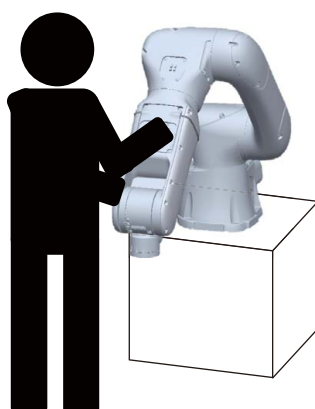
Part K	 DANGER	No. 38
--------	---	--------



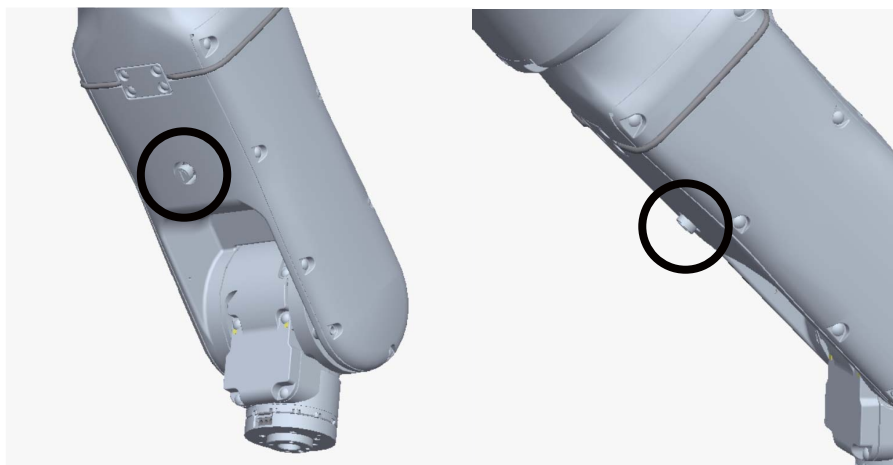
Part L	 CAUTION	No. 39
--------	--	--------



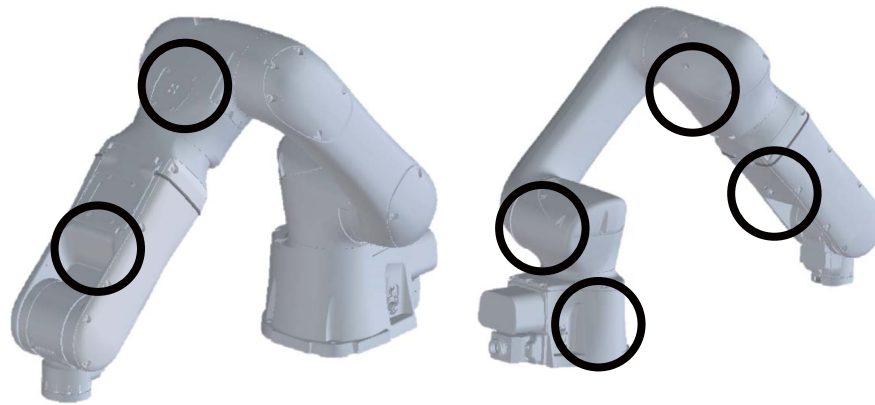
Part M	 CAUTION	No. 29, 30
--------	--	------------



Part N	 CAUTION	No. 40
--------	--	--------



Part O	 CAUTION	No. 41
--------	--	--------



LIST OF RESIDUAL RISKS FOR WHICH MACHINE USERS MUST TAKE PROTECTIVE MEASURES

PRODUCT NAME: MITSUBISHI ELECTRIC INDUSTRIAL ROBOT

Created on 04/10/2020

Mitsubishi Electric Corporation

Read and fully comprehend the information in instruction manuals before using the product. This manual is reference material. Do not use this product if you do not understand the information in the instruction manuals.

*2 In this manual, residual risks are classified as follows.

 DANGER	Indicates that death or severe injury is likely to occur if protective measures are not taken.
 WARNING	Indicates that death or severe injury may occur if protective measures are not taken.
 CAUTION	Indicates that minor injury may occur if protective measures are not taken.

*3 "No." and "Parts of machine" indicated in the table correspond to the protective measure number and the parts of machine described in the residual risk map of this product.

Refer to the following for details on the residual risk map.

 Page 3 RESIDUAL RISK MAP FOR WHICH MACHINE USERS MUST TAKE PROTECTIVE MEASURES PRODUCT NAME: MITSUBISHI ELECTRIC INDUSTRIAL ROBOT

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
1	Unpacking	Unpacking the robot	—	A	 CAUTION	Damage caused by unpacking the robot without following the specified procedure.	Do not hold the robot by its cover when removing the robot from its packaging.	- Collaborative Robot Safety Manual - Robot Arm Setup and Maintenance
2	Transportation	Transporting the robot and the controller	—	B	 DANGER	Bodily injury or property damage caused by falling of the robot or the controller, or from a fall.	Check the rating plate for the weight of the robot and the controller, and transport them following the specified procedure.	- Collaborative Robot Safety Manual - Standard Specifications - Robot Arm Setup and Maintenance - Controller Setup and Maintenance
3	Transportation	Transporting the robot	When transporting the robot using a crane or forklift, qualified persons must operate these lifting equipment.	B	 DANGER	Bodily injury or property damage caused by transporting the robot.	When transporting the robot, one person should hold the end of the forearm and elbow, while another person holds the area under the elbow. Ensure that the robot is in a fixed position before moving it.	- Collaborative Robot Safety Manual - Standard Specifications - Robot Arm Setup and Maintenance

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
4	Transportation	Installing the robot controller	When transporting the robot using a crane or forklift, qualified persons must operate these lifting equipment.	C	 CAUTION	Damage to protruding parts of the robot controller due to excessive force.	• Be careful not to apply an excessive force to protrusions, such as switches, terminal block, connectors, and radiating fins during transportation.	• Collaborative Robot Safety Manual • Controller Setup and Maintenance
5	Installation	Installing safety fences (for high speed operation)	—	D	 DANGER	Bodily injury caused by using the robot without installing a fence or enclosure around it.	• Install a guard or enclosure to prevent workers from entering the operating range of the robot. • Provide an interlock to the guard or enclosure so that the robot can be stopped upon opening of the door.	• Collaborative Robot Safety Manual • Standard Specifications
6	Mounting	Mounting the robot	—	B	 DANGER	Bodily injury or property damage caused by falling of the robot due to insufficient strength of the robot stand.	• Check that the robot stand is strong enough to withstand the weight of the robot and reaction force during operation.	• Collaborative Robot Safety Manual • Robot Arm Setup and Maintenance
7	Mounting	Mounting the robot	—	B	 DANGER	Bodily injury or property damage caused by transporting the robot.	• When placing the robot on the stand temporarily, make sure to secure the robot with bolts to prevent the robot from falling.	• Collaborative Robot Safety Manual • Robot Arm Setup and Maintenance
8	Installation	Installing the robot controller and control panel	—	D, G, H	 DANGER	Bodily injury or property damage caused by starting the robot from where the safeguarded space cannot be seen.	• Install starting equipment, such as the robot controller and control panel, outside the safeguarded space and where operators can check whether no one is in that space.	• Collaborative Robot Safety Manual • Controller Setup and Maintenance

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
9	Installation	Primary power supply connection	—	E	 DANGER	• Electric shock during wiring • Malfunction due to an error in power supply or voltage • Error while the robot is operating	• Wire cables after the primary power supply has been shut off. • Stabilize power supply, ensure capacity, and adopt an uninterruptible power supply device. • Use a power switch that is easier for operators to find the lever or other operating parts. All the switches must be clearly distinguishable.	• Collaborative Robot Safety Manual • Robot Arm Setup and Maintenance • Controller Setup and Maintenance
10	Installation	Installing the robot controller and control panel	—	D, G, H	 CAUTION	Robot system malfunction, property damage, or error due to cable disconnection or pipe damage.	• Do not apply excessive force, pull, trample, excessively bend the cables, connectors, or pipes. Use a protective cover if necessary. Make sure to tighten the fixing screws of the cable connectors or other fixtures. • Prevent cables from being entangled with or winding around the wrist, or interfering with the operation of the robot.	• Collaborative Robot Safety Manual • Robot Arm Setup and Maintenance • Controller Setup and Maintenance
11	During power-on	During power-on for teaching or automatic operation, etc.	—	D, G, H	 CAUTION	Electric shock, electrostatic charge, deterioration of noise resistance, or unnecessary electromagnetic radiation due to ungrounded equipment	• Securely ground the equipment as indicated in the instruction manuals.	• Collaborative Robot Safety Manual • Standard Specifications
12	Teaching and automatic operation	During teaching or automatic operation	—	D, G, H	 DANGER	Bodily injury or property damage caused by using the robot without a device such as an emergency stop switch.	• Install a manual emergency stop switch around the robot so that it can be operated easily, and connect it to the external emergency stop input terminal of the controller.	• Collaborative Robot Safety Manual • Standard Specifications • Controller Setup and Maintenance

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
13	Teaching and automatic operation	During teaching or automatic operation	—	D, G, H	 DANGER	Bodily injury or property damage because peripheral devices interacting with the robot did not stop.	• When peripheral devices interact with the robot, configure the system so that the emergency stop switch installed around the robot can also stop hazardous devices.	• Collaborative Robot Safety Manual • Standard Specifications • Controller Setup and Maintenance
14	Teaching	Teaching	Those who are engaged in teaching the robot must be qualified by completing the special education.	D, G, H	 DANGER	Bodily injury due to work mistakes in the safeguarded space.	• If a human enters the safeguarded space and disables safety protection devices temporarily, make sure to take the following actions in advance: creating a procedure for ensuring safety and deciding what corrective actions to take in an emergency.	• Collaborative Robot Safety Manual • Standard Specifications

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
15	Teaching	Teaching	—	D, G, H	 DANGER	Bodily injury or property damage during teaching in the safeguarded space.	(1) Teach the robot from outside the safeguarded space as much as possible. If a person must work within the space, prepare and follow working regulations. The following items shall be included in the working regulations. • Robot operation methods and procedures (who to engage, procedure for temporarily disabling safety protection devices, etc.) • Robot speed during operation (Jog operation is used in principle, automatic operation is forbidden, or collaborative operation) • Signaling method when multiple workers perform tasks at the same time • Actions to take in an emergency • Actions to prevent risks due to incorrect operation (2) When using a control device to start the robot, never start it while humans are in the safeguarded space, or start the robot in Collaborative operation mode. (3) If performing teaching work inside the safeguarded space, always ensure complete control over the robot beforehand. Failure to do so could cause a very dangerous situation as the robot could start with external commands.	• Collaborative Robot Safety Manual • Standard Specifications • Robot Arm Setup and Maintenance • Controller Setup and Maintenance • Detailed explanations of functions and operations

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
15	Teaching	Teaching	—	D, G, H	 DANGER	Bodily injury or property damage during teaching in the safeguarded space.	(4) When a key-type mode selector switch (supplied by customer) is connected to the controller, take the key out of the controller so that only a teacher can switch the mode during teaching. (5) Assign a monitor during teaching so that the robot operation can be stopped immediately if any abnormality occurs. The teacher and workers inside the safeguarded space all must have portable emergency stop switches.	• Collaborative Robot Safety Manual • Standard Specifications • Robot Arm Setup and Maintenance • Controller Setup and Maintenance • Detailed explanations of functions and operations
16	Automatic operation	Starting automatic operation	Those who are engaged in starting automatic operation must be qualified by completing the special education.	D, G, H	 DANGER	Bodily injury or property damage because automatic operation was started without safety check.	Always check the following points before starting automatic operation. • No one is in the vicinity of the robot or there are no dangerous elements in collaborative operation. • When a guard is installed around the robot, the door is locked and no one can get close to the robot unintentionally. • There are no unnecessary objects such as tools in the operating range of the robot. • Workpieces are positioned correctly. • All the associated peripheral devices are ready to perform automatic operation.	• Collaborative Robot Safety Manual • Detailed explanations of functions and operations

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
16	Automatic operation	Starting automatic operation	Those who are engaged in starting automatic operation must be qualified by completing the special education.	D, G, H	 DANGER	Bodily injury or property damage because automatic operation was started without safety check.	Check especially the following points: safety devices such as safety sensors can function correctly, safety logic work as designed, the operational status of the robot is correct accordingly, and the work details and selected program match. • Programs can operate correctly using a simulation, step operation, or low speed operation. • Workers fully understand how the robot operates in automatic operation, and the robot does not operate unexpectedly.	• Collaborative Robot Safety Manual • Detailed explanations of functions and operations
17	Automatic operation	During automatic operation	—	D, G, H	 CAUTION	Property damage or error because the robot operates beyond the rated load.	• Use tools, hands, and workpieces under the rated load of the robot. • Use hands and tools sufficient to grasp workpieces. • When using an unbalanced tool, check that the tool satisfies the permissible torque.	• Collaborative Robot Safety Manual • Standard Specifications
18	Automatic operation	During automatic operation	—	D, G, H	 CAUTION	Robot system malfunction, property damage, or error due to burst of the air hose in the robot.	• Do not apply air pressure higher than the specified value to the air hose in the robot.	• Collaborative Robot Safety Manual • Standard Specifications
19	Automatic operation	During automatic operation	—	D, G, H	 DANGER	Bodily injury or property damage caused by a workpiece popped out from the hand due to insufficient grasping force or slipping, or the release of the hand when power is shut off.	• Use a pneumatic hand with double solenoids or a self-locking electric hand to ensure that the hand does not change position or posture even if the power is interrupted. • Install a guard to prevent incidents even if a workpiece pops out from the hand.	• Collaborative Robot Safety Manual • Standard Specifications

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
20	Automatic operation	During automatic operation	—	D, G, H	 CAUTION	Robot system malfunction, property damage, or error due to a workpiece charged with static electricity.	Grasping a workpiece charged with static electricity could cause the robot to malfunction due to electrical discharge through the hand and the robot. Therefore, always use an insulated structure for the hand and the robot. When a charged workpiece is placed on the device, the device could malfunction due to the electrical discharge. Always construct the system so that the workpiece's charge is discharged through an appropriate route.	- Collaborative Robot Safety Manual - Standard Specifications
21	Automatic operation	During automatic operation	—	D, G, H	 CAUTION	Property damage caused by using the emergency stop switch of an unconnected teaching pendant (the robot was not stopped because an unavailable emergency stop device was used by mistake).	When not using a teaching pendant, keep it on a shelf or in another place to prevent operators from using it.	- Collaborative Robot Safety Manual - Standard Specifications
22	Automatic operation	During automatic operation	—	D	 DANGER	Bodily injury because the robot did not make an emergency stop or decelerate to the collaborative operation speed when the door of the guard was opened.	Install an emergency stop switch to safety protection devices such as the door of the guard, and provide an interlock so that the robot makes an emergency stop or decelerates.	- Collaborative Robot Safety Manual - Standard Specifications - Controller Setup and Maintenance

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
23	Automatic operation	During automatic operation	—	D, G, H	 CAUTION	Property damage due to emergency stop or power shut-off.	Depending on the posture of the robot, axes that do not have brakes may fall under their own weight in the event of a power failure or when an emergency stop switch is pressed. Due to inertia, even axes that have brakes may not stop immediately if they are operating at high speed. Prevent moving parts from interfering with peripheral devices or other dangerous situations.	—
24	Inspection	Inspection	Those who are engaged in inspecting the robot must be qualified by completing the special education.	F, H	 CAUTION	Property damage because the robot and the robot system did not operate normally.	- Check whether safety devices such as emergency stop devices function properly before starting the robot and the robot system. - Inspect the robot and the robot system according to the instruction manuals. If any damage or malfunction that may lead to an accident is found, take corrective actions immediately.	- Collaborative Robot Safety Manual - Robot Arm Setup and Maintenance

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
25	Inspection	Inspection	Those who are engaged in inspecting the robot must be qualified by completing the special education.	F, H	 DANGER	Bodily injury caused by electric shock or others due to stored energy after power shut-off.	• If the stored energy may cause a hazardous condition even after the power is shut off, provide a means for gradually releasing the energy. This energy source may be in the form of (but not limited to) fluid pressure, electric charge, springs, counter balances, and flywheels. Appropriate labels must be affixed to each stored energy source. • Do not open the controller door or cover immediately after turning the power off. Wait for the time described in the instruction manual before opening the door or cover.	—

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
26	Maintenance	Inspection, repair, cleaning, and lubrication	Those who are engaged in inspecting, repairing, cleaning, and lubricating the robot must be qualified by completing the special education.	F, H	 DANGER	Bodily injury because the signs indicating the locking of the power switch and work in progress were not placed.	• Make sure to shut off the power to stop the robot. Place the signs indicating the locking of the power switch and work in progress to prevent anyone from starting the robot unintentionally. • If the robot must be maintained with the power turned on, make sure to create a safe working procedure including ensuring complete control over the robot, and follow the procedure in order to prevent the robot from operating abruptly and operators from operating the robot incorrectly.	• Collaborative Robot Safety Manual • Robot Arm Setup and Maintenance
27	Inspection	Inspection	Those who are engaged in inspecting the robot must be qualified by completing the special education.	F, H	 DANGER	Bodily injury or property damage due to the arm falling under its own weight when the brake was released.	• Before releasing the brake, check that no one is in the operating range of the robot as the arm falls under its own weight. If the axes interfere with peripheral devices or other issues occur, change the posture of the robot to prevent any dangerous situations and then release the brake.	—

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
28	Teaching	Direct teaching	—	H	 CAUTION	Unintended movement of the robot because the robot parameters were not set correctly.	- After parameters have been changed, keep away from the robot, place an emergency stop switch near you, and check whether the robot will not move unintentionally before using the robot. - Parameters must be locked using a password to prevent them from being changed by anyone other than those who conduct risk assessments.	Collaborative Robot Safety Manual
29	Teaching	Direct teaching	—	M	 CAUTION	If the robot passes close to a singularity while the robot is being taught directly, some movement will suddenly speed up.	As the arm nears a singularity, there will be a change in its movement. For example, the arm will move slowly or quickly rotate. The robot controller will also sound an alarm when the arm approaches a singularity. Be aware of the movements that occur when the arm approaches singularities, and modify the movement of the robot so that the arm avoids passing close to them.	Collaborative Robot Safety Manual
30	Teaching	Direct teaching	—	M	 CAUTION	Pressing the operation buttons on the robot arm after the hand has been aligned will cause some movements to suddenly increase in speed when the arm is near a singularity.	Hand alignment stops when you take your hand off the buttons. If at any point you feel that the robot's acceleration is dangerous, release the operation buttons immediately and the robot will stop.	Collaborative Robot Safety Manual

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
31	Teaching and automatic operation	Collaborative operation	—	H	 DANGER	An operator pushed by an excessive force due to a collision with the robot because the STR function does not work properly.	• Limit the robot operating range or adjust the program to keep the posture of the robot in the conditions that the STR function works properly. • Limit the area where humans work and the area where humans can enter. • Limit the operating speed.	• Collaborative Robot Safety Manual
32	Teaching and automatic operation	Collaborative operation	—	H	 DANGER	Injury due to collisions with sharp parts of hands or workpieces.	• Design hands without sharp parts. • Install a guard if necessary. • Adjust the operating speed.	• Collaborative Robot Safety Manual
33	Teaching and automatic operation	Collaborative operation	—	G, H	 DANGER	Injury caused by collisions with the robot operating at high speed: Humans were not detected because safety sensors were incorrectly installed, set, or wired.	• Conduct sufficient risk assessments, check how the robot is used in each stage, and check that no risk is present. • Before starting automatic operation, check whether the safety sensors detect humans, safety logic works as designed, and the robot operation.	• Collaborative Robot Safety Manual
34	Teaching and automatic operation	Collaborative operation	—	G, H	 DANGER	Injury due to collisions with a human from the neck up.	• Review the installation position, the operating range, and the position limit of the robot. • Use a helmet, protective goggles, or other protectors properly.	• Collaborative Robot Safety Manual
35	Teaching and automatic operation	Collaborative operation	—	G, H	 DANGER	Injury due to falls or collisions arising from running.	• Install guards, etc. • Keep cables on the floor and peripheral devices organized. • Provide education and limit the area where humans can enter.	• Collaborative Robot Safety Manual

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
36	Teaching and automatic operation	Direct teaching and collaborative operation	—	I	 DANGER	Hands and arms may become trapped between the robot arm and base if axis J1 or J2 rotates while the base of the upper arm is held. (A 25 mm clearance between the arm No.1 and the robot base reduces the risk of fingers getting trapped.)	- Do not wear gloves thicker than the gap between the arm and base when holding or moving the robot. - Install a cover or another form of protection. - If possible, limit the position of the upper arm to prevent it from coming close to the top of the air pipe housing on the side of the base. Or limit the rotational angle of J1 axis. (Note: Limiting the rotational angle is not a safety function.) - Educate workers or instruct them not to hold the area around the base of the upper arm.	Collaborative Robot Safety Manual
37	Teaching and automatic operation	Direct teaching and collaborative operation	—	J	 DANGER	Hands may become trapped between the wrist and the forearm of the robot when axis J5 rotates. (The minimum size of the gaps is 16 mm.)	- Instruct workers not to hold the wrist (shaded area in Fig.1) and push the J5 axis towards the forearm while teaching the robot as it is highly likely that clothes or body parts will become pinched or trapped. - In particular, people who have thick hands are prone to getting pinched. - We suggest not wearing thick gloves while teaching the robot as wearing thick gloves makes it easier for your hands to get caught. - Limit the rotational angle of J5 axis. (Note: Limiting the rotational angle is not a safety function.)	Collaborative Robot Safety Manual

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
38	Teaching and automatic operation	Direct teaching and collaborative operation	—	K	 DANGER	Injury due to impacts with the corner of the robot wrist with stress applied locally to the impact area.	• Prevent the corner from colliding with workers. • Set a safe speed to prevent risks even if the corner collides with workers. • Installing a cover or others to the corner.	• Collaborative Robot Safety Manual
39	Teaching and automatic operation	Direct teaching and collaborative operation	—	L	 CAUTION	Contact with the plugs of the air-in/out ports on the forearm may cause injuries such as cuts or scratches.	• Ensure that the plug will not come into contact with workers during operation. • Set the robot to a speed that will not cause harm if the plug comes into contact with someone during operation. • Cover the plug.	• Collaborative Robot Safety Manual
40	Teaching and automatic operation	Direct teaching and collaborative operation	—	N	 CAUTION	Contact with the connector cover on the forearm may cause cuts or scratches.	• Ensure that this part will not come into contact with workers during operation. • Set the robot to a speed that will not cause harm if this part comes into contact with someone during operation. • Cover this part.	• Collaborative Robot Safety Manual
41	Teaching and automatic operation	Direct teaching and collaborative operation	—	O	 CAUTION	The surface of the robot heats up under prolonged operations involving high loads. Touching an unexpectedly hot robot may cause the user to move in an involuntary manner.	• Ensure that this part will not come into contact with workers during operation. • Revise the robot operation to prevent the robot from heating up. • Cover this part and do not touch it directly. • Make workers aware that the surface of the robot may be hot.	• Collaborative Robot Safety Manual

No. *3	Stage	What to do	Necessary qualifications and education	Parts of machine *3	Degree of danger *2	Risk	Protective measures taken by machine user	Reference instruction manual
42	Teaching and automatic operation	Direct teaching and collaborative operation	—	G, H	 DANGER	If the robot is used while there is a fault with the sensors, the forces generated in an impact will exceed the permissible values stipulated by the safety standards.	Take the following precautions to prevent this from happening. • Set conditions within the robot operation so that the robot periodically runs at an override speed of 10% or higher for more than 10 seconds. This will enable the sensor's fault detection function work sufficiently. • Periodically check if any unusual changes collision forces have occurred. • If there is a fault with any of the sensors, forces generated in a collision will be larger than if the STR function was functioning normally. In such instances, increase of the forces of roughly 40 N can be expected in a collision. Conduct a risk assessment that takes this into account.	• Collaborative Robot Safety Manual

RESIDUAL RISK (COMMON)

- If the origin setting, parameter settings or programs of the robot are incorrect, unexpected operation may occur and safety cannot be ensured. Check the robot operation using a simulation, step operation, or low speed operation, and perform operation tests to check whether the robot operates as intended.
- Until correct installation, wiring, and adjustment are achieved, safety cannot be ensured.
- Only a qualified person is given the authority to install, start, repair, adjust, etc. the equipment to which devices are installed. Installing or operating the equipment should be done by a trained engineer.
- For the safety monitoring function, perform the wiring separately from other signal wirings.
- Protect cables by appropriate means (installing inside the control panel, using a cable guard, etc.).
- It is recommended to use switches, relays, sensors, etc. conforming to safety standards. For using switches, relays, sensors, etc. not conforming to safety standards, sufficient verification of safety is necessary on the customer side.
- The safety function only works for the robot controller and the robot. The safety functions do not cover the functions of peripheral devices. When peripheral devices are used, customers are required to ensure and evaluate the safety.
- To perform the initial test of the robot, power cycle it regularly. The initial test should be performed at least every six months.
- The robot should never come into contact with a human's head. Thoroughly consider the positions of robots, the positions and postures of workers, the operating range of each robot so that no collision occurs.
- By referring to ISO/TS 15066, collaborative robots are designed so that humans can be safe even if collisions occur.

However, robot manufacturers are not required to examine and ensure safety under the following conditions: when robots are operated at a higher speed than the permissible speed, or when hands or other devices are mounted on the robots. Collaborative robots are designed for collisions in which humans are in a static position. Users or those who construct robot systems must conduct sufficient risk assessments and check that no risk is present before the robots are used.

- If the robot is used without any parameters being set, or if parameters are set incorrectly, the STR function will not function properly. The force generated upon an impact may also be larger than if the correct values were set, and errors may occur during operation. It is also possible that the robot will move in an unpredictable manner when the direct teaching function is enabled. Before starting the robot, make sure that the parameters have been set correctly. Furthermore, if anyone changes the parameters, workers must be notified of the change.

RESIDUAL RISK (SPECIFIC TO EACH FUNCTION)

- STO function

This function interrupts transmission of power to the motor installed in the robot arm, and may bring variation to the posture of the robot arms due to mechanical factors, such as a timing belt break or brake wear, etc. of the robot arm. Periodic maintenance of the robot arm is required. If a situation arises where the brakes fail to function correctly, the robot may not be able to maintain its current posture at servo OFF, which may cause the arm to fall down. The STO function can be used to stop the robot if the stop functions SS1 and/or SS2 are not functioning correctly. However, if the brakes have failed, the time and distance it will take for the robot to stop will be considerably longer than normal.

- SS1 function

This function controls and decelerates the motor speed installed to a robot arm. The movement cannot be stopped immediately after deceleration is started.

- SS2 function

This function controls and decelerates the motor speed installed to a robot arm. The movement cannot be stopped immediately after deceleration is started.

- SOS function

This function monitors motors installed in the robot so that they stay at rest. Mechanical factors, such as break of timing belts of the robot, may bring variation to the posture of the robot. Periodic maintenance of the robot arm is required.

- SLS function

This function monitors the speed of each part of the robot arm and tools specified beforehand. Depending on the robot posture, some undefined parts may move at a speed higher than the monitoring speed.

This function is only enabled when the robot is in the servo-on state and therefore does not monitor the speed when the robot is in the servo-off state.

- SLP function

In the following cases, the monitoring position may go across a position monitoring plane or a position monitoring area. The following shows some concrete examples.

When the position monitoring plane is applied, the robot position is beyond the plane.

When the position monitoring plane is applied, the robot is moving near the plane at a high speed.

The robot posture changes when the robot brake is released.

- Duplex input and output signal monitoring function

This function only monitors whether the duplexed input signals match each other, and does not detect malfunction or misconnection of the connected devices. The robot detects the mismatched signal when a signal mismatch for 0.1 seconds or more occurs.

- STR function

This function checks torque values of the robot axes. This function is enabled only when the robot is in the servo ON status. This means torque values are not checked during the servo OFF status. If the robot collides with something, a higher torque than usual will be generated, and the function detects the collision. However, collisions such as those with the part near the joint axis may not be detected even the collision force is strong. This is because the distance to the axis is short and thereby the torque is small. Moreover, the function is less likely to detect collisions under the following conditions: A collision occurs with the end of the arm while the arm is extended and the force is applied in the bending direction. This is because the torque enough to be detected cannot be generated on the every axis. When external forces are detected, this function checks the torques transmitted to the motor through the joint axis with friction force. Therefore, the function may not detect weak forces. Besides, friction force varies according to a change in temperature of the grease inside the joints, which may affect the

function. Check whether no problems do not occur in such conditions as just after the robot starts operation and after it stops continuous operation, operating conditions in each season, air-conditioned environments, or temperature changing environments. Before using this function, make sure that this function works properly in a safe manner. The function is not enabled just after servo ON. After servo ON, wait for 1 second or more before starting the robot operation. This robot has a friction compensation function that helps reduce the effects of joint friction variation. The joints need to be moving for several tens of seconds to make this function work sufficiently. The value of friction compensation are reset after the controller restarts or after STR errors are detected. Operate the robot for about 30 seconds after any of the aforementioned situations so that the compensation value is tuned enough. If joint friction is not properly compensated for, the impact force may be greater than usual. The robot has a collision detection function similar to the STR function, but the collision detection function is not a backup safety function. Use the STR function for safety.

The STR function monitors the difference between the torque feedback (actual torque) and the estimated output torque. Torque feedback is calculated based on information acquired from sensors. If a fault occurs with any of the sensors, the STR function will be affected as it will not be able to acquire the correct values. To prevent the STR function from being affected, there is an in-built function that will output an error and stop the robot if a fault with any of the sensors is detected. To check if a sensor is faulty, all axes of the affected sensor must be run at a speed higher than the certain operating speed and time set. Run each axis using an override speed of 10% or higher for about more than 10 seconds before using the robot to check if any of the sensors are faulty. If there is a low level fault with the sensor or the robot is run outside of the conditions used to check the sensor fault mentioned above and a fault occurs, there is a risk that the force generated during a collision will not be reduced by the STR function. The force generated in a collision may increase as much as 40 N if the STR function does not work properly due to a faulty sensor. Conduct a risk assessment assuming that a force of about 40 N can be expected in a collision, in situations where sensors cannot be periodically fault checked, or if a time line of collision forces under the same conditions cannot be checked before use.

- Collaborative operation

This function limits the operating speed of the robot to limit the energy during operation. The STR function checks abnormal torque outputs to detect collisions and stop the robot. The operable speed of the robot varies depending on the conditions whether humans may get caught between the robot and peripheral devices. The robot should never come into contact with a human from the neck up. The robot is less likely to stop if a weak force is applied to the robot. For example, a collision occurs with the arm around the primary axis of the robot, or a collision occurs with the end of the arm while the arm is extended and the force is applied in the bending direction. Make sure to conduct risk assessments, and check that no risk is present. When conducting risk assessments, identify the conditions where the robot is used, and check that no risk is present under all the conditions. The conditions include the following items: how to use the robot, ambient environments such as temperature, humidity, and lighting. Check whether safety is ensured especially under the following conditions: operating conditions in each season, air-conditioned environments, and just after the robot starts operation. Before using this function, make sure that this function works properly in a safe manner. If the robot is mounted on a travel axis, the speed cannot be monitored. Do not use the robot on a travel axis. Even when the operating speed of the robot is limited, injury cannot be prevented if a human collides with the robot.

- High speed operation

This function must be used under the following conditions: A guard is installed, and safety sensors such as laser scanners are used to detect humans in the safeguarded space. If the above conditions are satisfied, the robot can be operated at a higher speed than the collaborative operation speed. When the robot is in high speed operation, do not enter the safeguarded space. If a person must enter the safeguarded space such as for setups or adjustment, prevent the robot from operating at high speed unexpectedly.

- Direct teaching function

If the hand conditions parameters are not set or set incorrectly, the robot may start moving unexpectedly. Before using the function, check whether the settings have been made correctly. To prevent the robot from hitting your head or face, be aware of your posture at all times as the robot may move in an unintended direction. The user may feel an inertial like force when moving or stopping the robot. Be careful not to hit your hand or body against the robot or get caught between the robot and peripherals.

When the arm passes close to a singularity, it may move unexpectedly. For example, the J4 axis may rotate suddenly. Take care when moving the forearm during direct teaching. Movement of the robot may change when the arm passes close to a singularity. For example, the arm may not move smoothly or the speed of certain movements may gradually increase. The robot controller will also simultaneously sound an alarm when the arm approaches a singularity. It may be difficult to hear the

robot controller alarm under certain circumstances. For instance, if it is located away from the robot, is in a noisy environment, or is shielded.

When the arm passes close to a singularity while the operation button is pressed during hand alignment, the arm may move unexpectedly. For example, the J4 axis may rotate suddenly. Be aware that even though the robot stops moving once the operation button is released, there are instances when the forearm (the arm with buttons on) will suddenly start to rotate.

There is a risk of trapping your fingers if you hold near J5 axis and try to push it towards the forearm. For further information, refer to the Part J of the residual risk map or No.37 in the residual risk table.

NOTE TO THE USER

- As for the assurance of safety in design and construction of robot system, read this manual first.
- Please make sure that this manual is delivered to end users for their implementation of safety.
- Do not use robots in a potentially explosive atmosphere.
- Do not use robots in residential areas.

NOTES ABOUT THE EUROPE NEW BATTERY DIRECTIVE (2006/66/EC)



Point

This symbol mark is for EU countries only.

This symbol mark is according to the directive 2006/66/EC Article 20 Information for end-users and Annex II.

Your MITSUBISHI ELECTRIC product is designed and manufactured with high quality materials and components which can be recycled and/or reused.

This symbol means that batteries and accumulators, at their end-of-life, should be disposed of separately from your household waste.

If a chemical symbol is printed beneath the symbol shown above, this chemical symbol means that the battery or accumulator contains a heavy metal at a certain concentration.

This will be indicated as follows:

Hg: mercury (0,0005%), Cd: cadmium (0,002%), Pb: lead (0,004%)

In the European Union there are separate collection systems for used batteries and accumulators. Please, dispose of batteries and accumulators correctly at your local community waste collection/recycling centre.

Please, help us to conserve the environment we live in!

TRANSPORTATION PRECAUTION

The United Nations' Recommendations on the Transport of Dangerous Goods must be observed for transborder transportation of lithium batteries by air, sea, and land.

The lithium batteries (ER6V) used in Mitsubishi industrial robots contain lithium and fall under the definition.

When the lithium batteries are shipped for storage, etc., they will be classified as Class 9: Miscellaneous dangerous substances and articles. Please contact your transportation company and must provide appropriate transport safety measures as the customer's consignor.

WASTE MANAGEMENT

When disposing of this product, it is necessary to give consideration to the effective use of resources, waste handling and cleaning, and the collection and disposal of fluorocarbon. Please dispose of this product according to the waste management law of the country where it is used.

Effective Use of Resources

- Please recycle the old product as much as possible.
- For recycling purposes, we recommend disassembling this product into iron scrap and electrical parts, so that they can be sold to appropriate vendors.

Waste Handling and Cleaning

- Please try to sell the old product for recycling in order to reduce the amount of waste material.
- When disposing of this product, please do so according to the requirements of the appropriate industrial waste laws. Disposing of batteries and used grease by the customer will cause environment contamination.

Waste Handling and Cleaning

- Handle the coolant inside the heat radiation fins used for heat dispersion in the power supply unit (converter unit) and the driving units (inverter unit, amplifier unit) appropriately, according to the designated fluorocarbon collection and disposal regulations.

PRECAUTIONS WHEN DISPOSING OF BATTERIES

In the European Union there are separate collection systems for used batteries and accumulators.

INSTALLATION OF EMERGENCY STOP SWITCHES

As a safety measure, place an emergency stop switch in an easily operable position, and be sure to wire the switch to the controller in order to stop the robot immediately in an emergency.

For the connection method, refer to the following.

 Page 67 Emergency stop

The above section has information on how to connect door switches and mode selector switches. Use them together with an emergency stop switch.

SAFETY INSTRUCTIONS FOR USING ROBOT SYSTEMS

- Before installing or using a robot, make sure to conduct risk assessments. Check the operating speed or operation status of your robot, shapes of hands, and the positions of peripherals. Make sure that there is no danger or risk in all uses, including automatic operation, teaching, adjustment, and maintenance.

For information on precautions for designing hands, refer to the following page.

 Page 66 Hands

- Make nearby workers easily distinguish the safeguarded space, the operating range of the robot, and others by using the following methods: Coloring floors, installing lighting equipment or safety fences, or posting the layout of the robot system.
- In Collaborative operation mode, the operating speed limit for the robot is set by default. The limit is determined so that the values for the maximum permissible force in case of a collision between a robot and a human (defined by ISO/TS 15066 (2016)) are not exceeded. However, this does not guarantee that no injury will occur. Make sure to conduct risk assessments, and check that no risk is present.
- The STR function stops a robot in case of a collision. There is an area which the function may not detect. To avoid a collision between a robot and a human in this area, check the positions and operating ranges of robots and the workspace for workers, and conduct risk assessments to remove any risk.
- As a safety measure, when operating the robot in a mode other than Collaborative operation mode, install a guard or others to prevent workers from getting close to the robot unintentionally, or use safety sensors such as light curtains and laser scanners to check whether no body is in the safeguarded space.
- When using guards to reduce risks, install either of the following interlocks:
 - 1) An interlock that closes safety fence doors so that workers cannot enter safeguarded spaces when the robot is in operation.
 - 2) An interlock that automatically turns the robot servo power OFF and stops peripheral devices (servo power OFF) when the door of the safety fence is opened.
 - 3) An interlock that reduces the robot operating speed and puts it into Collaborative operation mode. The interlock signal must be connected directly to the robot and peripheral devices without using a programmable controller or other devices. When using our robots, connect the interlock signal to the emergency stop input terminal or the door switch input terminal.
- When reducing the risk of collisions by using safety sensors, such as light curtains and laser scanners, make sure to check whether the safety sensors are connected correctly, and the robot can decelerate or stop properly at the time of startup or setup change, or at other occasions periodically such as maintenance.
- If a system is configured such that several robots are installed within the safety area, employ a design and structure where each robot and related device can be operated independently of one another.
- Robot systems should be designed so that the robot controller is installed outside the safety area.
- Install a manual emergency stop switch at a location near the robot where it can be easily operated and connect it to the external emergency stop input terminal of the controller. (NC contact, provided with a mechanical latching function. Compliant with IEC 60204-1 specifications.)
- Use an indicator light or other method so that workers can easily check the status of the robot. For example, if the robot is in High-speed or Collaborative operation mode, if the servo is ON or OFF, or if there is an error.
- For the safety of all operators in the immediate vicinity, all errors should be accompanied by an audible alert as well as a visual signal.
- Implement external means to manually shut down all power supplied to the robot system.
- Be sure to configure the robot system so that it begins automatic operation on startup. Also, configure the system so that the robot does not resume automatic operation whenever the system is reset.
- Be sure to ground the robot arm and controller to prevent electric shock and electrostatic discharge, improve noise resistance and minimize unnecessary electromagnetic irradiation.
- If a person must enter the safeguarded space for teaching, adjustment, or other reasons while the robot is in the servo ON status, check that the robot is in manual operation or collaborative operation, and take safety precautions appropriately, such as wearing a helmet, protective goggles, or others. When using the teaching pendant, turn ON robot servos using the Enable switch (3-position switch). Ensure that the robot servos can be turned OFF anytime and bodily harm can be avoided before turning ON the robot servos. When turning ON robot servos using the software installed on the computer, make sure

to install an emergency stop switch nearby so that the robot servos can be turned OFF anytime and bodily harm can be avoided.

- When multiple workers perform tasks at the same time, determine a responsible person so that the person commands and gives signs to the workers to ensure their safety.
- Be sure to indicate with hand and voice signals when turning the power supply on, operating electric wiring, and/or operating cranes and other heavy equipment so that everyone involved is alerted and dangerous situations can be avoided.
- To maintain the security (confidentiality, integrity, and availability) of the Robot and the system against unauthorized access, DoS^{*1} attacks, computer viruses, and other cyberattacks from unreliable networks and devices via network, take appropriate measures such as firewalls, virtual private networks (VPNs), and antivirus solutions.

Mitsubishi Electric shall have no responsibility or liability for any problems involving Robot trouble and system trouble by unauthorized access, DoS attacks, computer viruses, and other cyberattacks.

^{*1} DoS: A denial-of-service (DoS) attack disrupts services by overloading systems or exploiting vulnerabilities, resulting in a denial-of-service (DoS) state.

CONTENTS

BASIC PRECAUTIONS AND IMPORTANT POINTS WHEN USING COLLABORATIVE ROBOTS	1
STRUCTURE OF THE COLLABORATIVE ROBOT SAFETY MANUAL	1
RESIDUAL RISK MAP FOR WHICH MACHINE USERS MUST TAKE PROTECTIVE MEASURES	
PRODUCT NAME: MITSUBISHI ELECTRIC INDUSTRIAL ROBOT	3
LIST OF RESIDUAL RISKS FOR WHICH MACHINE USERS MUST TAKE PROTECTIVE MEASURES	
PRODUCT NAME: MITSUBISHI ELECTRIC INDUSTRIAL ROBOT	10
RESIDUAL RISK (COMMON)	25
RESIDUAL RISK (SPECIFIC TO EACH FUNCTION)	26
NOTE TO THE USER	28
NOTES ABOUT THE EUROPE NEW BATTERY DIRECTIVE (2006/66/EC)	29
TRANSPORTATION PRECAUTION	29
WASTE MANAGEMENT	30
PRECAUTIONS WHEN DISPOSING OF BATTERIES	30
INSTALLATION OF EMERGENCY STOP SWITCHES	30
SAFETY INSTRUCTIONS FOR USING ROBOT SYSTEMS	31
INTRODUCTION	36
CHAPTER 1 FUNDAMENTAL CONCEPT OF SAFETY MEASURES	37
1.1 Purpose, application	37
1.2 Safeguarding	38
Prevention of hazards in automatic operation	38
Safeguarding in programming	39
Safeguarding in maintenance and trouble shooting	40
Verification of safety before starting operation	40
CHAPTER 2 INFORMATION ON ROBOTS	41
2.1 Operating environments	41
2.2 Operating range and load capacity	42
Operating range diagram	42
Load capacity	42
2.3 Safety-related control system performance and conforming standards	43
2.4 Stopping time and stopping distance	45
Safe stopping distance	45
2.5 Lubricant used in robots	53
2.6 Robot functions and basic operation	54
Basic operation	54
Operation using RT VisualBox	54
Function details	54
Explanation of operation methods	54
2.7 Limiting the robot operating range	54
Setting free plane limits	54
Setting the safely-limited position function (SLP)	54
2.8 Safe torque range function (STR)/power and force limiting (PFL)	55
Safe torque range function (STR)	55
Power and force limiting (PFL)	59
Robot power and force limiting (PFL)	60
2.9 Safely-limited speed function (SLS) for automatic speed adjustment	60
2.10 Status display	61

2.11	Safety Input	61
2.12	Parameters and status variables	61
2.13	Recovery mode	61
2.14	How to release the brake of the robot	62
	Releasing the brake by using the emergency power supply	62
	Releasing the brake by using the teaching pendant in the servo OFF status	62
	Releasing the brake by using RT VisualBox	62
2.15	Error information	63

CHAPTER 3	PROCEDURES AND SAFETY CONSIDERATIONS IN EACH OPERATION	64
------------------	---	-----------

3.1	Unpacking	64
3.2	Carrying	64
3.3	Preparation of installation and operation	65
	Robot arm, controller and control panel	65
	Cables	65
	Hands	66
	Operating device	67
	Grounding	67
	Emergency stop	67
	Safety stop	68
	Indicators	68
	Isolation of power sources	69
	Applying power	69
3.4	Teaching and programming	69
3.5	Program verification	70
3.6	Automatic operation	72
3.7	Maintenance	73
3.8	Troubleshooting	74
3.9	Modifications	75
3.10	Disposal	75

CHAPTER 4	SAFEGUARDING	76
------------------	---------------------	-----------

4.1	Safeguard	76
4.2	Awareness means	77

CHAPTER 5	SYSTEM DOCUMENTATION	78
------------------	-----------------------------	-----------

CHAPTER 6	TRAINING	79
------------------	-----------------	-----------

CHAPTER 7	DEGREE OF DANGER AND DAMAGE, AND INDICATIONS	80
------------------	---	-----------

CHAPTER 8	RISK ASSESSMENT AND SELECTING SAFETY FUNCTIONS	81
------------------	---	-----------

8.1	Specifying restrictions on the use of machinery	82
8.2	Specifying the maximum robot operating range	83
8.3	Specifying areas where people exist	83
8.4	Understanding safety distance	84
8.5	Specifying areas where collisions may occur	84
8.6	Methods for reducing risks	85
	Using a guard (safety fence)	85
	Using the safely-limited position function (SLP)	86

Using Safety Rated Monitored Stop (SRMS)	86
Using Safety Speed Monitoring (SSM)	87
Using Power and Force Limiting (PFL)	88
Other precautions	88
8.7 Setting example.....	88

APPENDIX	89
-----------------	-----------

Appendix 1 Examples of safety protection device configuration	89
Safety protection device configuration methods	89
Examples of safety protection device configuration	90
Appendix 2 Glossary of terms (according to ISO 10218: 1992).....	91
Appendix 3 Supplementary explanation of symbols	94
REVISIONS	95
TRADEMARKS	96

INTRODUCTION

Nowadays, industrial robots have been widely introduced to many production lines and are estimated to increase more and more in the future. This is owing to many merits of industrial robots that conventional machines don't possess. Industrial robots, in place of human, can do elaborate jobs without saying. They can also continue to work in hazardous conditions for human without taking a rest.

On the contrary, industrial robots could act peculiar hazards against human if sufficient precautions were not provided.

Industrial robots may give rise to hazards of injuring operators or damaging equipment.

We who have given created them must do our best to make them work safely to prevent such accidents. It is not only us as manufacturers that need to consider safety and take precautions, but also end-users and those who install robots into production lines and systems, too. Even though these robots are called collaborative robots, and are designed so that they can come in contact with humans, safety precautions still need to be taken.

This manual is intended to give general precautions and safeguarding to secure safety of all persons who are involved in the robots. Before introduction, installation, arrangement and so on of the robots, please read through this manual as well as the operation manual of the robot itself to be able to operate them safety and efficiently.

We strive to include all the descriptions related to the handling of robots in this manual or other manuals. Do not handle the robots in ways other than those described in the manuals. Doing so may cause an error.

The fundamental idea of this manual bases on the following 'EC directive', 'International standard', and 'European norm', provisions of which are cited frequently through this manual. Refer to these documents if necessary.

- International Standard ISO 10218-1-2011

Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots

- Technical Specification ISO/TS 15066 - 2016

Robots and robotic devices - Collaborative robots

- EC Machine directive (89/392/EEC, 91/368/EEC, 98/37/EC, 2006/42/EC)

Applicable Models

This manual is targeted for the following model series.

- RV-5AS-D

-
- No part of this manual may be reproduced by any means or in any form, without prior consent from Mitsubishi.
 - The contents of this manual are subject to change without notice.
 - This is the original document.
 - Ethernet is registered trademarks or trademarks of Xerox Corporation in the United States.
 - All other company names and production names in this document are the trademarks or registered trademarks of their respective owners.
-

1 FUNDAMENTAL CONCEPT OF SAFETY MEASURES

This section explains the fundamental concept of safety that should be understood by all persons who use robots.

1.1 Purpose, application

We have developed industrial robots to contribute to economic activities, human health and safety by improving productivity, flexibility, and quality of manufacturing industry, as well as by securing safety in hazardous operation. Therefore, we request users to understand our intention and never to make use of robots for purpose against above intention.

Typical applications of robots in manufacturing industry have included, for example, parts assembling, testing, machining, loading and unloading palletizing, sealer dispensing, painting, soldering brazing and deburring. In other applications such as education, and even amusements, robots are now being used. Robots have functions that enable them to work together with humans in the same workspace.

However, applications of robots will not be limited to those above. If you make a use of a robot in a new application, particular attention should be paid in order to assess the risks on your own responsibility, because a different application may involve different hazards and different levels of risks. (Safety is not guaranteed in environments containing explosive or flammable material, harmful laser beams, radioactive rays, hazardous chemicals, or harmful microbes.)

1.2 Safeguarding

Prevention of hazards in automatic operation

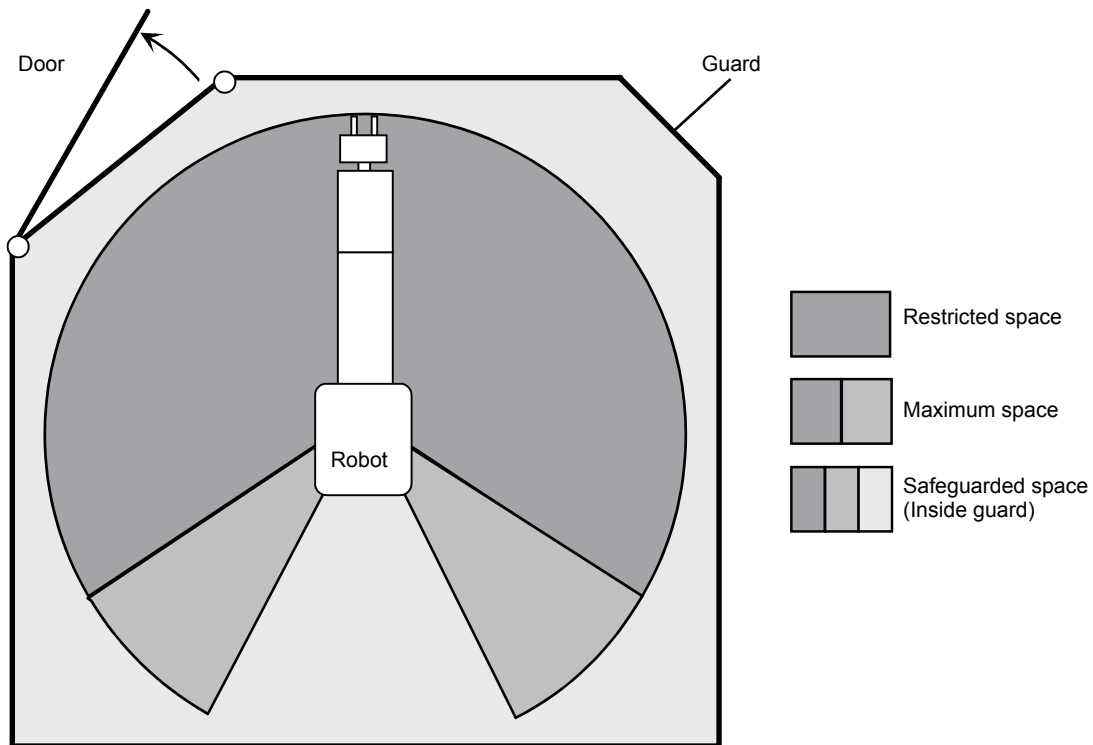
Using guards

If the operation of an industrial robot can give rise to hazards of impact, trapping, or flying objects released by the gripper, methods for protection of person(s) must be taken using fixed guards or fences.

It is obvious that if an operator does not enter into a safeguarded space, no hazard of impact nor trapping will occur. Therefore, the separation of any person from any robot by creating a safeguarded space and a restricted space is one of the fundamental principles of safeguarding. In other words, unless actions are taken to work together with collaborative robots, the principle prohibits a person from entering the safeguarded space during automatic operation. Further, the interlock must be installed so that the guard remains locked closed or opening the guard gives a stop instruction during automatic operation.

In addition to a guard and a fence, a presence sensing device that detects any intrusion into a space, or awareness means that provides a signal to persons of an approaching or present hazard may be used.

- Installing a guard



The three types of space in the above figure are defined as follows.

Limit region: Max. region limited with mechanical stoppers, etc.

Max. region: Max. movement region of robot, including hand installed on end, etc.

Safety protection region: Region protected with guard, including limit region

Collaborative operation

As described in the previous section, guards eliminate the risks of collisions between humans and robots. With the following four measures, humans and robots can work together in the same workspace without a guard.

- SRMS (Safety Rated Monitored Stop)
- HG (Hand Guiding)
- SSM (Speed and Separation Monitoring)
- PFL (Power and Force Limiting)

(Refer to ISO 10218-1 and ISO/TS15066: 2016/TS B 0033:2017.)

When adopting the above measures, make sure to use safety devices such as laser scanners, light curtains, and safety mats, and connect these devices correctly. Conduct a risk assessment, carefully checking not only robot settings and programs, but also the entire system, including hands, ancillary equipment, and peripheral devices. Conduct risk assessments in every stage of the product life cycle (not only during continuous operation, but also during startup, adjustment, maintenance, and troubleshooting). If the robot will not need to be in automatic operation all the time, create a procedure outlining how to stop the robot temporarily before approaching it.

Safeguarding in programming

In collaborative operation, robots move at a speed that will not cause serious injury to humans in the event of a collision. However, injury may occur depending on the type of hand being used, what is in the hand, and the positions and movements of surrounding peripheral devices. Conduct sufficient risk assessments to take safety precautions against hazards, and carefully check that no risk is present.

High speed operation may cause damage to a human if a collision occurs. Before performing high speed operation, use a safety sensor to check that nobody is inside the safeguarded space. When a human approaches a robot for teaching or maintenance, the robot must be at a stop or in collaborative operation. However, if a person is troubleshooting problems in an area where the safety sensor cannot detect the person, or if for any reason the safety sensor is interfered with, safety cannot be ensured. To prevent such situations, fully consider the system configuration and conduct sufficient risk assessments. Some maintenance and programming personal are at times required to be within the restricted space while power is available to the machine actuators for teaching, program verification, maintenance, and trouble shooting.

On the other hand, it is recognized that operational characteristics of robots can be significantly different from those of other machines and equipment. Robots are capable of high energy movements through a large volume beyond the base of robots. The pattern and initiation of movement of the robot arm are difficult to predict and can vary because of variables in product and environmental conditions.

Therefore, hazards must be eliminated or reduced before a person enters a safeguarded space or steps foot within a guard while power is supplied to the robot actuator. Robot systems should be designed so that humans can perform almost all tasks outside a safeguarded space or guard. If a person must enter a safeguarded space or step foot within a guard, instead of temporarily disabling safety protection devices, prepare a procedure that ensures safety and outlines what actions should be taken in an emergency.

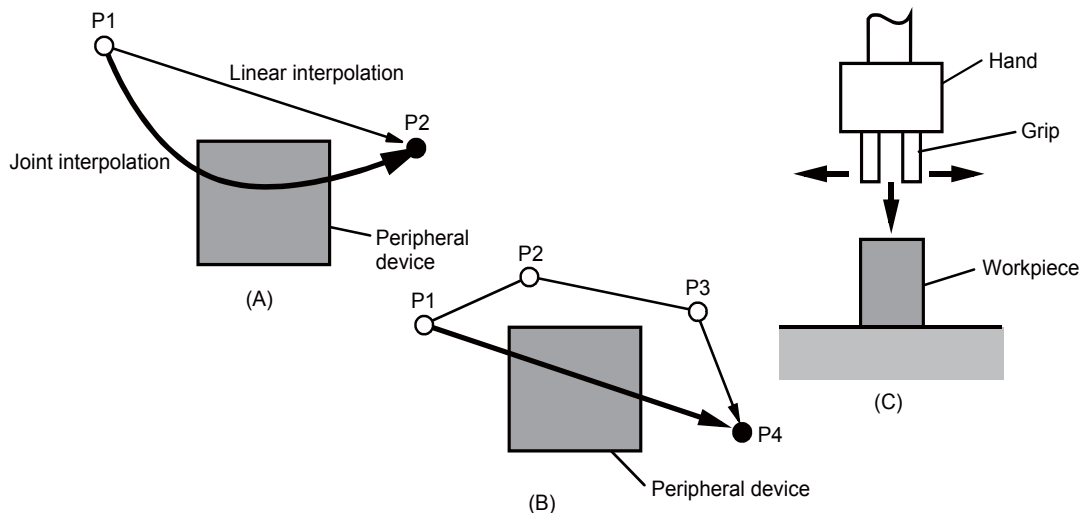
When constructing a system that contains multiple robots within a safeguarded space or guard, design and install the robots and devices so that they can be controlled independently.

When using direct teaching to teach the robot, the user directly controls the robot while the robot servos are ON. As the servos are ON, the user may feel an inertial like force when moving or stopping the robot. Be careful not to hit your hand or body against the robot or get caught between the robot and peripherals. To prevent the robot from hitting your head or face, be aware of your posture at all times when moving the robot as the robot may move in an unintended direction. If the hand parameters are set incorrectly, the robot may start moving at the moment when the direct teaching function is enabled. Make sure to set the hand parameters correctly.

When operating the robot, install an emergency stop switch nearby and connect the switch to the emergency stop input terminal of the robot controller. When operating the robot from a computer without an emergency stop switch, make sure to carry an emergency stop switch so that you can stop the robot immediately in an emergency.

The figures below show common examples of robots interfering with peripheral devices and workpieces during teaching. Here, (A) is interference during movement with joint interpolation, (B) is interference caused by an incorrectly set movement destination position No., and (C) is interference caused by an incorrect hand grip open/close setting.

- Example of work mistake during teaching



Safeguarding in maintenance and trouble shooting

When entering the safeguarded space for inspection, repair, cleaning, and maintenance, be sure to stop the robot and shut down the power supply with placing a lock and/or tag on the energy isolating device to prevent unwilling operation. When an intervention within the safeguarded space while power is available to the robot is required, appropriate safe working procedures must be used to prevent a sudden motion of a robot and a careless operation of person.

Verification of safety before starting operation

Prior to the use in normal operation, ensure the proper operation of the robot and the robot system. If any damage or malfunction that may lead to an accident is found, required corrections must be completed and retesting must be performed. Be sure that all system emergency stop devices remain functional. Make sure to check whether safety sensors, the STR function, and the collision detection function^{*1} work properly before operating the robot. After robot parameters or programs have been changed, check for errors in them.

^{*1} The collision detection function is not a safety function.

2 INFORMATION ON ROBOTS

This section describes the information necessary to determine restrictions on use of machinery and basic usage of robots to conduct risk assessments.

2.1 Operating environments

The operating environments of a robot can affect its lifetime, function, performance, and safety. If the operating environments of a robot do not satisfy the following conditions, appropriate means should be taken to prevent the robot from being exposed to such undesirable conditions.

Power supply

- The line voltage must be within $\pm 10\%$ of the rating.
- The duration period of an instantaneous power failure must be within 15 milliseconds.
- The power supply must provide enough electricity needed at the maximum consumption.

[Recommendation] a larger transformer; a stabilized power supply; an UPS.

Electromagnetic noise

- Where a surge voltage exceeding 2000V, 5kHz (equivalent to EN 61000-4-4) may be applied on the primary voltage.
- Locations where a strong electric field or magnetic field exists, such as near large inverters, high output frequency oscillator, large contactors and welding machines.

[Recommendation] a noise-cut transformer; a noise filter; reinforcement of ground lines and electromagnetic shields; isolation by keeping away from noise sources; reduction of noise level of emission.

- This product has undergone EMC testing for products intended for use in industrial environments (tested to standards EN 61000-6-2 and EN 61000-6-4). This product is not intended to be connected to residential, commercial, or light-industrial power supplies.

Static electricity

- Where static electricity exceeding 4kV could be directly applied on the robot body or controller. Or where static electricity exceeding 8kV could be applied through airborne electrical discharge.

[Recommendation] prevention from storing static electricity; discharging of static electricity.

Temperature, humidity

- Where the atmospheric temperature exceeds 40°C, lower than 0°C.
- The robot must be kept away from direct sunlight and any heat source.
- Locations where the relative humidity exceeds 75% RH or below 45% RH, or condensation may occur.

[Recommendation] a local heating or cooling equipment; a heat-resistant jacket; isolation by keeping away from a heat source.

Atmosphere

- No dust, no oil mist, and no corrosive gas must be contained in the atmosphere.
- No metal shavings and conductive material must be scattered.
- No combustible and explosive gas must be contained in the atmosphere.

[Recommendation] use the dust or an oil mist resistant jacket. (Never use robots in a combustible or explosive atmosphere.) Install the controller in a shielded enclosure if used in a bad atmosphere.

Liquid

- Water and other liquid must not splash a robot and a controller directly.
- Any portion of a robot and a controller must not be dipped in water and other liquid.

Vibration

- Locations where the product is subject to a vibration or impact of 3.5 G or more during transportation.
- Locations where the product is subject to a vibration or impact of 0.1 G or more during operation.

[Recommendation] Use a reinforced package for transportation, and take measures to suppress vibrations during operation.

Precautions

If the robot is installed on equipment such as an automated guided vehicle (AGV), turn OFF the robot servos while the AGV is moving. Robot servos cannot be turned OFF with RT VisualBox.

Radioactive ray

- The radioactive ray must not be more than a permitted level of ordinary person.

[Recommendation] isolation from and of a radioactive source.

Air pressure

- The altitude should not be more than 1000 m. The robot cannot work in vacuum.

[Recommendation] Giving pressure to reach to 1 atmosphere, approximately $10^5 \text{ Pa} = 100 \text{ kPa} = 1000 \text{ hPa}$

Magnetic field

- Locations where the external magnetic field is over 10 mT.

[Recommendation] Do not use the robot near devices that generate magnetic forces.

2.2 Operating range and load capacity

For details on the robot operating range and load capacity, refer to the following manuals.

Operating range diagram

For details on the diagram of the robot operating range, refer to the following manual.

📖RV-5AS-D Standard Specifications (BFP-A3727)

Load capacity

For details on the load capacity of the robot, refer to the following manual.

📖RV-5AS-D Standard Specifications (BFP-A3727)

2.3 Safety-related control system performance and conforming standards

The following shows the safety-related control system performance and conforming standards and the stop category of the protective stop circuit input.

Item			Description	Remarks
Safety function ^{*1}	STO function		Electrically shuts off power to the motors in the robot.	Applicable to stop category 0 of IEC 60204-1:2016
	SS1 function		Decelerates the motors in the robot. After the motors stop, the robot goes into the STO state.	Applicable to stop category 1 of IEC 60204-1:2016
	SS2 function		Decelerates the motors in the robot. After the motors stop, the robot goes into the SOS state.	Applicable to stop category 2 of IEC 60204-1:2016
	SOS function		Checks that the robot has stopped without shutting off power to the motors in the robot.	When SOS, SLS, SLP, and STR detect error, activate SS1. EN 61800-5-2:2017 compliant
	SLS function		Checks that parts of the robot arm do not exceed the speed limit.	
	SLP function		Checks that a predetermined position does not pass through the position monitoring plane.	
	STR function		Ensures that the torque limits of each motor in the robot are not exceeded.	
Safety performance	Standard		EN ISO 10218-1:2011 ISO/TS 15066:2016 EN ISO 13849-1:2015 EN 61800-5-1:2007/A1: 2017 EN 61800-5-2:2017 EN 61000-6-7:2015 EN 61326-3-1:2017 IEC 61508-1:2010 IEC 61508-2:2010 IEC 61508-3:2010	—
Safety extension unit	Power supply specifications	Voltage	24 V DC ±5% Ripple voltage: 0.2 V (P-P)	Supplied by customer
		Maximum current consumption	300 mA	—
	Structure (IP rating)		IP20	—
	Mass		0.8 kg	—
	Environment	Operating temperature	0 to 40°C	Do not use the unit near heat sources including heating appliances.
		Relative humidity	45 to 75%	Non-condensing
		Vibration	During transportation: 3.5 G or less, during operation: 0.5 G or less	—
		Atmosphere	No corrosive gas, flammable gas, oil mist, and dust	—
		Installation environment	Indoor use. Install on environments free from strong electric or magnetic fields. Install on a smooth, level surface.	No direct sunlight. Do not install the unit on a rough surface.
	Input signal		8 routes (duplicated signal)	—
	Output signal		4 routes (duplicated signal)	—

*1 The safety functions conform to EN 61800-5-2:2017.

following table shows the safety performance of the CR800-05VD controller.

Function	Item	Performance	Remarks
STO	Safety Level	SIL 3 (IEC 61508:2010)	Performance when: • External emergency stop input when the test pulse diagnosis settings are enabled ^{*1}
		Category 4, PL e (EN ISO 13849-1:2015)	
	Mean time to dangerous failure (MTTFd)	MTTFd ≥ 100 years	
	Diagnostic coverage (DC)	DC = 99%	
	Probability of dangerous failure per hour (PFH) ^{*2}	PFH = 1.40×10^{-8} [1/hour]	Performance when: • External emergency stop input when the test pulse diagnosis settings are disabled (factory settings) • Door switch input • Mode selector switch input • Safety extension unit's safety input ^{*3}
	Safety Level	SIL 2 (IEC 61508:2010)	
		Category 3, PL d (EN ISO 13849-1:2015)	
	Mean time to dangerous failure (MTTFd)	MTTFd ≥ 100 years	
SS1, SS2, SOS, SLS, SLP	Safety Level	SIL 2 (IEC 61508:2010)	^{*3}
		Category 3, PL d (EN ISO 13849-1:2015)	
	Mean time to dangerous failure (MTTFd)	MTTFd = 24 years	
	Diagnostic coverage (DC)	DC = 90%	
	Probability of dangerous failure per hour (PFH) ^{*2}	PFH = 3.42×10^{-7} [1/hour]	
STR	Safety Level	SIL 2 (IEC 61508:2010)	^{*3}
		Category 3, PL d (EN ISO 13849-1:2015)	
	Mean time to dangerous failure (MTTFd)	MTTFd = 24 years	
	Diagnostic coverage (DC)	DC = 90%	
	Probability of dangerous failure per hour (PFH) ^{*2}	PFH = 3.62×10^{-7} [1/hour]	

^{*1} To use this product at a performance level of SIL 3, Category 4, PL e, set the relevant parameters. For details, refer to "Safety diagnosis function (test pulse diagnosis)" in the following manual.

 RV-5AS-D Standard Specifications (BFP-A3727)

^{*2} The robot controller PFH or PFHd (Probability of Dangerous Failure per Hour). The PFH of the emergency stop switch and enable switch on the teaching pendant is shown in the table below.

Teaching pendant	Switch	B10d [cycle]	N _{op} [cycle/year]	MTTFd [year]	DC [%]	PFH [1/hour]
R32TB	Emergency stop switch	1×10^6	6000	1667	≥ 99	2.47×10^{-8}
	Enable switch	1×10^6	6000	1667	≥ 99	2.47×10^{-8}
R56TB	Emergency stop switch	1×10^6	6000	1667	≥ 99	2.47×10^{-8}
	Enable switch	7×10^6	6000	11667	60 ≤ DC < 90	1.57×10^{-7}

^{*3} For systems using the I/O signals of the safety extension unit, add the PFH value in the table below. Safety performance of the safety extension unit complies with PL d/Category 3.

MTTFd [[year]	DC [%]	PFH [1/hour]
318	90	2.41×10^{-8}

2.4 Stopping time and stopping distance

Safe stopping distance

The concept of the maximum stopping distance of the robot is described below.

How to calculate a stopping distance

Assuming that the power supply to the robot controller is shut off during operation or that an error triggers the SS1 function, the maximum stopping distance in the worst scenario can be approximated by the following formula. (Assume that the robot has brakes on all the axes.)

$$d_{\max} = (V_{\max} \times T_{\text{res}}) + (0.5 \times V_{\max} \times T_{\max} \times \alpha)$$

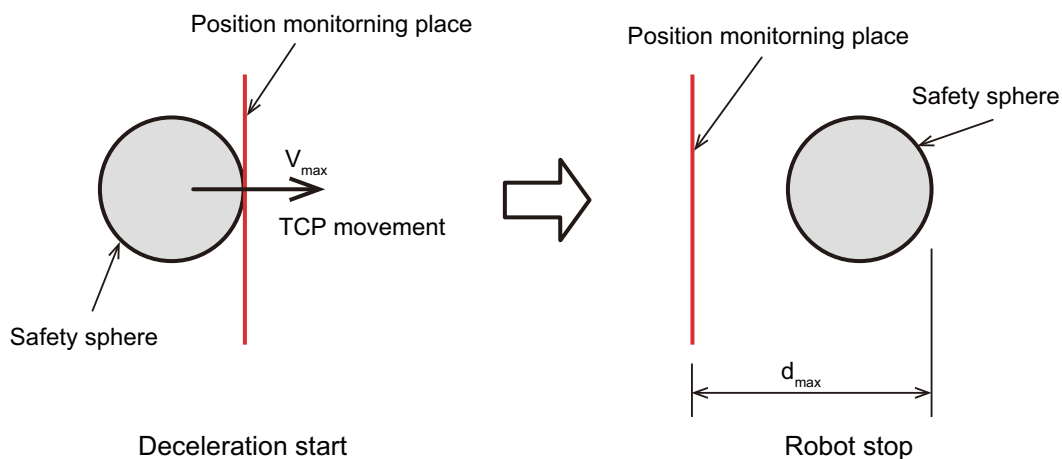
$d_{\max}$: Maximum stopping distance

$V_{\max}$: Maximum speed (Equivalent to the SLS monitoring speed when the SLS function is enabled)

T_{res} : Reaction time (time from error detection to stop) (Approximately 7.1 msec)

$T_{\max}$: Maximum stopping time (Differs from robot to robot)

α : Safety factor (1 or more)



■Maximum speed

When the safely limited speed function (SLS) is enabled, detection of a speed exceeding the SLS monitoring speed causes the SS1 function to immediately stop the robot. Therefore, the SLS monitoring speed can be considered equivalent to the maximum speed. Thus, reducing the SLS monitoring speed enables shortening the maximum stopping distance when power supply shut-off or an internal error shuts off the driving energy.

When Advanced Mode of the SLS function is configured, each of the X, Y, Z components are monitored for their speed, which enables restricting the maximum stopping distances for each of the X, Y, Z components. For example, if there is a safeguarded space in +X direction and the other directions are covered with safety fences, reducing the SLS speed only in +X direction enables ensuring safety and minimizing impact on tact time.

■Reaction time

The delay between when an error detection enables the SS1 command and when deceleration starts is approximately 7.1 ms. Using the DSI input of the Safety extension unit to stop the robot will have an effect on the DSI filter time specified in the DSI filter settings. For further information, refer to "DSI filter configuration" in the following manual:

📖 Robot Safety Option Instruction Manual (BFP-A3531)

The initial value is 10 ms, therefore there will be a delay of 10 ms until the DSI input is enabled for the input signal.

If an error occurs in the reading of the DSI input, there may be a delay of up to 72 ms before the signal is read out.

■Maximum stopping time

The maximum stopping time differs from robot to robot.

For details, refer to the following.

☞ Page 46 Maximum stopping time and stopping distance

Ex.

In case of the table below, the maximum stopping time is the stopping time of J1 or 0.29 seconds, which results in the maximum stopping time of the robot being 0.29 seconds.

For meanings of the symbols in the table, refer to the following section.

☞ Page 46 What symbols mean

Axis	Arm extension	Load rate	Stopping time [s]	Stopping distance [deg]
			Ovrd 100%	Ovrd 100%
J1	L = 100%	M = 100%	0.29	58.80
J2	L = 100%	M = 100%	0.26	42.48
J3	L = 100%	M = 100%	0.24	28.80
J4	—	M = 100%	0.20	49.80
J5	—	M = 100%	0.23	61.56
J6	—	Load 1	0.14	66.48

Maximum stopping time and stopping distance

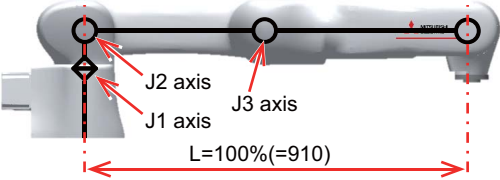
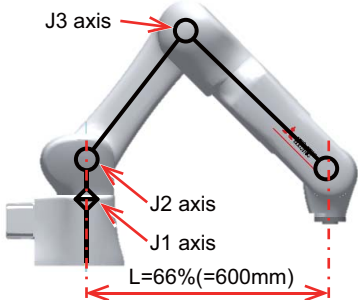
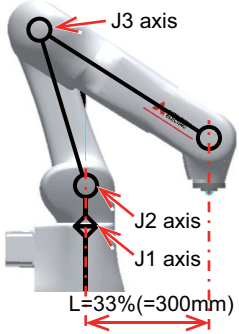
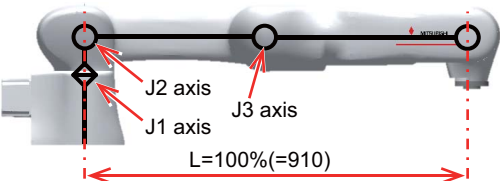
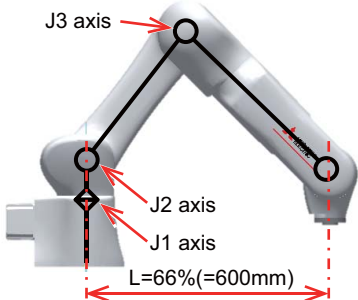
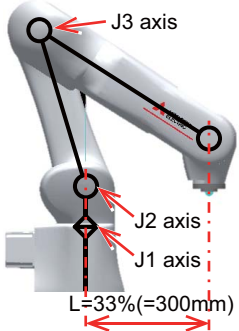
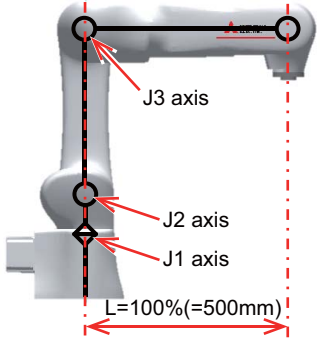
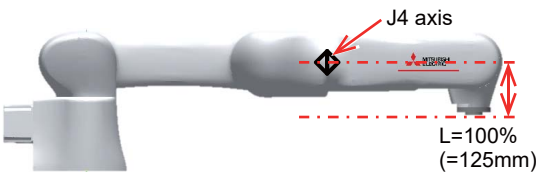
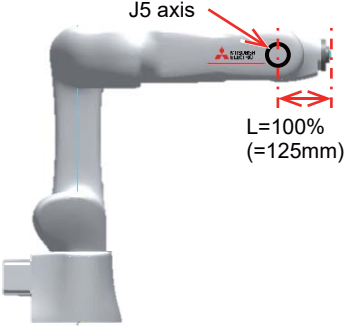
The time and distance mean the maximum elapsed time and distance from when the SS1 function is activated until the robot stops. In the stop time and stop distance tables in this section, the time at which the robot's TCP speed drops to 10 mm / s or less is assumed stop time. It is completely stopped within 0.2 seconds after that. The time from when the SS1 function is activated to when the power supply to the motor is cut off by STO is 1.28 seconds at maximum. The distance means an operating distance during the time. With low movement speed, which makes deceleration time short, operation will require a shorter elapsed time and smaller operating distance than those shown here. Improper use of the robot can result in a longer maximum elapsed time and a higher maximum movement speed than the values shown here.

■What symbols mean

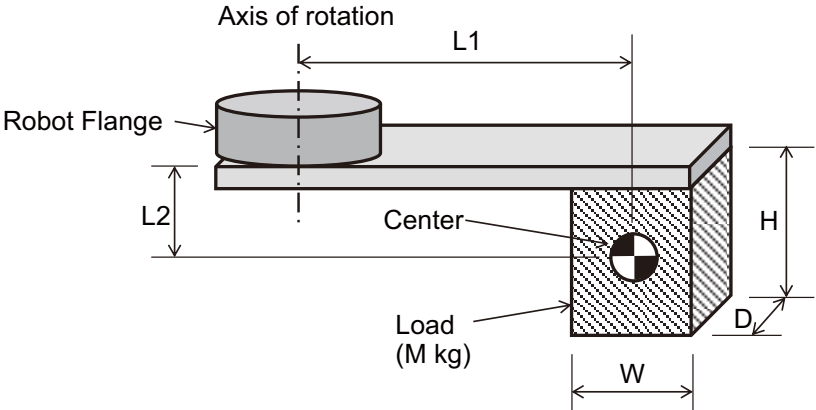
Meanings of the symbols used in this chapter are as follows.

String	Unit	Meaning	Description
L	mm	Degree of arm extension	This is the degree of extension of the arm in relation to each rotation axis. For details, refer to the following. ☞ Page 47 The degree of extension of the robot arm
M	%	Load ratio	This is the ratio of a load on the robot to the maximum load. Take for an example a robot with a maximum load of 4 kg. If M = 66%, the load on the robot is 2.64 kg.
OVRD	%	Robot override	This is an override for the robot speed.
t	s (second)	Stopping time	This is the maximum duration that elapses from when the SS1 function starts to when the motor power supply is shut off.
deg	° (degree)	Stopping angle	This is the maximum angle that the robot moves from when the SS1 function starts to when the robot stops.

■The degree of extension of the robot arm

Axis	L = 100%	L = 66%	L = 33%
J1			
J2			
J3		—	—
J4		—	—
J5		—	—

■Load dimension for RV series



Robot model	Load type	Mass [kg]	Size [mm]				Distance [mm]	
		M	W	D	H	L1	L2	
RV-5AS-D	Load 1	5	86	86	86	100	135	

• Stopping time and stopping distance (emergency stop)

200V

Axis	Arm extension	Load rate	Velocity	Stopping time [s]			Stopping distance [deg]		
				Ovrd 30%	Ovrd 60%	Ovrd 100%	Ovrd 30%	Ovrd 60%	Ovrd 100%
J1	L = 100% (910 mm)	—	Angular velocity [deg/s]	17	35	58	17	35	58
			TCP velocity [mm/s]	281	558	931	281	558	931
		M = 100% (5 kg)	—	0.43	0.45	0.47	5.50	9.98	16.05
		M = 0% (0 kg)		0.41	0.43	0.45	5.29	9.55	15.56
	L = 66% (600 mm)	—	Angular velocity [deg/s]	26	53	88	26	53	88
			TCP velocity [mm/s]	279	559	930	279	559	930
		M = 100% (5 kg)	—	0.43	0.45	0.48	7.81	14.53	23.88
		M = 0% (0 kg)		0.41	0.44	0.46	7.40	14.08	23.23
	L = 33% (300 mm)	—	Angular velocity [deg/s]	37	74	124	37	74	124
			TCP velocity [mm/s]	195	390	650	195	390	650
		M = 100% (5 kg)	—	0.41	0.45	0.46	10.48	20.40	31.98
		M = 0% (0 kg)		0.40	0.43	0.44	10.02	19.53	30.85
J2	L = 100% (910 mm)	—	Angular velocity [deg/s]	17	34	57	17	34	57
			TCP velocity [mm/s]	276	553	920	276	553	920
		M = 100% (5 kg)	—	0.43	0.46	0.48	5.30	9.94	16.50
		M = 0% (0 kg)		0.40	0.43	0.45	4.97	9.30	15.30
	L = 66% (600 mm)	—	Angular velocity [deg/s]	25	51	85	25	51	85
			TCP velocity [mm/s]	270	540	899	270	540	899
		M = 100% (5 kg)	—	0.43	0.46	0.48	7.48	14.59	23.41
		M = 0% (0 kg)		0.41	0.43	0.45	7.35	13.61	22.12
	L = 33% (300 mm)	—	Angular velocity [deg/s]	37	74	123	37	74	123
			TCP velocity [mm/s]	195	389	647	195	389	647
		M = 100% (5 kg)	—	0.42	0.44	0.46	10.58	20.32	31.67
		M = 0% (0 kg)		0.40	0.42	0.44	10.26	19.20	30.13
J3	L = 100% (500 mm)	—	Angular velocity [deg/s]	31	62	103	31	62	103
			TCP velocity [mm/s]	271	541	902	271	541	902
		M = 100% (5 kg)	—	0.43	0.45	0.47	8.97	16.71	26.27
		M = 0% (0 kg)		0.41	0.43	0.45	8.48	16.20	25.32
J4	L = 100% (125 mm)	—	Angular velocity [deg/s]	89	178	297	89	178	297
			TCP velocity [mm/s]	195	389	648	195	389	648
		M = 100% (5 kg)	—	0.42	0.45	0.43	23.68	46.74	67.89
		M = 0% (0 kg)		0.41	0.43	0.40	23.30	43.80	65.37
J5	L = 100% (125 mm)	—	Angular velocity [deg/s]	107	213	354	107	213	354
			TCP velocity [mm/s]	233	465	774	233	465	774
		M = 100% (5 kg)	—	0.43	0.45	0.45	29.03	54.80	83.87
		M = 0% (0 kg)		0.41	0.43	0.41	27.41	52.46	77.35

Axis	Arm extension	Load rate	Velocity	Stopping time [s]			Stopping distance [deg]		
				Ovrd 30%	Ovrd 60%	Ovrd 100%	Ovrd 30%	Ovrd 60%	Ovrd 100%
J6	—	—	Angular velocity [deg/s]	108	216	360	108	216	360
			TCP velocity [mm/s]	189	378	629	189	378	629
		Load 1	—	0.42	0.44	0.40	28.84	54.35	78.28

100V

Axis	Arm extension	Load rate	Velocity	Stopping time [s]			Stopping distance [deg]		
				Ovrd 30%	Ovrd 60%	Ovrd 100%	Ovrd 30%	Ovrd 60%	Ovrd 100%
J1	L = 100% (910 mm)	—	Angular velocity [deg/s]	17	35	58	17	35	58
			TCP velocity [mm/s]	281	560	931	281	560	931
		M = 100% (5 kg)	—	0.36	0.38	0.40	4.78	8.55	13.75
		M = 0% (0 kg)		0.35	0.37	0.39	4.69	8.15	13.22
	L = 66% (600 mm)	—	Angular velocity [deg/s]	18	35	59	18	35	59
			TCP velocity [mm/s]	188	375	625	188	375	625
		M = 100% (5 kg)	—	0.35	0.38	0.38	4.71	8.79	13.37
		M = 0% (0 kg)		0.34	0.36	0.37	4.69	8.38	12.95
	L = 33% (300 mm)	—	Angular velocity [deg/s]	18	35	59	18	35	59
			TCP velocity [mm/s]	94	187	312	94	187	312
		M = 100% (5 kg)	—	0.32	0.35	0.36	4.68	8.65	13.34
		M = 0% (0 kg)		0.31	0.34	0.35	4.59	8.37	12.92
J2	L = 100% (910 mm)	—	Angular velocity [deg/s]	10	20	34	10	20	34
			TCP velocity [mm/s]	165	326	540	165	326	540
		M = 100% (5 kg)	—	0.34	0.36	0.38	3.03	5.27	7.91
		M = 0% (0 kg)		0.33	0.34	0.36	2.94	5.11	7.60
	L = 66% (600 mm)	—	Angular velocity [deg/s]	10	20	34	10	20	34
			TCP velocity [mm/s]	107	215	356	107	215	356
		M = 100% (5 kg)	—	0.32	0.35	0.37	3.10	5.20	8.03
		M = 0% (0 kg)		0.31	0.33	0.35	2.98	5.04	7.85
	L = 33% (300 mm)	—	Angular velocity [deg/s]	10	20	34	10	20	34
			TCP velocity [mm/s]	53	107	178	53	107	178
		M = 100% (5 kg)	—	0.29	0.33	0.33	2.99	5.24	7.83
		M = 0% (0 kg)		0.28	0.31	0.33	2.91	5.03	7.71
J3	L = 100% (500 mm)	—	Angular velocity [deg/s]	10	20	34	10	20	34
			TCP velocity [mm/s]	89	179	298	89	179	298
		M = 100% (5 kg)	—	0.29	0.32	0.31	2.96	5.02	7.05
		M = 0% (0 kg)		0.29	0.31	0.30	2.87	4.77	6.82
J4	L = 100% (125 mm)	—	Angular velocity [deg/s]	43	85	142	43	85	142
			TCP velocity [mm/s]	93	187	311	93	187	311
		M = 100% (5 kg)	—	0.34	0.37	0.35	10.84	20.13	29.50
		M = 0% (0 kg)		0.33	0.36	0.33	10.37	19.22	28.26

Axis	Arm extension	Load rate	Velocity	Stopping time [s]			Stopping distance [deg]		
				Ovrd 30%	Ovrd 60%	Ovrd 100%	Ovrd 30%	Ovrd 60%	Ovrd 100%
J5	L = 100% (125 mm)	—	Angular velocity [deg/s]	65	129	215	65	129	215
			TCP velocity [mm/s]	141	282	470	141	282	470
		M = 100% (5 kg)	—	0.39	0.42	0.42	17.34	32.89	49.38
		M = 0% (0 kg)		0.38	0.41	0.38	16.40	31.41	46.15
J6	—	—	Angular velocity [deg/s]	108	216	360	108	216	360
			TCP velocity [mm/s]	189	377	629	189	377	629
		Load 1	—	0.46	0.49	0.44	31.18	59.97	87.28

• Stopping time and stopping distance (power off)

200V

Axis	Arm extension	Load rate	Stopping time [s]	Stopping distance [deg]
			Ovrd 100%	Ovrd 100%
J1	L = 33%	M = 0%	0.16	11.08
J2	L = 33%	M = 100%	0.12	8.30
J3	L = 100%	M = 100%	0.12	6.57
J4	L = 100%	M = 100%	0.12	17.37
J5	L = 100%	M = 100%	0.12	20.20
J6	—	Load 1	0.07	14.48

100V

Axis	Arm extension	Load rate	Stopping time [s]	Stopping distance [deg]
			Ovrd 100%	Ovrd 100%
J1	L = 100%	M = 100%	0.18	5.98
J2	L = 66%	M = 0%	0.08	2.37
J3	L = 100%	M = 100%	0.06	1.75
J4	L = 100%	M = 100%	0.06	4.61
J5	L = 100%	M = 100%	0.08	7.96
J6	—	Load 1	0.07	11.91

Calculating stopping distance and stopping time

This section explains how to calculate stopping distance and stopping time with RT ToolBox3.

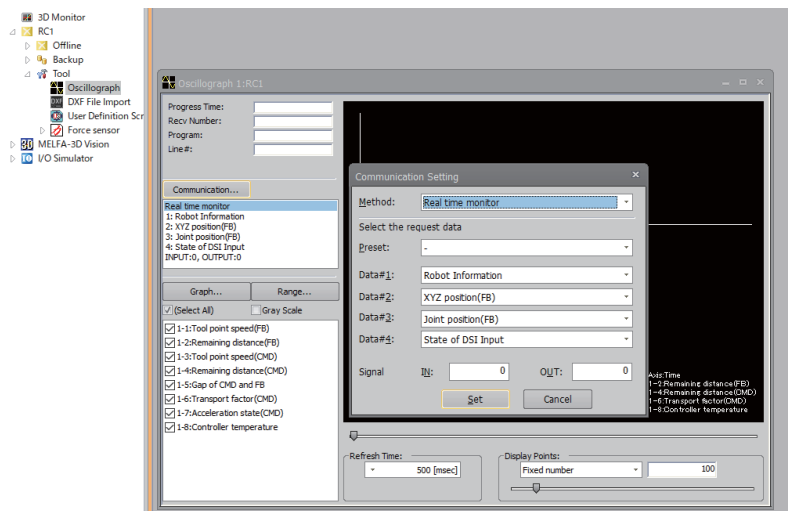
Calculating the stopping distance and time based on actual peripheral devices (such as hands) and the program that will be used will provide more accurate results. For information on how to use RT ToolBox3 or how to configure the advanced settings, refer to the following manual:

 RT ToolBox3 / RT ToolBox3 mini User's Manual (BFP-A3495)

1. Configure the log settings of the oscillograph function.

Connect the robot controller to RT ToolBox3 via Ethernet, set the controller to Online mode, then select Tool → Oscillograph. Configure the communication settings as follows:

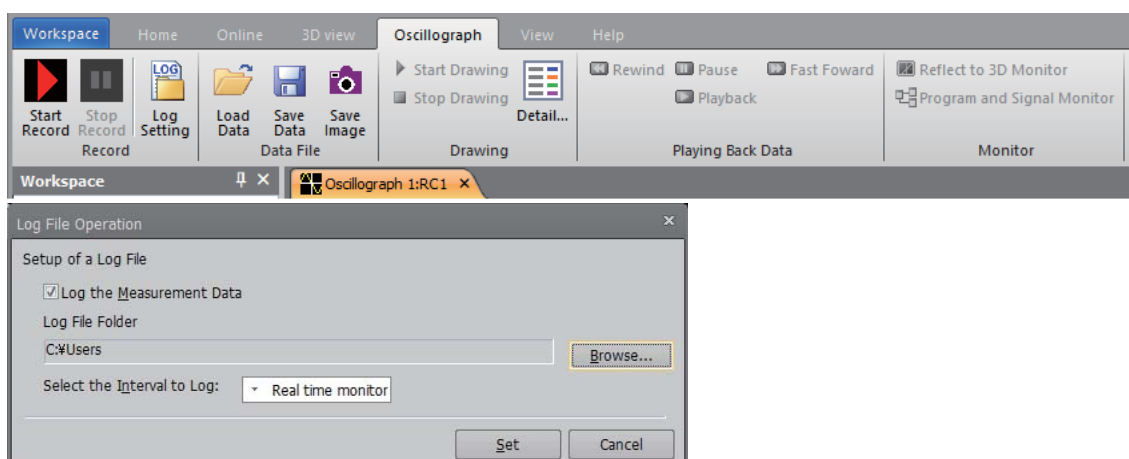
- Method: Real time monitor
- Data No.1 to 4: Robot Information / XYZ position (FB) / Joint position (FB) / State of DSI Input



Note that Real time monitor cannot be selected when the robot controller is connected to RT ToolBox3 via USB. If some received data are lost, we recommend to connect the robot controller and computer directly (not via a network hub), use a high-performance computer, or do not use this software while any other application is open.

2. Create the robot log.

Open [Log Setting] from the menu bar, then check the Log the Measurement Data check box. Select [Real time monitor] in the [Select the Interval to Log] drop down box, then choose a folder to save the log file in. Select [Start Record] to start logging data. Select [Stop Record] to stop logging data.



3. Log data.

Operate the robot and start the data logging.

Next, input the stop signal. Finish the data logging after the robot has stopped. A simple way to input the stop signal is from the emergency stop switch (EMS Switch) connected to the emergency stop input of the robot controller. If a teaching pendant is connected, the emergency stop switch on the teaching pendant can also be used. The robot can also be stopped by connecting a signal which acts as a trigger to the DSI input of the Safety extension unit. In this case, you need to assign SS1 to the relevant DSI input in the safety input settings using RT ToolBox3.



Using the DSI input of the Safety extension unit to stop the robot will have an effect on the DSI filter time specified in the DSI filter settings. For further information, refer to "DSI filter configuration" in the following manual:

Robot Safety Option Instruction Manual (BFP-A3531)

The initial value is 10 ms, therefore there will be a delay of 10 ms until the DSI input is enabled for the input signal.

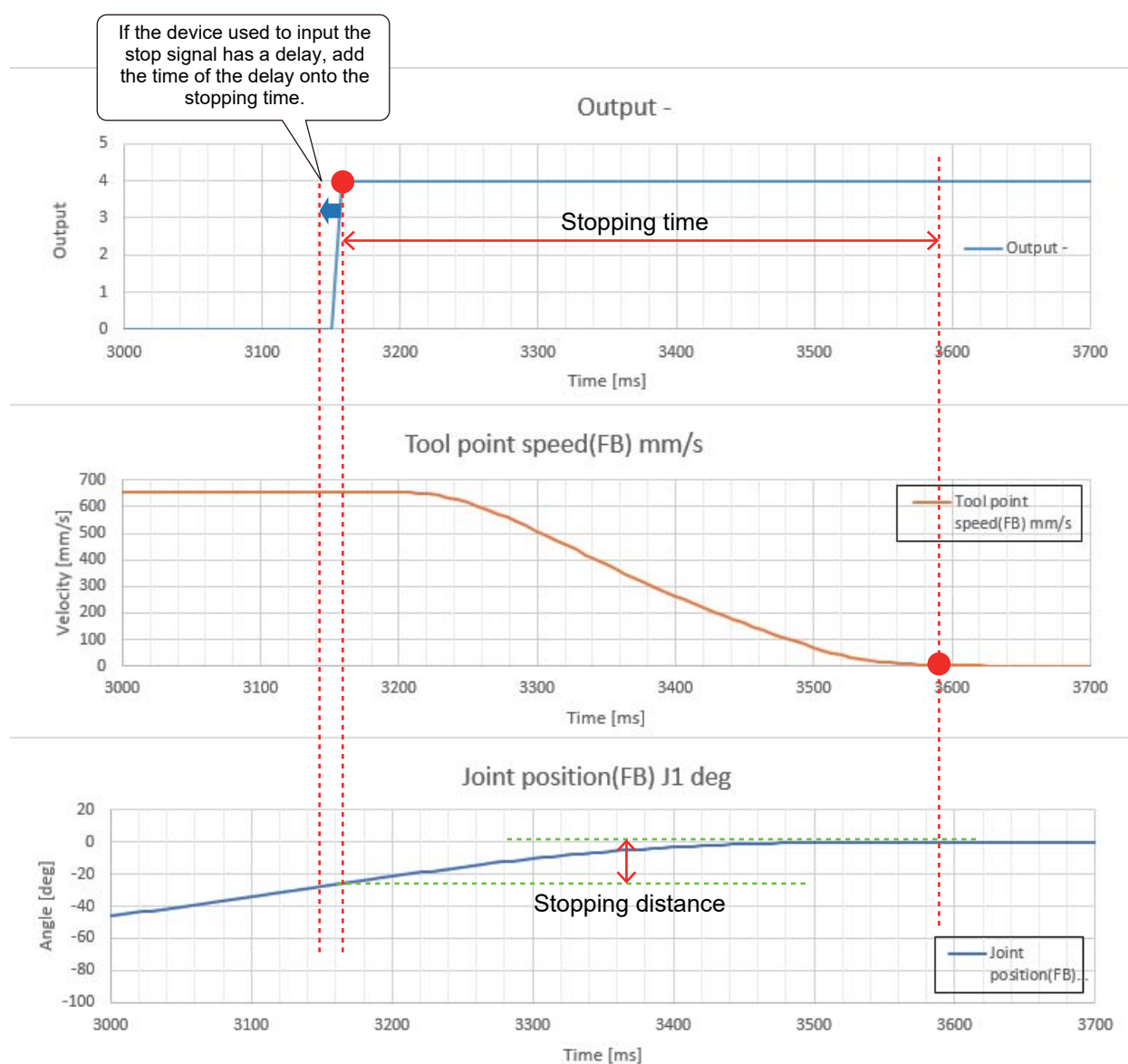
4. Interpret the stopping distance and stopping time.

The logged data will be saved as a file in the folder you have specified. The current date and time will be used as the file name (e.g. "LOGYYYYMMDD-hhmmss.csv"). The first three rows in the CSV file contain information such as column titles and units

of measurement. Data sampled at intervals is contained in the rows from the fourth row onwards. Check the values in the Output column. This number has been changed from a 32-bit binary value (assigned to the general-purpose output signal) to a decimal value. If the output signal of "ERRRESET" is set to "2", the value will increase to four ($2^2 = 4$) when an error occurs. When the emergency stop signal is input, the robot will enter an error state. By checking the time when bit 2 changes to "4" in the output column, you can see when the stop signal was input.

The CSV file can be used to check the time that the robot stopped. The "Tool point speed (FB)" column in the file shows the speed of the tool control point. Look for where the speed decreases to zero after the stop signal has been input.

The stopping time is the time from when the stop signal is input to when the speed becomes zero. By checking the XYZ position (FB) data or Joint position (FB) data at the times when the stop signal was input and at the time the robot stopped, it is possible to find the stopping distance of the tool center point within the XYZ coordinate system and the stopping distance (angle) of individual axes. Refer to the graphs on the following page which show an example of the stopping distance of the J1 axis. If there is a delay when the stop signal is input, consider the time that the signal was output as earlier than what is shown in the graph.



2.5 Lubricant used in robots

The following lubricant is used in robots.

Location	Product name	Manufacturer
Reduction gear	Harmonic Grease SK-1A, SK-2	Harmonic Drive Systems

2.6 Robot functions and basic operation

For details on the functions and operation of the robot, refer to the following manuals.

Basic operation

For details on the parts identification and power on or off of the controller and teaching pendant, jog operation using the teaching pendant, program creation, and others, refer to the "Basic operations" in the following manual.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

Operation using RT VisualBox

For details on the operation using RT VisualBox, refer to the following manuals.

 RT VisualBox Instruction Manual (BFP-A3696)

The manual describes when the movement of the robot is simulated with the functional safety always activated.

Function details

For further information on operation rights, refer to "Operation rights" in the following manuals.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

For details on the teaching pendant functions and characteristic functions, refer to the "Explanation of functions" in the following manual.

 Instruction Manual: Detailed explanations of functions and operations (BFP-A3478)

Explanation of operation methods

For details on the teaching pendant operation, Jog feed, hand operation, programming, debugging, and other detailed operations, refer to the "Explanation of operation methods" in the following manual.

 Instruction Manual: Detailed explanations of functions and operations (BFP-A3478)

2.7 Limiting the robot operating range

To limit the robot operating range, refer to the following manuals.

Setting free plane limits

For details, refer to the "Free plane limit" in the following manual.

 Instruction Manual: Detailed explanations of functions and operations (BFP-A3478)

Setting the safely-limited position function (SLP)

For details, refer to the "Safely limited position function (SLP)" in the following manual.

 Robot Safety Option Instruction Manual (BFP-A3531)

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

2.8 Safe torque range function (STR)/power and force limiting (PFL)

Precautions regarding the safe torque range function (STR function) and the power and force limiting function (PFL) are noted in an attempt to reduce injury and damage from human-robot impacts.

2

Warning

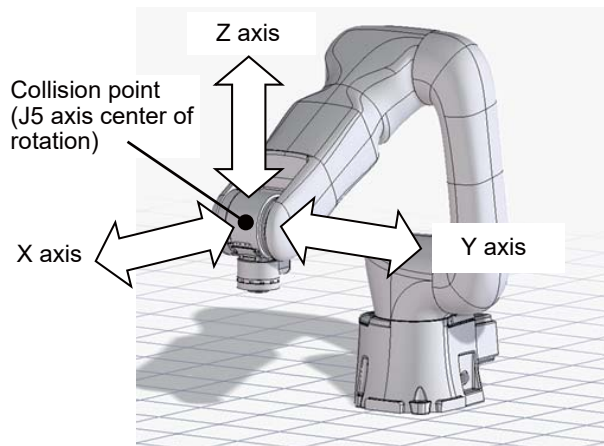
In this section, the reference of STR and PFL, contents of collision examination that we tested by this robot are explained. Though, the user who use this robot in the robot system must check contact force whether is acceptable or not. Do not use without a verification.

Safe torque range function (STR)

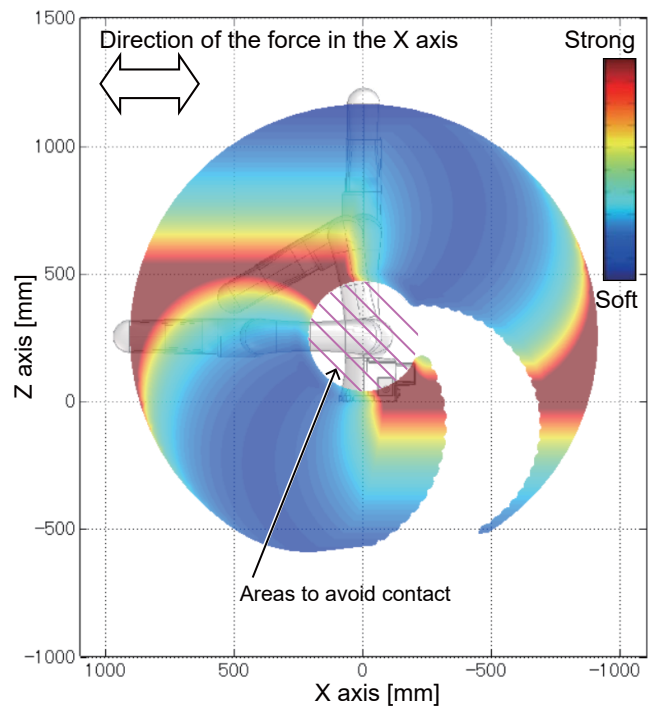
The STR function monitors the difference in the estimated amount of torque required (estimated torque) and the torque that is actually output (actual torque) when the motors of each joint are operating. This function stops the robot if it detects a collision. The force generated in a collision with the robot arm is the amount of torque generated in the collision which is determined by the direction and distance of the force from the joint. This torque is added to the actual torque and creates a discrepancy between the estimated torque and the actual torque that occurs during a collision. The torque generated in a collision increases the further away from the point of impact. Therefore, the closer a collision is to a joint, the less torque is applied to that joint. The direction of the force also has an effect on the amount of torque applied to the joint.

Even if a collision occurs at the same place on the arm on separate occasions, how much force is applied to the joint depends greatly on the posture of the robot at the time of the collision.

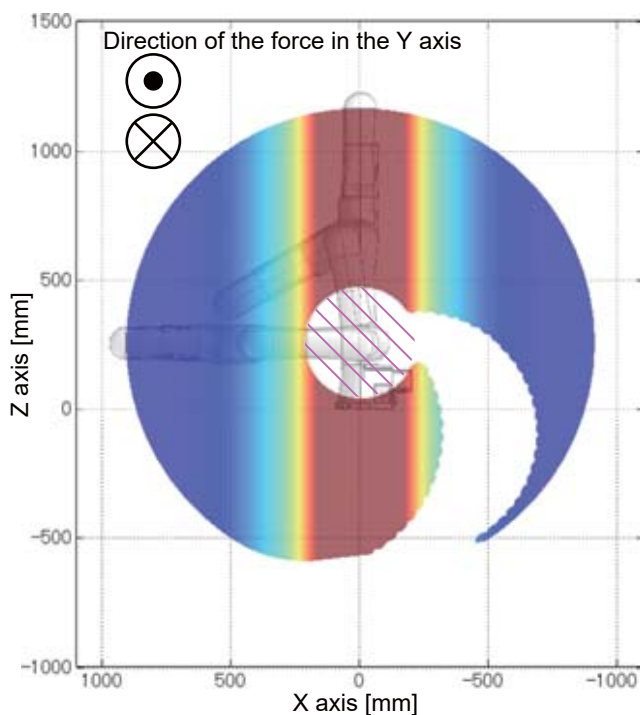
The difference in the size of the force required for a collision to be detected (which changes depending on the direction and posture of the robot) is shown in the following figures.



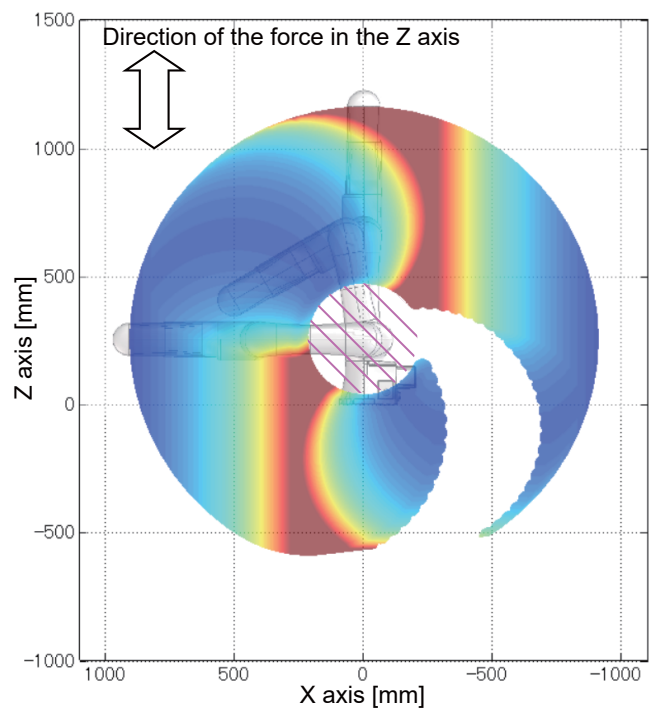
(a) Direction and point of collision



(b) The size of the force required for a collision to be detected in the direction of the X axis



(c) The size of the force required for a collision to be detected in the direction of the Y axis



(d) The size of the force required for a collision to be detected in the direction of the Z axis

Figure (a) indicates the direction of the collision and the point of impact.

The colors in figures (b) and (c) indicate the size of the force required for a collision to be detected by the STR function. The force required for a collision to be detected increases as the color changes from blue through to yellow, then yellow through to red. The arrows and symbols in the figures indicate the direction of the force generated upon impact.

For further information on the figures above, refer to the following.

☞ Page 57 Collision detection sensitivity in relation to the position and posture of the robot

Even if a collision occurs at the same place on the robot arm on separate occasions, the force required for a collision to be detected differs depending on the direction of the force. For example, a large force is required for a collision to be detected when the robot moving in the direction of the X axis with its arm extended. Similarly, a large force is required for a collision to be detected when the robot arm is moving in the direction of the Z axis in front of the lower base.

General speaking, if the robot can detect small collisions, it should be able to suppress small collision forces by immediately stopping the movement of the arm after the collision has been detected. Understanding what impact the direction of the collision and the robot's posture has on the ability for the STR function to detect a collision is essential. This should be understood before planning the operation of the robot or conducting risk assessments. Logically, the STR function cannot detect a collision if the collision is in the direction that the arm is pointing in and the arm cannot move any further than its current position. Therefore, it is important to thoroughly consider what effects the robot's operation range and its movements will have upon safety in order to reduce risk to a minimum.

The STR function is also affected by joint friction. Friction can adversely affect how the force generated from the collision is transmitted to the sensors and is attributed to decreased sensitivity in collision detection. Friction substantially increases if the grease in reduction gears becomes cold. This can occur if robots are used in cold temperatures (during winter or in refrigerated facilities) or after they have been stood for a while. Use of the wrong grease and grease degradation is also attributed to increased friction. Measures to prevent friction from increasing due to the points mentioned above should be implemented.

Collision detection sensitivity in relation to the position and posture of the robot

This section provides information on collision detection sensitivity. Note the following points when referring to figures (a) to (d).

- Figures (b) to (d) indicate the force required for the STR function to detect a collision. The values in the figures are theoretical. These values may fluctuate depending on friction and the circumstances the robot is being used in. To gain a better understanding of the collision forces that may occur in a robot system, we recommend taking measurements in the environment that the robot will be used in.

Theoretical values shown in the figures were calculated under the following conditions.

- The collision point is set to the center of the J5 axis as indicated in Figure (a). The arrows indicate the direction of the collisions. The direction of the X axis is pointing out in front of the J1 axis, while the J2 axis is at 90° and all other axes are at 0°. The X coordinate rotates about the origin of the J1 axis. Therefore, the position of the J1 axis does not affect the information in figures (b) to (d). Because the collisions occur in the center of the J5 axis, torque is not applied to axes J4, J5, or J6. A collision may occur at a point in front of the J5 axis when the robot is used in a real-world situation. (For example, when a hand is attached to the mechanical interface.) Collisions can be detected through torque differences generated in the J4, J5, and J6 axes. However, collision detection from these axes is greatly affected by factors such as the posture of the robot and the size of the hand. The figures show the different forces required for a collision to be detected within the operating range of the robot. The data presented in these figures is therefore limited to axes J1, J2 and J3.
- The effects of joint friction are not taken into account. Joint friction may prevent torque generated in a collision from transferring to the motors properly, contributing to a reduction in collision detection sensitivity.
- The origin of the coordinates in figures (b) to (d) is the origin of the robot base coordinate system (the area where the base of the robot intersects with the center of the J1 axis). The center of the J5 axis is represented in the figures. Therefore the position of the origin needs to be changed in order to apply these results to the TCP. Areas where the J5 axis cannot reach due to it interfering with the base of the robot are also indicated in the figures.
- The results in the figures are based on the amount of force required for the torque difference to exceed the threshold set in the STR function from a torque difference of zero. In the real world, torque difference could be in positive or negative values just before a collision. Whether torque difference increases or decreases depends on how the robot is moving at the time of the collision and what direction the robot is traveling in. Even if the torque difference is in a positive value, it may decrease with the impact and exceed the negative threshold value. As such, the change in torque difference in situations where torque difference moves from a positive value to negative value that exceeds the negative value threshold, is larger than when torque difference exceeds the threshold (in positive or negative values) from a torque difference of zero. This means that in these situations the values for the force required for a collision to be detected are larger than those in the figures.
- Figures (b) to (d) indicate the amount of force required for a collision to be detected by the STR function. The robot will slow down once a collision has been detected, but will not come to a sudden stop. This gradual slow to a stop absorbs some of the force of the impact, so the actual force of the impact will be larger than the amount of force detected.
- In figures (b) to (d), blue represents places on the arm that require small forces for a collision to be detected. The colors yellow through to dark red represent places on the arm where large forces are required for a collision to be detected. Blue represents a force below a certain value and dark red represents a force above a certain value. Be aware that within these two colors, the same color can represent both large and small forces. The closer to a singularity, the larger the value is.

- The movement of the J3 axis is evaluated when the axis moves between 0° and a positive value. The dispersion of the force when the J3 axis is in a negative position is reflected in the YZ plane.

Refer to "Safe torque range function (STR)" in the following manual for further details.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

Power and force limiting (PFL)

Power and force limiting is used in some of the following ways to reduce risks attributed to quasi-static and transient collisions.

1. The SLS function is used to keep the speed of the robot below a predetermined speed during collaborative operation.
2. The STR function is used to detect collisions.
3. The SS1 function is used to stop the robot after a collision has been detected by the STR function.

Using these functions helps to limit the amount of stored energy in the robot arm, stop the robot quickly when a collision occurs, and prevent the energy from the robot arm transferring into the person/object involved in the collision.

However, because not all of the energy can be prevented from transferring between the person involved in the collision and the robot, a force from the collision will still be generated.

The points mentioned below cumulatively effect the size of the collision force.

- The mass of the robot arm (including the weight of any devices, hands, or workpieces)
- The point of impact of the robot arm, as well as the position and posture of the arm
- The direction of the collision
- The relative speeds of the robot arm and the person/object involved in the collision
- The surface area or shape of the robot arm and person/object involved in the collision
- The hardness of the object or the area of the human body involved in the collision
- The mass of the person/object
- Whether the person or object is static, or has become trapped during the collision
- Factors that affect friction on the robot joints (surrounding temperatures, robot operation status, etc.)

Due to other factors (not attributed to the robot) that affect the force of the collision, the robot functions alone cannot sufficiently reduce all risks associated with collisions. Think carefully about the risks that may arise during a collision and devise suitable measures against them. This includes risks applicable to surrounding personnel as well as the robot system.

In regards to working with collaborative robots, ISO/TS 15066 stipulates regulations not only on force, but on pressure too. Please consider whether any parts that may come in contact with a human during a collision may cause injury due to their size (e.g., if they are too small). As a rule of thumb, pressure must be considered for any area of the robot that may come in contact with a human that has a diameter of less than 1.5 cm. Refer to the residual risk map or the residual risk table in this manual for information on hazardous parts of the robot.

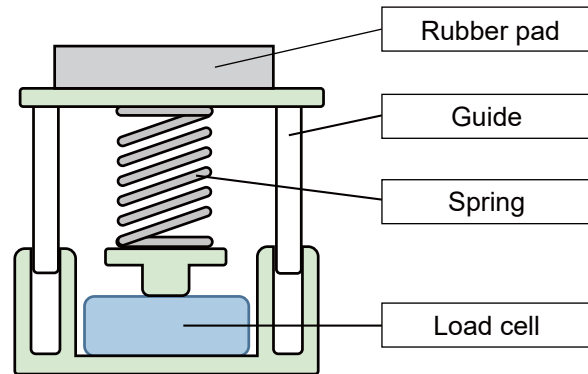
Under conditions where sensors that use the STR function cannot detect a collision, the amount of force generated during an impact may be more than if the function had detected the collision. For further information, refer to the explanation of the STR function on the following page:

 Page 26 RESIDUAL RISK (SPECIFIC TO EACH FUNCTION)

In order to reduce the force at the time of contact, consider the various factors and operating conditions in the robot system, taking into account the factors that affect the contact force described above. It is effective to keep the speed low. If the PFL cannot sufficiently reduce the risk during operation, a safety sensor such as a laser scanner or light curtain can be used to detect the approach of a human to the robot, Stop the robot or introduce a protective fence to isolate people from the robot.

Robot power and force limiting (PFL)

The robot's power and force limiting capabilities have been tested and checked using the conditions in the following table. A force-measuring device such as the one in the following figure is used to measure force in the test.



The robot impacted the force-measuring device in the X, Y, and Z directions shown in "Fig. a" under the conditions stated in the table below. The data was then checked to see if the collision forces exerted in the impacts were within the permissible values of ISO/TS 15066.

Direction of collision	Body part collided with (assumed)	Permissible value (transient/quasi-static) [N]	Spring rate [N/mm]	Rubber pad	Collision point (x, y, z) [mm]	Weight [kg]	Status	Collision speed [mm/s]
X	Back/shoulders	420/210	35	A30	(500, 0, 0) (500, 0, 750) (700, 0, 350)	—	Fixed	50
						40	Free	250
Y	Back/shoulders	420/210	35	A30	(700, 0, 350)(400, 0, 350)	—	Fixed	50
						40	Free	250
Z	Hand/fingers	280/140	75	A70	(600, 0, 150)(600, 0, 500)	—	Fixed	50

The test was conducted with a 5 kg load placed or without load in the hand. The impact points were in the center of the J5 axis. Collisions in the X and Y directions are performed to replicate collisions with the upper body (back/shoulders) where there is a lot of weight, increased pressure on the spring of the force-measuring device, and large transient forces. The collision in the Z direction is performed under test conditions replicating situations where fingers or hands are being trapped. Verification of contact force is based on ISO / TS 15066 and DGUV-Information Collaborative robot systems Design of systems with "Power and Force Limiting" function, Issue 08/2017, Translation of the German version, FB HM-080. However, in FB HM-080, the peak value was measured with the measuring device fixed to confirm the transient contact force, but in our verification, the measuring device was mounted on a freely movable dolly. This is based on the assumption that in ISO / TS 15066, in the case of transient contact, the person to be contacted moves by contact, but the conditions of the FB HM-080 where the measuring device is fixed. In this case, the force of the measurement results is expected to be large, and it is expected that the verification results will be quite conservative.

2.9 Safely-limited speed function (SLS) for automatic speed adjustment

For details, refer to the "Safely-limited speed function (SLS)" in the following manual.

Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

2.10 Status display

The collaborative operation status of the collaborative robot is required to be informed to people around. The Status indicator LED on the robot arm indicates the status of the robot by a mixture of flashing and solid lights. For further information, refer to "Status indicator LED" in the following manual:

 RV-5AS-D Standard Specifications (BFP-A3727)

Status indicator lights can also be connected to the safety output of the Safety extension unit or the Parallel I/O interface (option) to display the status of the robot when it is in Collaborative operation mode.

For the settings of collaborative operation status display with the safety output of the safety extension unit, refer to the "Safety Output" in the following manual.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

For the settings of collaborative operation status display with the output signal of the parallel I/O interface, refer to the "Dedicated Output" in the following manual.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

2.11 Safety Input

Refer to "Safety input setting" in the following manual for details.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

2.12 Parameters and status variables

Refer to the following manual for details.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

2.13 Recovery mode

Occurrence of SLP or STR errors can be suppressed in the recovery mode.

If the error triggered by the safely-limited position function (SLP) occurs, an error will occur immediately after servo-on. Therefore, errors in jog operation or others cannot be eliminated. With the teaching pendant, temporarily stop the safety monitoring functions. Thereby, the recovery mode that allows jog operation is available.

In the initial settings, the dedicated output for the recovery mode is available for the robot.

1. Change the controller mode to MANUAL.
2. Set the Enable switch of the teaching pendant to ENABLE.
3. Press the [JOG] key to display the JOG screen.

Point

When force sense control is used, you can use recovery mode using the Force sense function screen (accessed from the JOG screen).

4. Lightly hold the Enable switch (3-position switch).
5. Hold down the relevant key.
When using the R32TB: [RESET] key
When using the R56TB: [CAUTION] key
6. Press the [SERVO] key to turn the servo on.
7. Move the robot using Jog operation.

Completing these steps temporarily clears all errors.

Recovery mode can be disabled using any of the following methods:

- Releasing the [RESET] key or the [CAUTION] key.
- Setting the Enable switch of the teaching pendant to DISABLE and changing the controller mode to AUTOMATIC.

- Displaying the JOG screen or a screen unrelated to the force sense function. (This method will only work for the RT32TB.)

Precautions

Errors will still occur after recovery mode is disabled if they have not been resolved.

Press and hold the [RESET] key or [CAUTION] key when moving the robot in Jog operation mode.

For details on the recovery mode, refer to "Recovery mode" in the following manual.

 Robot Safety Option Instruction Manual (BFP-A3531)

The recovery mode suppresses the occurrence of the following errors.

Function	Error code	Description
SLP	H220x	SLP (Position error:CMD Plane) SLP (Position error:FB Plane) SLP (Position error:CMD Area) SLP (Position error:FB Area) SLP (Joint error:Cmd) SLP (Joint error:FB)
STR	H221x	STR (ROBOT torque error)

Errors will not occur in the following functions.

Error cause	Function
Position	Narrow angle/Wide angle limit Joint movement/XYZ movement range limit ABS limit Interference avoidance User-designated area Free plane limit
External force	Collision detection Error notification upon excess of permissible limits in the force sense control
Signal	FLS/RLS signals Hand error input Hand pneumatic error input

2.14 How to release the brake of the robot

To perform troubleshooting or maintenance by releasing the brake of the robot or moving the robot joints, refer to the following manual.

CAUTION

The robot arm may fall under its own weight depending on which brake is released or how the robot is configured. Take steps such as supporting the arm to prevent it falling under its own weight.

Releasing the brake by using the emergency power supply

For details on the method of releasing the brake by using the emergency power supply, refer to the "How to release the brake in an emergency" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

Releasing the brake by using the teaching pendant in the servo OFF status

For details on the method of releasing the brake of the servo motor in the servo OFF status by using the teaching pendant, refer to "Operation of the origin and the brake screen" in the following manual.

 Instruction Manual: Detailed explanations of functions and operations (BFP-A3478)

Releasing the brake by using RT VisualBox

For details on the method of releasing the brake by using RT VisualBox, refer to the following manual.

 RT VisualBox Instruction Manual (BFP-A3696)

2.15 Error information

For information on errors, refer to the following manual.

 Instruction Manual: Troubleshooting (BFP-A3480)

3 PROCEDURES AND SAFETY CONSIDERATIONS IN EACH OPERATION

This section refers to the general precautions in each operation from unpacking to trouble shooting of robot system. Prior to the actual use of a robot, be sure to read relating items in the attached operation manual together with this safety manual.

3.1 Unpacking

- When unpacking the robot and robot controller, refer to the procedures in the manuals stated below.
- Do not hold the robot by its cover when removing the robot from its packaging.
- After unpacking the robot, keep the support bracket and packaging in a safe place so that the robot can be moved to a new location in the future if necessary.

For details on taking out the controller, refer to the "Unpacking procedures" in the following manual.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

For details on taking out the robot, refer to the "Unpacking procedures" in the following manual.

 RV-5AS-D Standard Specifications (BFP-A3727)

3.2 Carrying

- Confirm the weight on the rated nameplate before transporting the robot arm.
- Use two people to move the robot. Carry the robot supporting it from the base.
- When transporting the robot by suspending the robot with a crane, use wire ropes that sufficiently withstand the robot weight. Always check that the robot has been fixed to the wire ropes before transporting the robot. The robot does not have eye bolts. Make sure to fix the wire ropes to the robot in a reliable manner. Moreover, secure the arm joints so that they do not move under the own weight.
- Many resin covers are used on the exterior surface of the robot. Never hold these parts and never apply forces to them. If you carry the robot by holding these covers, that may cause hazards of damaging covers and eventually dropping the robot.
- When putting the robot on an installing base temporarily, fix the robot with one or more bolts to prevent from falling down.
- When putting the robot or the controller on an installing base or a pushcart, don't apply an excessive shock and an excessive vibration to the robot and the controller.
- Transport the controller by inserting your hands into the gaps at the bottom of the controller from the front and rear sides. Do not apply excessive force to switches, terminal blocks, or connectors, etc.
- Before moving the robot to a new location, put the robot back into the posture that it came in from the factory and re-attach the support bracket to the mechanical interface. Then, secure the robot in the packaging that it came in.

For details on transporting the controller, refer to the "Transportation procedures" in the following manual.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

For further information on the transportation of the robot, refer to "Transport procedure (with two people)" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

3.3 Preparation of installation and operation

Robot arm, controller and control panel

- When installing the robot arm, secure the area required for the work based on the layout design before-hand. At the same time, provide a sufficient clearance so that the robot's movable sections and periphery do not catch or collide. If the robot requires the origin to be set, make sure that there is no interference with the periphery in the origin setting posture.
- If the operating range needs to be set narrower by limiting the movable range of the arm, install the robot by considering the coasting distance before the robot stops and sufficient reliability.
- Install the controller and control panel starting device where the entry of operators in the safety protection region can be confirmed from the operator control position.
- If the working areas of robots overlap each other, provide interlock functions to prevent the robots from simultaneously entering their common area. (position detecting switches, etc.)
- When the safeguarding methods are not in place prior to commissioning and functional testing, interim means of designating the restricted space must be in place before proceeding.
- When it is intended that operators will perform manual operations associated with the robot, such as loading and unloading of parts, this must be taken into account in the arrangement of the robot system, either by providing loading devices so that the operator cannot access the hazardous area, or by providing appropriate safeguards for the manual activity.
- Securely fasten the robot to the specified installing surface with four fastening bolts being careful to prevent deviation of the position. The installing base requires enough stiffness to withstand the weight of the robot and the reaction force.
- Remove the support bracket once the robot has been installed.
- Install the controller outside the safety protection region (outside the safety fence). Install the controller's operation panel so that the operator can monitor the robot without facing his/her back to the robot, and at a height where the panel can be operated easily. (For maintenance workability, set the operation panel height at 0.6m or more.)
- Install the controller on a level surface. Be sure not to prevent the heat fin from radiating heat and the fan from ventilating hot air. The ambient temperature of the controller must be within the rated range.
- If the controller must be fixed to prevent dropping or movement, etc. from external vibration, always fix on the base surface. (Do not remove the rubber legs.)
- When installing the robot, the controller and the peripheral equipment, take mens of access into account to allow access in safety to all areas used for production, adjustment and maintenance operations.
- Do not get on or hang from the robot.
- Do not get on or place heavy objects on the controller.
- Make sure that foreign matter does not enter the robot arm or controller. Entry of conductive matter such as screws or metal pieces, or the entry of flammable matter such as oil could lead to ruptures or damage, etc.

For details on installing the controller and installing option devices to the controller, refer to the "Installation procedures" and the "Installing the option devices" in the following manual.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

For details on installing the robot and connecting option devices to the robot, refer to the "Installation procedures" and the "Installing the option devices" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

Cables

- Tighten the connectors of the cables between the robot and the controller according to the instructions of the manual.
- Don't pull or bend the cables with force. Protect the cables with ducts or covers if necessary. Tighten all the screws and fastening mechanisms of cable connectors. Otherwise, the cables may come loose during operation.
- When installing ducts or covers, means should be taken to prevent persons from stumbling, and caution signs should be indicated necessary. Do not step on cables or allow them to get damaged.
- Keep the robot machine cables and the external I/O cable away from other cables such as power cables and earth lines. Be sure that the external I/O cable is shielded. Only apply voltages that are specified in the Instruction Manuals to terminals. Otherwise, the terminals will be damaged.

- Do not mistake the terminal connections. Otherwise, the terminals will be damaged.
- Do not mistake the polarity (+, -). Otherwise, the terminals will be damaged.
- The machine cables may be broken if the robot is moved on the travel axis, etc. Do not use the robot installed on the travel axis, etc.
- Before connecting the power source line, be sure that the voltage of the power is within the rated range and the power switch of the controller is off. Then connected to the correct portion.
- Do not connect or disconnect the cables or connectors while the power is ON.

For details on connecting the power cable to the controller and connecting to the robot, refer to the "Connecting the power cable and grounding cable" and the "Connecting to the robot arm" in the following manual.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

For details on connecting the controller and the robot, refer to the "Connecting with the controller" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

For details on connecting the safety extension unit to the controller, refer to the "Installation and connection" in the following manual.

 Robot Safety Option Instruction Manual (BFP-A3531)

Hands

Be careful of the following points when using a hand. Even if the robot collides with something and the operating speed is safe, a dangerous situation may occur depending on the shape of the hand or how the hand grasps a workpiece. Conduct sufficient risk assessments before using a hand.

- When attaching a hand, always follow the instructions. Be sure that the total weight including workpieces is within the rated load.
- If necessary, attach the specially machined picking tool to the end of the hand according to the shape of workpieces. Be sure that the tool has no sharp edges nor projections except functionally necessary portions.
- When fixing a customer-made hand, be sure that the total weight including workpieces is within the rated load. Especially, when fixing an unbalanced hand, the rated torque of the wrist axes should also be taken into account.
- When attaching a customer-made hand to the flange of the robot, size it securely with specified bolts. Be sure that the hand has no sharp edges nor projections except functionally necessary portions, and provide covers and other protections as necessary.
- If cables and hoses are connected to the hand, prevent cables and hoses from getting twisted round or damaged and from restricting the motion of the robot.
- When using a pneumatic hand, supply clean air at the specified pressure. Use an air pressure of up to 0.54 MPa [5.5 kgf/cm²]. Using an air pressure greater than this may damage the air pipes.
- If there is the possibility of a hand releasing a workpiece during motion thus causing a hazardous conditions, necessary means should be taken for the gripping mechanism of the hand to prevent such hazards.
- The hand must be designed and constructed so that power failure does not cause release of the load or result in a hazardous condition. If the hand needs to be kept open or closed in instances where the power is interrupted, use a hand with a double solenoid or a self-locking electric hand.
- Grasping a workpiece charged with static electricity could cause malfunctioning due to electrical-discharge through the hand and robot arm. Thus, always use an insulated structure for the hand and robot arm. When a charged workpiece is placed, the device on which is it placed could malfunction due to the electrical-discharge. Always structure the system so that the charged workpiece's charge is discharged with an appropriate electrical-discharge route.
- The power supply for the hand and sensors is supplied to the hand cable of the robot. If the cable end cannot be treated sufficiently due to this, the end could contact the peripheral device or robot arm while the power is turned ON, and could lead to short circuit accidents. Thus, always treat the end when using the hand check cable.
- Devise a way to release the grip of the hand when power is not being applied to it so that hands/fingers can be released immediately and safely if they become trapped. Inform workers of how to release the hand in such situations.

Operating device

Computer and tablet computer

- When operating the robot using an operating device without an emergency stop switch, such as RT VisualBox installed on the computer, make sure to install an emergency stop switch nearby.

Teaching pendant

- Tighten the connector of the teaching pendant cable. Don't pull or bend the cable with force.
- Determine the area where the teaching pendant is stored, and prevent the pendant from being carelessly dropped thus causing malfunction or damage.

Operation buttons

- Accidentally pressing the wrong operation button on the robot arm while the robot is operating may cause the robot to malfunction or unexpectedly come into contact with the user. Only use the operation buttons while the robot is not in operation.
- Be careful when starting programs via the operation buttons as the arm will start moving immediately after the program starts.
- Some movements, the movement of the J4 axis for example, may suddenly speed up as the arm nears a singularity. Take care when moving the robot arm during direct teaching or hand alignment.
- The operation buttons may not be visible depending on the posture of the robot and where you are positioned. Do not reach for the buttons blindly. Doing so may cause unintended operation. Before pressing a button, check that it is the button you intend to press.
- Before opening/closing the hand with the [HAND] button, ensure that doing so will not cause workpieces to fall or fingers to become trapped.

Operating device using external inputs and outputs

- When an emergency stop switch is wired to a control panel and the robot is started or stopped using the external inputs and outputs of the robot, install the operating device in the following location: outside the safeguarded space, where operators can check whether no one is in the safeguarded space and always monitor the robot without turning around, and at an easily accessible height.

Grounding

- Be sure to ground the robot and the controller electrically according to the instructions of the manual. The grounding is indispensable to prevent electric shock, to reduce electrostatic charges, to improve electric noise resistance, and to reduce electromagnetic interference.
- Use a wire of more than 2 mm² in cross section, and make its length as short as possible.
- The robot and the controller should be grounded separately. Keep the ground points away from those of other large electric equipment.

For details on grounding the robot, refer to the "Grounding procedures" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

Emergency stop

- Install a manual emergency stop switch at a location near the robot where it can be easily operated and connect it to the external emergency stop terminal of the controller. (NC contact, provided with a mechanical lock function. Compliant with IEC 60204-1 specifications.) When there are multiple installation places, install multiple switches. Refer to the instruction manual for the electrical specifications.
- Install a switch on the safety protection devices, such as the guard door. Provide an interlock mechanism so that the robot will enter the emergency stop state if the switch is activated. (Example: The emergency stop state is entered when the guard door is opened during robot operation.)
- In the case of the complex robot system designed to work together, emergency stop devices should stop not only the robot

itself but also all relating equipment if its continued operation can be dangerous. In this case, for example, an emergency switch that has more than one contacts is desirable.

- When operating the robot using an operating device without an emergency stop switch, such as RT VisualBox installed on the computer, make sure to install an emergency stop switch nearby.
- In an emergency stop, acceleration occurs while the robot is decelerating quickly. Thereby, the object in the hand may pop out, objects not secured to the robot may fall, or other issues may occur. To prevent this, carefully design hands and take protective measures including securing objects.

For details on connecting external emergency stop inputs and outputs, refer to "Emergency stop input and output etc.", "Connecting the external emergency stop and mode selector switch", and "Examples of safety measures" in the following manual. Use a 2-contact type emergency stop switch and duplicate the wiring to the emergency stop input of the robot controller.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

Safety stop

- Install the stop switch near the robot where it can be operated easily. Connect it to the external input/output terminal on the controller. When there are multiple installation places, install multiple switches. Refer to the instruction manual for the electrical specifications.
- Do not install the stop switch on the safety protection devices, such as the safety fence door. Install an emergency stop switch on the safety protection device
- Collaborative operation mode negates the risk of collision. However, there is a risk of collision if the robot suddenly moves while it is in High-speed operation mode. Before entering a safeguarded space, check that the safety sensor prevents the robot from moving, or that the robot enters Collaborative operation mode when somebody enters the safeguarded space.
- The STR function stops the robot as soon as the robot is touched. However, check in advance whether touching the robot is risky as the danger depends on the robot system and operating conditions.

For details on the special stop input, refer to "Special stop input (SKIP)" in the following manual.

 RV-5AS-D Standard Specifications (BFP-A3727)

Also refer to "Dedicated input/output" in the following manual.

 Instruction Manual: Detailed explanations of functions and operations (BFP-A3478)

Indicators

- A status indicator LED is located on the forearm. The color and behavior of this LED indicate the operation status of the robot. If the user decides that the Status indicator LED is not sufficient enough, use an indicator light or other method so that workers can easily check the status of the robot. (For example, if the robot is running, has stopped, or has an error.) For this purpose, use the dedicated I/O bits of the controller. (e.g. run, wait, reset, error)
- Under certain lighting, the colors of the Status indicator LED may become difficult to distinguish. Ensure that this does not result in unintended operation.
- Where the risk may arise by a fault in the operation of unsupervised machinery, the machine must be equipped to give an appropriate acoustic or light signal as a warning.
- When the robot is operated at high speed without a guard, a safety sensor must be used to detect presence of a human. When a human is in the safeguarded space, the robot must be in collaborative operation. Display the status of the robot so that a person can find easily whether the robot is in high speed operation or collaborative operation because contacting the robot in high speed operation is dangerous.

For details on external input/output signals for displaying the status of the robot, refer to "Dedicated input/output" in the following manual.

 Instruction Manual: Detailed explanations of functions and operations (BFP-A3478)

Also refer to "Dedicated output" in the following manual.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

For information on the behavior of the Status indicator LED which indicates the operation status of the robot, refer to "Status indicator LED" in the following manual:

 RV-5AS-D Standard Specifications (BFP-A3727)

Isolation of power sources

- Each robot system must have means to isolate each of its power sources by manual operation.
- Isolation must be either visible (visible interruption of continuity in the power supply) or visibly ensured by permitting a check of the position of the operating control on the isolating unit, and it must be made clear which areas of the machine are isolated.
- If necessary, means should be taken to lock the isolation device in the 'OFF' or 'OPEN' position to prevent careless operation.
- If power is shut off to the system, the operating axes without brakes may move by its own weight. If the axes interfere with peripheral devices or other issues occur, to ensure safety, use brakes and then shut off the power.
- When the power to the robot is shut off, the hand, etc., may drop slightly from the time that the power is shut off to when the brakes activate. If there is any risk of interference, etc., with the peripheral devices, set the robot to a posture where a hazardous state will not be created before shutting off the power.
- If the robot is stopped by a power shut-off, acceleration occurs while the robot is decelerating quickly. Thereby, the object in the hand may pop out, objects not secured to the robot may fall, or other issues may occur. To prevent this, carefully design hands and take protective measures including securing objects. To prevent any dangerous situations arising from the object popped out from the hand due to a power shut-off, carefully design the hand and take protective measures to surroundings.

Applying power

- Before turning on the power, check whether no body is in the safeguarded space of the robot. If a human is in that space, check that the robot is in collaborative operation, safety sensors are operating properly, or no risk is present. Moreover, check whether the current situation is the same as when risk assessments were performed. For example, check that unnecessary tools or devices do not exist.
- Verify that the cables, hoses, and connectors are not damaged nor disconnected nor loose.
- Verify that the workpiece and the peripheral equipment are positioned as specified. Also verify that applying power to peripheral equipment does not result in hazardous motion.
- If some sequence in applying power to peripheral equipment may cause a hazardous condition, obey the safety sequence specified in advance. (The situation is the same as in the power shut down.)
- After applying power, be sure to verify that emergency stop devices and other safeguards are functional. If the movement of the robot is set to vary according to the output of safety protection devices such as safety sensors, check that the robot moves according to the settings.
- Verify that each axis of the robot moves functionally by job operation and is restricted in motion as intended.
- Do not open the cover or door of controller, after turning on the power supply.

3.4 Teaching and programming

- It is recommended to teach the robot outside the safeguarded space whenever possible for safety reasons. Before working within the robot operating range or in the safeguarded space such as for teaching the robot directly, prepare and follow working regulations. The following items shall be included in the working regulations.

Operation method and procedure, including authorization of operator and suspension procedure of safeguards

Robot speed during operation (Jog operation is used in principle, automatic operation is forbidden, or speed as low as possible is used even in collaborative operation)

Signaling method for several workers

Measure for emergency

Measure to prevent malfunction

- When starting the robot by selecting "Operation" in the teaching pendant, computer, or operating device, do not start the robot in a safeguarded space such as inside a guard, or until you make sure that the robot starts in collaborative operation and does not operate dangerously.
- If performing teaching work inside the safeguarded space, always ensure complete control over the robot beforehand. (When using the teaching pendant, always use "MANUAL mode" for the mode selector switch connected to the controller (supplied by customer) and set the Enable/Disable switch of the teaching pendant to "Enable".) Failure to do so could

cause a very dangerous state as the robot could start with external commands. When ensuring complete control over the robot by using a computer, make sure to check the actual robot and its surroundings.

- When a key-type mode selector switch is prepared by customer and connected to the controller, when teaching, remove the key so that no one other than the teacher can change the mode.
- When the Enable/Disable switch of the teaching pendant is set to "Enable", holding down the Enable switch (3-position switch) on the back of the teaching pendant will turn ON robot servos, or releasing (or firmly pressing) the Enable switch (3-position switch) will turn OFF robot servos. If the Enable/Disable switch is set to "Disable", the Enable switch (3-position switch) will not operate. When performing tasks that require turning ON robot servos, such as teaching the robot in the safeguarded space, always set the Enable/Disable switch to "Enable" and hold down the Enable switch (3-position switch). When performing tasks that can be done with robot servos OFF, such as modifying programs, or if a dangerous situation arises during the teaching process, release (or firmly press) the Enable switch (3-position switch) to turn OFF robot servos.
- Suppress any device movement that could cause a hazard in the safety protection area, or make sure that only the teaching operator can control the device.
- Assign a monitor during the teaching work so that the robot operation can be stopped immediately if any abnormality occurs. Make sure that the operators, other than the teaching operator, inside the safety protection area have a portable emergency stop switch. When operating the robot using an operating device without an emergency stop switch, such as a computer, make sure to install an emergency stop switch nearby.
- Maintain sufficient illumination to produce an easy-to-work environment for the operators.
- The teachers of the robot must wear clothes properly, and put on safety shoes and a helmet if necessary.
- As an emergency countermeasure during teaching, don't face your back toward the robot, and be sure to maintain a passage to shelter.
- The programmer must return the suspended safeguards to their original effectiveness prior to initiating automatic operation of the robot system.
- If programs are changed, always notify robot users and other workers of the program change before the robot is operated. Otherwise, the robot may move unexpectedly, causing a dangerous situation such as a collision.
- After completing the teaching work, validate and safety protection devices that were temporarily invalidated, and recovery the original function. (Example: Validate the door interlock of the guard, etc.)
- If high speed operation is set to be triggered by the input of devices such as safety sensors, make sure to consider and check under what conditions the robot operates in high speed operation. This is because if a worker teaches the robot in areas where continuous operation is not performed, the safety sensor may not detect the worker, causing the robot to start operating at high speed unexpectedly.
- Some movements, the movement of the J4 axis for example, may suddenly speed up as the arm nears a singularity. Take care when moving the robot arm during direct teaching or hand alignment.

3.5 Program verification

- After teaching and programming, check the movement of the robot using a simulation on a computer, the operation with step operation, and lower the override sufficiently to operate the robot at low speed before starting automatic operation.
- When confirming the operation inside the safety protection area, follow the predetermined work procedures in the same manner as the teaching work.
- When a peripheral device is to start in synchronization with the I/O signal from the robot during the confirmation, take special care to the operation. As with teaching operation, suppress any device movement that could cause a hazard in the safety protection area (inside the safety fence), or make sure that only the operator can control the device.
- When starting a program in the middle, be sure to avoid collision between the robot and the peripheral equipment.
- If a job program is long or complicated, check the movement of the robot using a simulation beforehand. Print out the program and fully understand the sequence in the program before checking the operation.
- In a simulation of the movement of the robot, check whether monitoring points have been created and there are any differences between the actual robot and the simulation model.
- Note that there may be differences in movement between the test operation after the override has been lowered or step operation and high speed operation due to a difference in the input and output timing of peripheral devices or a change in the trajectory arising from high speed operation.
- Be careful when starting programs via the operation buttons as the arm will start moving immediately after the program

starts.

For the method of checking the movement of the robot, refer to the "Confirming the operation" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

For the method of checking the movement using signals connected to the safety inputs and outputs in the safety logic function, refer to the "Checking operation of the safety inputs and outputs" in the following manual.

 Robot Safety Option Instruction Manual (BFP-A3531)

For the method of checking the movement using the safely-limited speed function (SLS) and the safely-limited position function (SLP), refer to the "Operation check" in the following manual.

 Robot Safety Option Instruction Manual (BFP-A3531)

3.6 Automatic operation

- Before initiating the automatic operation, ensure that there are no exposed persons in the safeguarded space. If it is impossible, the control system must be designed and constructed so that a warning signal is given whenever the machinery is about to start. The exposed person must have the time and the means to take rapid action to prevent the machinery from starting up. (Example: Installing an emergency stop switch or others inside the guard.) When using the system for collaborative and non-collaborative operation, which is designed to prevent any risk if the robot operates while a human is in the safeguarded space, be careful of the following point: Before starting collaborative and non-collaborative operation, safely check that every safety function and safety protection device operates correctly and there is no problem.
- Before initiating the automatic operation, be sure that all peripheral equipment is functional and there is no signals indicating malfunction.
- Always start automatic operation outside the safety protection area. Even when resuming operation by resetting after stopping the robot with emergency stop, etc., during automatic operation, always start outside the safety protection area.
- Before starting automatic operation, always confirm that the work details and selected program match. Use low-speed operation, when possible, until the first cycle ends. The speed override change function changes the speed.
- If any abnormality is observed in the robot or peripheral devices, stop the operation immediately. Note that if a new risk is posed due to the position where the robot is stopped, etc., take care to the timing for stopping the robot. In this case, do not stop the robot by touching it. Always use the stop switch or emergency stop switch on a control device or others. Risk of contact between humans and the robot can be reduced by controlling the robot. However, the robot may not be controlled properly due to an error. Never touch the robot while the error is occurring.
- If the robot stops due to an unknown cause during automatic operation, avoid approaching the stopped robot. When the robot must be approached, input the emergency stop, or turn the main power off first. When turning the main power off, make sure that there will be no new risk caused.
- When halting and resuming the program during automatic operation, make sure that there will be no new risk with the peripheral device when the program is started. (Adequacy of work start position, necessity of peripheral device initialization, etc.)
- When the program is interrupted during automatic operation and a change is made to the program or position data, always perform the test operation before resuming automatic operation.
- When selecting a different operation speed with the speed override change function during automatic operation, make sure that there will be no new risk caused. Risk may arise when the operating speed is too fast or too slow.
- If a held workpiece or other object may fly out and cause a hazard by the centrifugal force during automatic operation or by the impact force of an emergency stop, suitable means must be taken to prevent such hazard.
- In an emergency stop or at power shut-off, the movable parts without brakes may fall depending on the posture of the robot. Also, when speed of the robot is fast, even the axis with a brake may not stop immediately because of its remaining power of speed. Prevent the hand from conflicting with peripheral equipment.
- If the robot collides with a workpiece or the peripheral equipment at high speed due to e.g. a program error, then the workpiece, the peripheral equipment, the robot arm, and the reduction system of the robot may be considerably damaged. To avoid the hazardous condition caused by the collision, particular attention should be paid to assess the risks.
- Be careful when starting programs via the operation buttons as the arm will start moving immediately after the program starts.

3.7 Maintenance

- Where possible, maintenance of the robot and peripheral equipment should be performed from outside the safeguarded space.
- When operations from outside the safety protection area are not possible and the fence must be entered, as a general rule, turn the power off first. At this time, make sure that no new risk will be caused by turning the power off.
- When work must be carried out inside the safety protection area without turning the power off, always secure the priority right for the robot control. When using the teaching pendant, always use "MANUAL mode" for the mode selector switch connected to the controller (supplied by customer) and set the Enable/Disable switch of the teaching pendant to "Enable". When using a control device with which modes cannot be switched, such as a computer, ensure complete control over the robot and establish communication between the controller and the computer using a LAN cable suitable for the communication before entering the safeguarded space. Failure to do so could cause a very dangerous state as the robot could start with external commands. When stopping the robot, make sure to stop the programs. If the robot is stopped temporarily by the input of safety sensors such as laser scanners, and irregular tasks such as maintenance and inspection are performed, the robot may not be stopped by signals of the safety sensors, causing a dangerous situation.
- If the stored energy may cause a hazardous condition after shutting down the power, means must be provided for the controlled release of stored energy. This energy source may be in the form of (but not limited to) fluid pressure accumulators, capacitors, springs, counter balances, and flywheels. Appropriate label must be affixed to each stored energy source.
- Do not open the controller door or cover immediately after turning the power off. Wait for the time given in the controller and instruction manual before opening the door or cover.
- Be sure to place working notices on the power supply and start switches to prevent a third person from operating them carelessly. If necessary, provide a watchman to operate the emergency stop device immediately when the robot operators unexpectedly.
- Securely carry out daily and periodic inspections referring to the operation manual. Regarding to the maintenance of the robot system, observe the inspection and maintenance program of the robot system manufacturer. If a skilled operation is needed for the robot itself, consult with our service shop.
- When maintaining the controller, check the normal operation of the internal cooling fan by e.g. examining the air flow.
- When the brakes are released, the robot will drop with its own weight, so make sure that there are no operators in the robot's movable range. If there is any risk of interference, etc., with the peripheral devices, set the robot to a posture where a hazardous state will not be created before releasing the brakes.
- A small amount of lubricating grease may ooze out of the robot arm. If the surrounding environment could be contaminated from this grease dropping, check for grease oozing during the periodic inspection. If any grease is oozing out, wipe it off before it contaminates the surrounding environment.
- For maintenance, provide a sufficient space of working and sufficient illumination to produce an easy-to-work environment for operators.
- Don't modify the robot or use any unspecified parts. Be sure to prevent modifying any safety devices.
- When turning on the power after completing the maintenance, ensure that the restoration of the power does not result in hazardous condition.
- After completing the maintenance, the suspended safeguards must be returned to their original function. (Example: Interlocking the door of a guard). Check that the safety functions, safety protection devices, and safety logic work as designed before starting automatic operation.
- Do not carry out a megger test (insulation resistance test) during the inspections.
- Do not short-circuit, charge, heat, incinerate or disassemble the battery.
- Those who are engaged in maintaining and inspecting the robot must be qualified by completing education necessary to work with robots. Provide safety education related not only to works with robots but also inspection, maintenance, and other works.
- Maintenance and inspection are irregular tasks. Workers tend not to understand these tasks well, and failures related to such unfamiliar tasks may occur. Prepare documents such as working procedures for tasks such as maintenance. Thereby, workers can acquire knowledge about tasks in advance and find the risks inherent in the tasks. To work safely, make previous arrangements and give education to workers in advance.

- Itemize daily inspections and perform daily startup inspection to check that there is no problem. Define the criteria of periodic inspections considering the surroundings of the robot and how often the robot is used. Perform periodic inspection accordingly. Keep the record of periodic inspections and repairs for necessary terms according to the law of the country where it is used.
- When multiple workers perform tasks at the same time, determine a signaling method. The safety protection device may not ensure safety for two or more workers. When multiple workers perform tasks at the same time, share information among workers properly and prevent misunderstanding or insufficient understanding for safety reasons.

For details on maintaining and inspecting the controller, refer to "Maintenance and Inspection" in the following manual.

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

For details on maintaining and inspecting the robot, refer to the "Maintenance and Inspection" in the following manual.

 Instruction Manual: Robot Arm Setup and Maintenance (BFP-A3729)

For details on maintenance and inspection items of the safety extension unit, refer to the "Maintenance" in the following manual.

 Robot Safety Option Instruction Manual (BFP-A3531)

3.8 Troubleshooting

- As with maintenance, consider whether the priority of the work can be set as (1) work outside the safety protection region , (2) work inside the safety protection region with the power turned off, (3) work inside the safety protection region with automatic operation canceled.

When a person must work inside the safeguarded space, ensure complete control over the robot with an operating device to prevent anyone from operating the robot. Ensure complete control over the robot with an operating device as shown below.

Teaching pendant: Use "MANUAL mode" for the mode selector switch connected to the controller (supplied by customer) and set the Enable/Disable switch of the teaching pendant to "Enable". Engineering software (RT VisualBox or others):

Establishes communication with the controller.

- Be sure to place working notices on the power supply and start switches to prevent a third person from operating them carelessly. If necessary, provide a watchman to operate the emergency stop device immediately when the robot operates unexpectedly.
- If an alarm occurs on the robot, first check the alarm number or error mode which is useful is useful for trouble shooting. Record this information and refer to the corresponding pages of the manual.
- If the content of trouble shooting exceeds the range of the user, consult with our service shop as far as the robot is concerned with the trouble.
- If a person gets stuck with the robot due to a collision or other reasons, the direct teaching function may help move the joints of the robot against external force to get the person out of there. However, if the hand conditions are set incorrectly, the force may be increased due to gravity or other elements. When using the function, make sure to set the hand conditions correctly. Using the direct teaching function will put the robot in the servo ON status and use the control function. If the robot malfunctions and that causes a human to collide or get stuck, use a method other than the direct teaching function. For the method that does not use the driving force of actuators of the robot joints, refer to the following.

 Page 62 How to release the brake of the robot

Applying external force exceeding the one holding the brakes to the joints will move the robot. This is for emergency use because damage may be given to reduction gears or brakes, and maintenance or repair may be required after use.

- If the error triggered by the safely-limited position function occurs, an error will occur immediately after servo-on. Therefore, errors in jog operation or others cannot be eliminated. With the teaching pendant, temporarily stop the safety monitoring functions. Thereby, the recovery mode that allows jog operation is available. In the initial settings, the dedicated output for the recovery mode is available for the robot.

1. Change the controller mode to MANUAL.
2. Set the Enable switch of the teaching pendant to ENABLE.

3. Press the [JOG] key to display the JOG screen.



When force sense control is used, you can use recovery mode using the Force sense function screen (accessed from the JOG screen).

4. Lightly hold the Enable switch (3-position switch).

5. Hold down the relevant key.

When using the R32TB: [RESET] key

When using the R56TB: [CAUTION] key

6. Press the [SERVO] key to turn the servo on.

7. Move the robot using Jog operation.

Completing these steps temporarily clears all errors.

Recovery mode can be disabled using any of the following methods:

- Releasing the [RESET] key or the [CAUTION] key.
- Setting the Enable switch of the teaching pendant to DISABLE and changing the controller mode to AUTOMATIC.
- Displaying the JOG screen or a screen unrelated to the force sense function. (This method will only work for the RT32TB.)

Precautions

Errors will still occur after recovery mode is disabled if they have not been resolved.

Press and hold the [RESET] key or [CAUTION] key when moving the robot in Jog operation mode.

For details on the recovery mode, refer to "Recovery mode" in the following manual.

Robot Safety Option Instruction Manual (BFP-A3531)

3.9 Modifications

- Avoid modifications by user-judgements, and you must use the specified maintenance parts. Never modify the sections related to safety, such as the emergency stop.
- Faults caused by modifications made by the user will not be covered by the warranty.

3.10 Disposal

- Treat this unit as general industrial waste.
- Do not disassemble the parts.
- Dispose of batteries according to local laws.
- Contact the Mitsubishi Service Dept. for collection of used grease. Disposal of used grease by the user will pollute the environment.

4 SAFEGUARDING

Safeguarding includes the use of safeguards such as interlocking guards, awareness means in addition to the safe-guards, and safe working procedures to reduce the possibility of injury while performing an assigned task. Here, the guidance on safeguards and awareness means are provided for customers to check their safeguarding.

4.1 Safeguard

The following precautions assume that robots operate at high speeds which are not permitted for collaborative work. However, these precautions still apply when robots are in Collaborative operation mode. The precautions may not need to be fully adhered to when stopping the robot while it is in Collaborative operation mode. Furthermore, it may be possible to continue collaborative operation even if a person is in the safeguarded space. To judge whether robots can work together with humans, define under what conditions the robots are used throughout each stage of their life cycle (startup, adjustment, production, and maintenance), and conduct risk assessments.

- Fixed guards must be installed outside the maximum space of the robot.
- Fixed guards must be constructed to withstand foreseeable operational and environmental forces.
- Set the fixed guard to prevent entry into the safety protection region from entrances other than those provided with an interlock device or presence detection device. (So that an operator cannot climb over, go under or get over the fence.)
- Fixed guards must be permanently fixed in position and only be removable with the aid of a tool.
- Fixed guards must be free of sharp edges and projections and must not themselves be a hazard.
- The interlocking guards should be designed so that interlock prevents the robot system from automatic operation until the guard is closed. The closure of the a deliberate action at the control station.
- The interlocking guard with guard locking should be designed so that the guard remains locked closed until the risk of injury from the hazard has passed or that opening the guard while the robot system is working gives a stop or emergency stop instruction. Where the hazard cannot be eliminated immediately by power interruption, the interlocking system must need to include a guard locking and/or a braking system.
- When the operator's entire body can enter the safety protection region from the door with interlock, install a device so that the door cannot be closed unintentionally.
- The interruption, re-establishment after an interruption of fluctuation in whatever manner of the power supply to the safeguards must not lead to a dangerous situation.
- Guards and protection devices must cause minimum obstruction to the view of the production process.
- Guards and protection devices must enable essential work to be carried out on installation and/or replacement of tools and also for maintenance by restricting access only to the area where the work has to be done, if possible without the guard or protection device having to be dismantled.
- Reestablishing the interlocked gate or presence sensing device field must not in itself restart automatic operation.
- A presence sensing device must be installed and arranged so that persons cannot enter and reach into a hazardous area without activating the device or cannot reach the restricted space before the hazardous conditions have ceased.
- Barriers used in conjunction with the presence sensing device may be required to prevent persons from bypassing the device.
- The operation of presence sensing device must not be adversely affected by any of the environmental conditions for which the system was intended.
- Resumption of robot motion must require the removal of the sensing field interruption. This must not be the control to restart automatic operation.
- Where laser ray equipment or other harmful ray equipment is used, guards and protection devices must prevent any accidental radiation as well as reflections and diffusion that may damage health.
- When multiple workers do their jobs, safety may not be ensured depending on what and how safety protection devices are used. Even if a guard with a trapped key interlock switch is used, a worker may not be able to see a colleague in a blind spot inside the guard. That worker may then lock the door and start the system. Furthermore, presence sensing devices can only detect workers in areas the workers normally work in. The devices may not be able to detect workers in areas used for maintenance or other areas where work is not regularly carried out. Identify all possible risks that may arise when using safety protection devices. Upon doing so, ensure that workers are properly trained and that relevant warning signs

are displayed.

4.2 Awareness means

1

- An awareness barrier must be constructed and installed so as to prevent inadvertent entry into the restricted space.
- An awareness signal device must be constructed and located such that it must provide a recognizable audible or visual to persons of an approaching or present hazard.
- When awareness signals in the form of light are used to warn of hazards in the restricted space, sufficient devices must be used and located so that the lights can be seen by all persons in the proximity of the space.
- Audible awareness devices must have a distinctive sound of greater intensity than the ambient noise level.

5 SYSTEM DOCUMENTATION

The robot system documentation to be supplied by the robot system manufacturer shall contain the documents of all the components included in the system with their identification *e.g. robot, associated equipment, safeguards. (It shall also as a minimum include the following:

- a clear, comprehensive description of the robot system and its installation including mounting and connection to external power sources;
- a description of foreseeable hazardous conditions and how to avoid them;
- a description *including interconnecting diagrams (of the safeguards, interacting function, and interlocking of guards with hazardous conditions particularly with interacting installation;
- any further instructions for use specific to the system.

The following methods stated in ISO 10218-2 can be used to verify and validate systems:

- Review application-specific schematics, circuit diagrams and design material.
- Review safety-related application software and/or software documentation.
- Review layout drawings and documents.
- Review specifications and information for use.
- Supply instruction manuals
- Supply training materials
- Display warnings
- Supply procedure manuals

Regarding "information for use", instruction manuals must include the following information: handling, installation, commissioning (startup, inspection, delivery, and transfer) or procedures for starting operation, system details, system use, maintenance, suspension of use, emergency situations, and robot specifications. Moreover, robot systems must bear the following information: business name and full address of the manufacturer, authorized representative (if applicable), designation of the machinery, designation of series or type, serial number (if any), year of construction (the year in which the manufacturing process is completed). Machinery designed and constructed for use in a potentially explosive atmosphere must be marked accordingly. For details, refer to ISO 10218-2 "6 Verification and validation of safety requirements and protective measures" and "7 Information for use".

6 TRAINING

Personal who perform maintenance or repairs on robot or robot systems must be trained in the procedures necessary to perform safely the required tasks. Therefore, the user must have an inspection and maintenance program and ensure those personnel are adequately trained and demonstrate competence to perform their include, but is not limited to, the following:

- a review of applicable standard safety procedures and the safety recommendations of the robot manufacturer(s) and the robot system designers;
- a clear definition of assigned tasks and responsibility of each person;
- identification and explanation of all control devices and their functions used in performing the assigned task;
- identification of the hazards associated with the assigned task;
- the designated method(s) of safeguarding including the safe working procedures from the identified hazards;
- the method for testing or otherwise ensuring the proper functioning of the safeguards and interlocks.

Those who are engaged in working with robots must be qualified by being educated on points such as those mentioned above.

Besides the points mentioned above, provide workers beforehand with information or education on how to perform troubleshooting, and give them training so that they can deal with troubles properly.

7 DEGREE OF DANGER AND DAMAGE, AND INDICATIONS

Warning labels, corresponding to the degree of danger and damage are attached to the robot arm and controller. Fully understand the meaning of the warning label, and take special care when handling. Do not remove, modify or contaminate the warning labels.

Refer to the following table for details on the degree of danger and damage.

- Degree of danger and damage, and indications

Level	Degree of danger and damage	Caution prompting symbol and signal term
DANGER	When there is a great risk that the operator could be subject to fatalities or serious injuries ^{*1} if handling is mistaken.	 DANGER
WARNING	When the operator could be subject to fatalities or serious injuries ^{*1} if handling is mistaken.	 WARNING
CAUTION	When the operator could be subject to injuries ^{*2} or when only physical damage ^{*3} could occur if handling is mistaken.	 CAUTION

*1 Serious injury refers to injuries with after effects such as blindness, injury, burns (high temperature, low temperature), electric shocks, bone fracture, and poisoning, and to injuries requiring hospitalization or long-term medical treatment.

*2 Injury refers to injuries, burns and electric shocks that do not require hospitalization or long-term treatment.

*3 Physical damage refers to extended damage to buildings, peripheral devices or workpieces.

8 RISK ASSESSMENT AND SELECTING SAFETY FUNCTIONS

The following shows the International Standards related to machinery safety. Refer to the standards to conduct risk assessments.

- ISO 12100 (Safety of machinery - General principles for design - Risk assessment and risk reduction)
- ISO 10218-1, 2 (Robots and robotic devices - Safety requirements for industrial robots)
- ISO/TS 15066:2016 (Robots and robotic devices - Collaborative robots)

To evaluate the force of collisions between humans and robots, refer to the following document provided by DGUV (German Social Accident Insurance).

- DGUV - Information Collaborative robot systems Design of systems with "Power and Force Limiting" function, Issue 08/2017, Translation of the German version, FB HM-080

Note that the value stated for the transient contact force stated in the document above is the maximum value taken from the quasi-static contact test results (measured using a fixed measuring device). However, in ISO/TS 15066: 2016, transient contact is defined as contact where the operator's body part does not become trapped and moves freely along with the part of the robot the operator has come into contact with. When the measuring device is secured in place, it does not move with the contact, so the contact force tends to be higher than when the measuring device is not secured. Therefore, the value given for the transient contact force (where the operator does not become trapped) tends to be conservative.

The following briefly explains how to identify risks of collisions with humans and how to select safety protection devices and safety functions in the process of constructing robot systems.

8.1 Specifying restrictions on the use of machinery

The following information is required to conduct risk assessments.

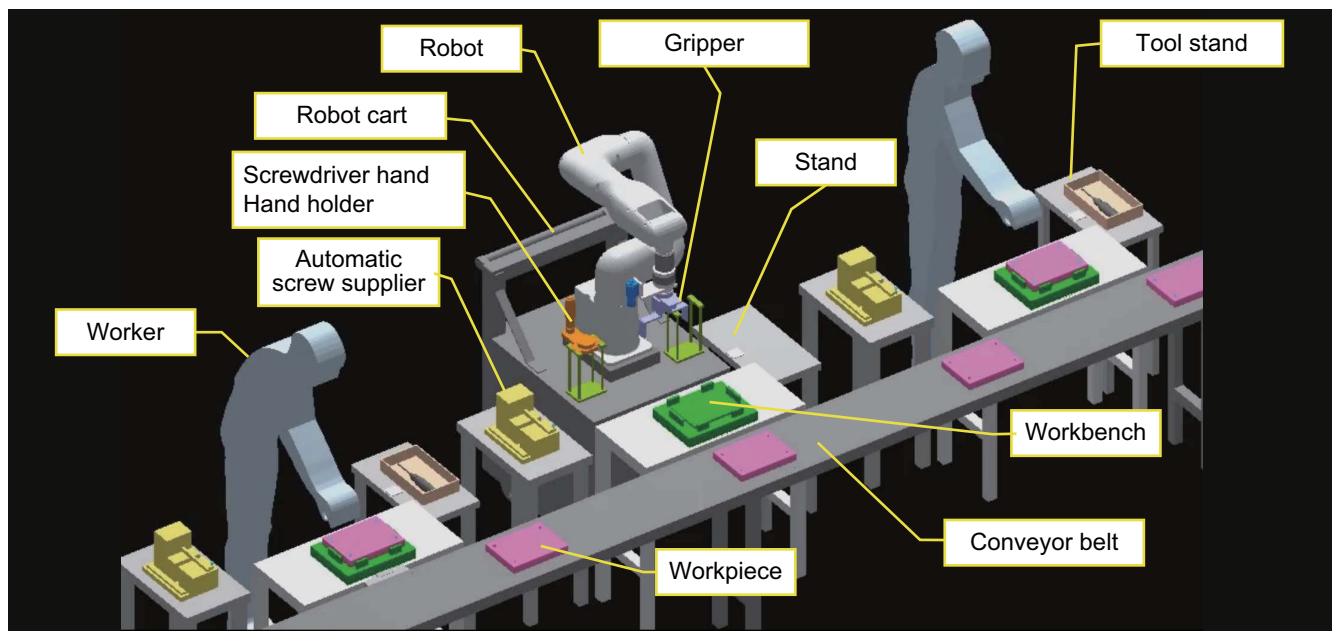
Machine specifications	• Robot system specifications • Robot specifications • End effector specifications • Peripherals specifications • Movement specifications • Specifications of products and materials
Use conditions	• Use conditions

For details of the above items, refer to documents such as the "Manual for functional safety - Robot system" mentioned previously.

This section contains examples of how to predict what risks of collisions are present in a robot system by utilizing the information mentioned above.

The figure below shows an example of a collaborative robot system.

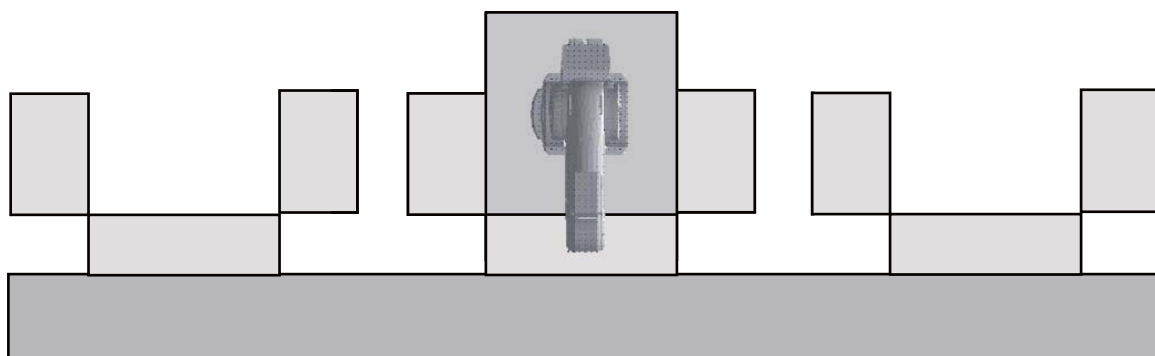
- Sample robot system



The robot uses the gripper to pick up a workpiece from the conveyor belt, and sets the workpiece on the workbench. The robot changes the gripper to the screwdriver hand to tighten screws. Finally, the robot puts the workpiece back on the conveyor belt.

The robot installed on a cart works with the workers on both sides.

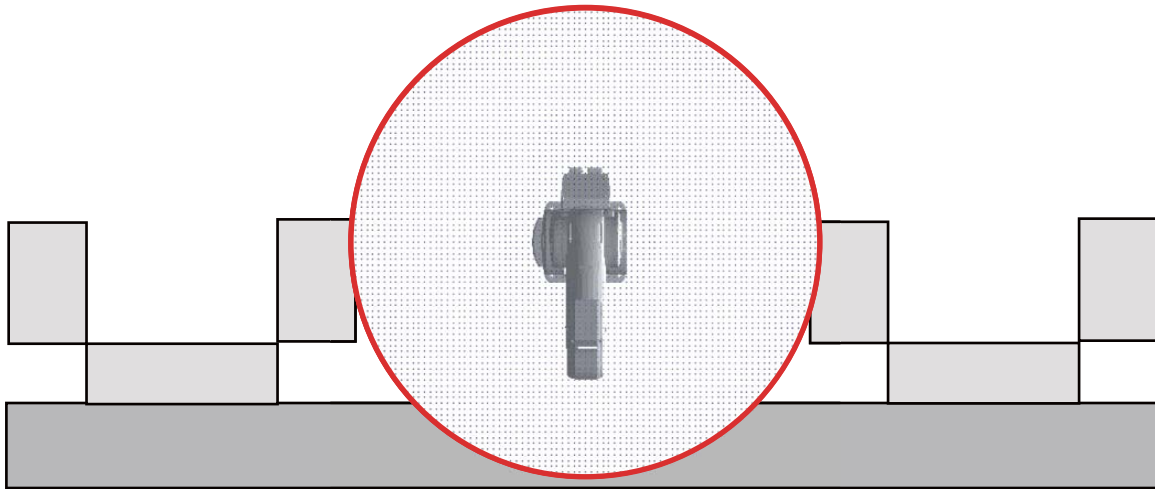
- Positions of the robot and peripherals



As a first step, use the information about restrictions on use of machinery to locate the robot and peripheral devices as shown in the figure above.

8.2 Specifying the maximum robot operating range

- Positions of the robot and peripherals



Based on the locations of the robot and peripheral devices as indicated in the previous section, specify the maximum space in which the robot can operate.

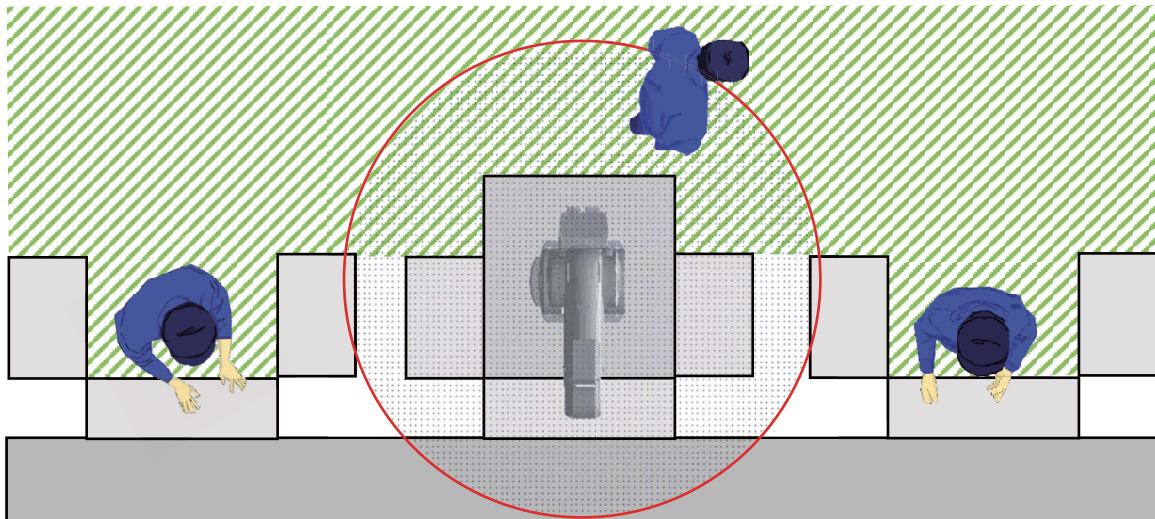
Point

How big the maximum space is depends on the size of the end effector (hand) and workpiece. Therefore, the space may be larger than the maximum robot operating range depending on the design of the hand and workpiece. If changes are made to the design of the hand during risk assessment, consider whether or not a new risk assessment is required.

8

8.3 Specifying areas where people exist

- Specifying areas people work in



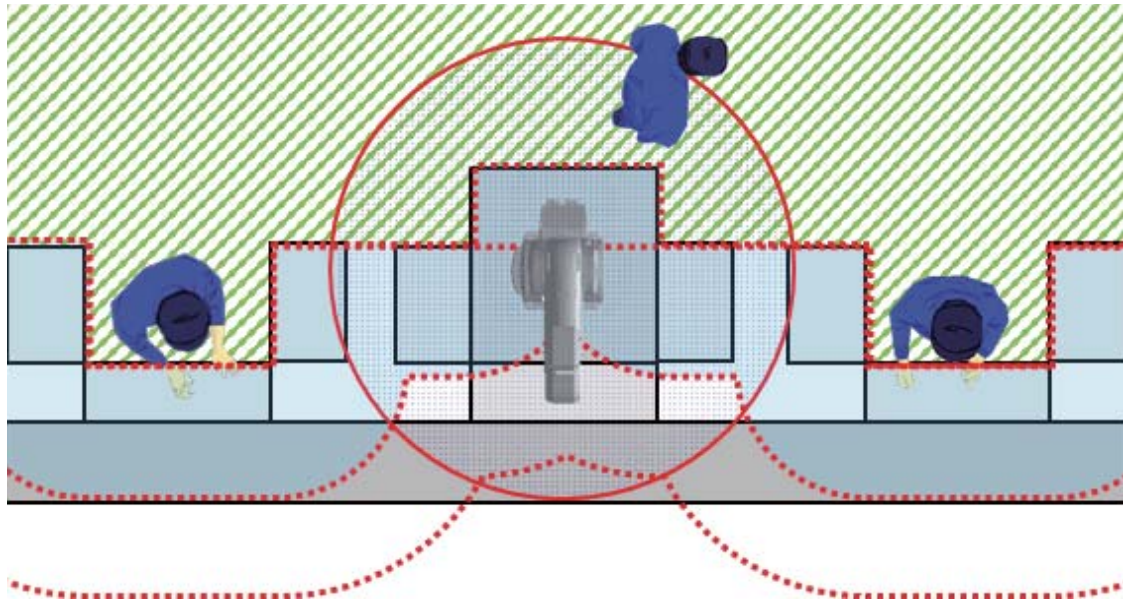
Specify the areas where people may exist.

Specify workspaces and other areas that people enter. Keep in mind that the size of this area may vary during installation, adjustment, production, setup, and maintenance of the robot.

When workers change setups or carry out maintenance, they may get close to the robot or enter areas that people do not usually enter during production.

8.4 Understanding safety distance

- Specifying a safety distance



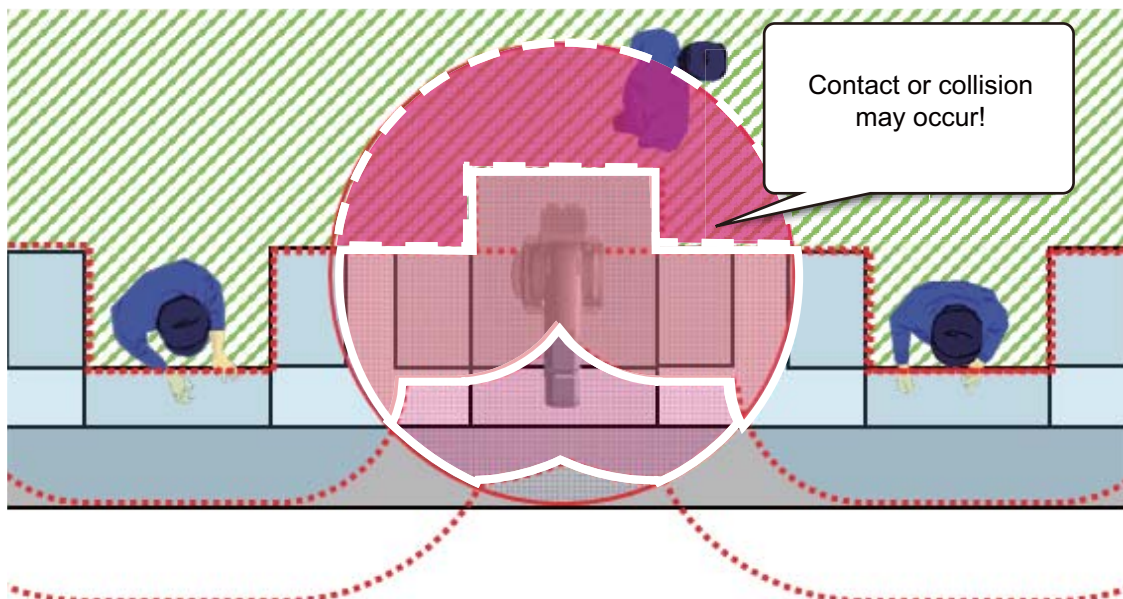
Areas where humans work and move in and out of are specified in the previous section. Specify areas where workers may accidentally enter the robot operating area if they raise their hands or bend forward with their arms stretched out in front of them. For example, a clearance of 850 mm or more is required between the shoulders and hazard sources all the time. The safety distance for humans to use the arms and go over a protective structure with a height of 1000 mm or lower shall be 1500 mm or more.

The following standards define the safety distance.

ISO 13857 (Safety of machinery - Safety distances to prevent hazard zones being reached by upper and lower limbs)

8.5 Specifying areas where collisions may occur

- Hazard area where collisions may occur



Based on the maximum space of the robot operation and the area where humans work as indicated in the previous sections, specify the hazard areas where collisions between robots and humans may occur.

For the maximum space of the robot operation, refer to the following.

📖 Page 83 Specifying the maximum robot operating range

For the area where humans work, refer to the following.

☞ Page 83 Specifying areas where people exist

☞ Page 84 Understanding safety distance

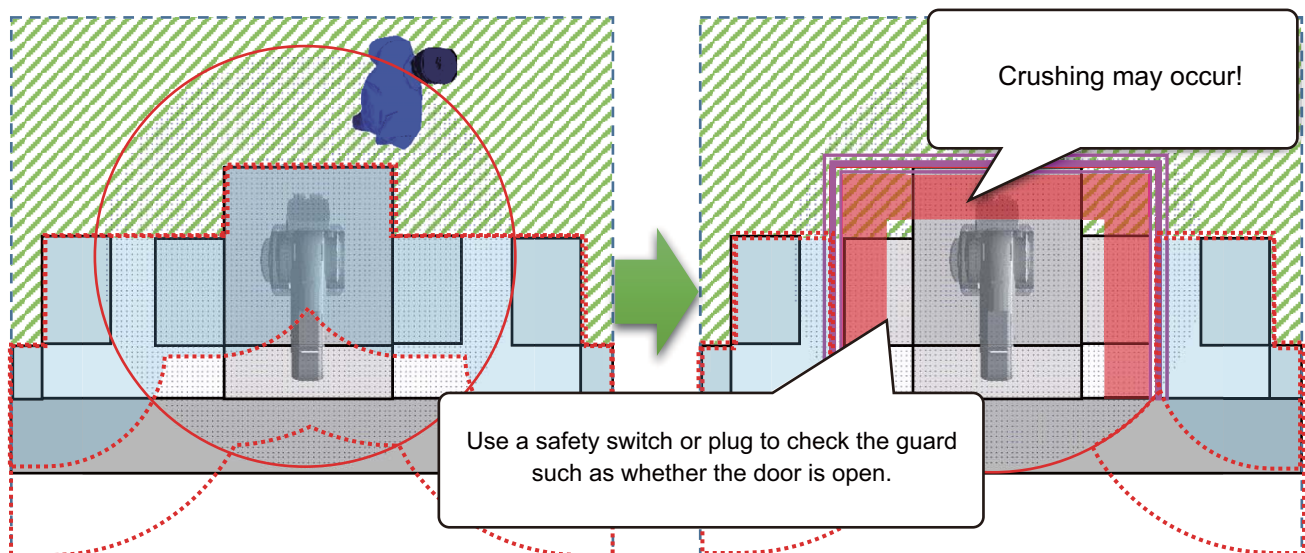
Take further actions to remove risks. Otherwise, an incident may occur. The following section describes how to take actions against collision risks.

8.6 Methods for reducing risks

Some precautions can be taken against collision risks identified in the previous section. Select suitable precautions to meet desired conditions. The effects of reducing risks, usability of the system, cost required for system configuration, and work efficiency vary depending on what precautions are taken. The 3-step Method is known as a procedure for reducing risks identified in risk assessments. The method includes the following three steps: 1. Inherently safe design measures, 2. Safeguarding and complementary protective measures, and 3. Information for use. In the method, the above three steps are repeated to reduce risks. The methods stated below are to be used as additional safeguards.

Using a guard (safety fence)

- Using a guard



Guards reduce risks by completely separating areas where humans work and areas where robots operate. Guards have been used frequently as a safety precaution, and many examples exist. If workers need to supply the robot system with workpieces or other materials from outside, or adjust or maintain the robot system, provide an opening or a door to the guard, or workspace inside the guard. A clearance of 500 mm or more is required between the guard and the robot to prevent a human from getting caught between them. Leave a safety distance according to the size of the opening, and take appropriate actions such as installing safety sensors such as light curtains to stop the robot upon detection of humans. When providing a door for the guard, make sure to install safety sensors such as safety plugs to prevent the robot from operating with the door open.

Refer to the following to use a guard.

Requirements for guards

- ISO 14120 (Safety of machinery - Guards - General requirements for the design and construction of fixed and movable guards)

Design of interlocks with safety switches or plugs

- ISO 14119 (Safety of machinery - Interlocking devices associated with guards - Principles for design and selection)

Guidelines for preventing humans from getting stuck

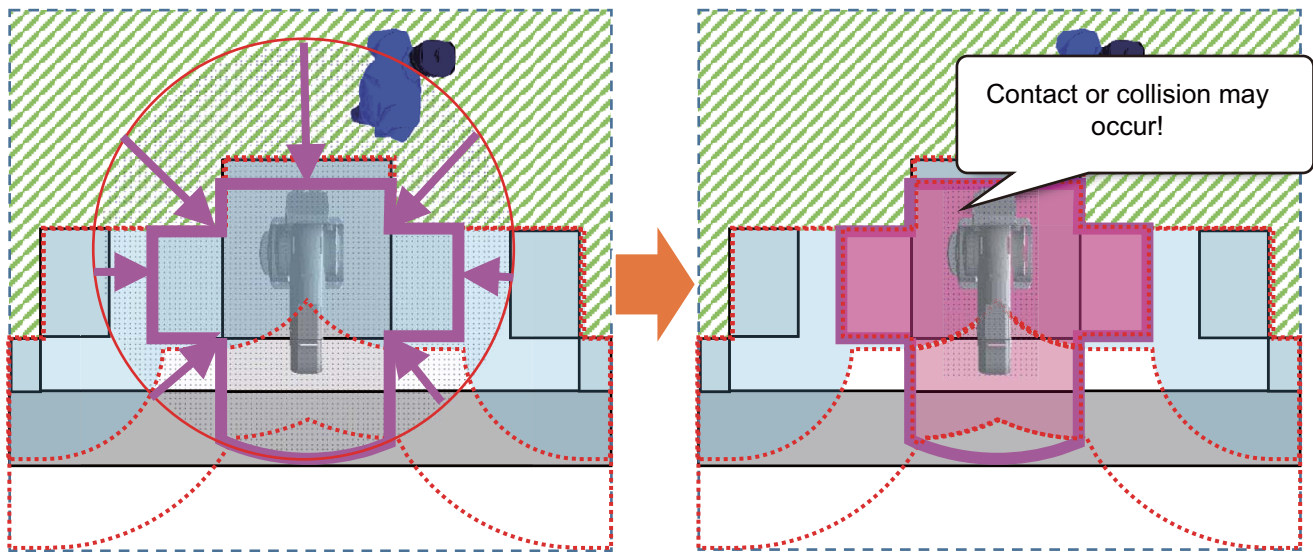
- ISO 13854 (Safety of machinery - Minimum gaps to avoid crushing of parts of the human body)

Consider safety distances corresponding to the shape of guards (size of openings in fences, etc.)

- ISO 13857 (Safety of machinery - Safety distances to prevent hazard zones being reached by upper and lower limbs)

Using the safely-limited position function (SLP)

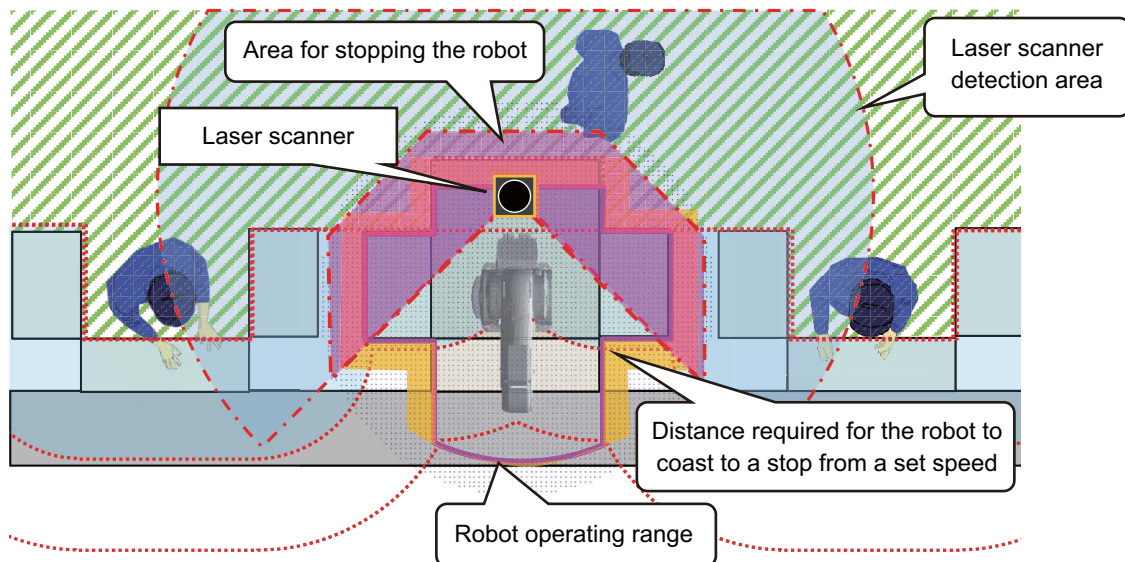
- Using the safely-limited position function (SLP)



The safely-limited position function (SLP), one of the safety functions of the robot, monitors the position of the robot. If the robot goes beyond the specified area, the function stops the robot. The function narrows the maximum space of the robot operation to where the robot actually operates. Thereby, the areas where collisions with humans may occur can be reduced. As shown in the figure above, these areas can be reduced sufficiently, but some risks remain. Therefore, take further safeguarding. Moreover, set monitoring positions correctly. Otherwise, even if the robot is within the area, the hand or workpieces may go beyond the area.

Using Safety Rated Monitored Stop (SRMS)

- Using Safety Rated Monitored Stop (SRMS)



SRMS (Safety Rated Monitored Stop) is one of the precautions for collaborative operation described in TS15066. SRMS monitors intrusion of humans by a safety sensor such as a laser scanner. If an intrusion is detected, the robot will stop. However, the robot cannot stop at the position where a stop command is given to the robot because the robot may coast to a stop. Determine where to give a stop command to the robot also considering the following points: the time taken for the safety sensor to give a stop command after a human has been detected, and the speed of humans walking toward the robot after they enter the monitoring range. Therefore, the safety sensor may be required to give a stop command to the robot at the position far from the robot operating range. The areas indicated in the figure above are examples. Set areas according to the usage.

The figure above shows the following situation: The SLP function limits the operating range, the safety input receives a signal from the laser scanner, and then the signal activates the SS1/STO functions to stop the robot.

Refer to the following to use Safety Rated Monitored Stop (SRMS).

Calculating safety distances

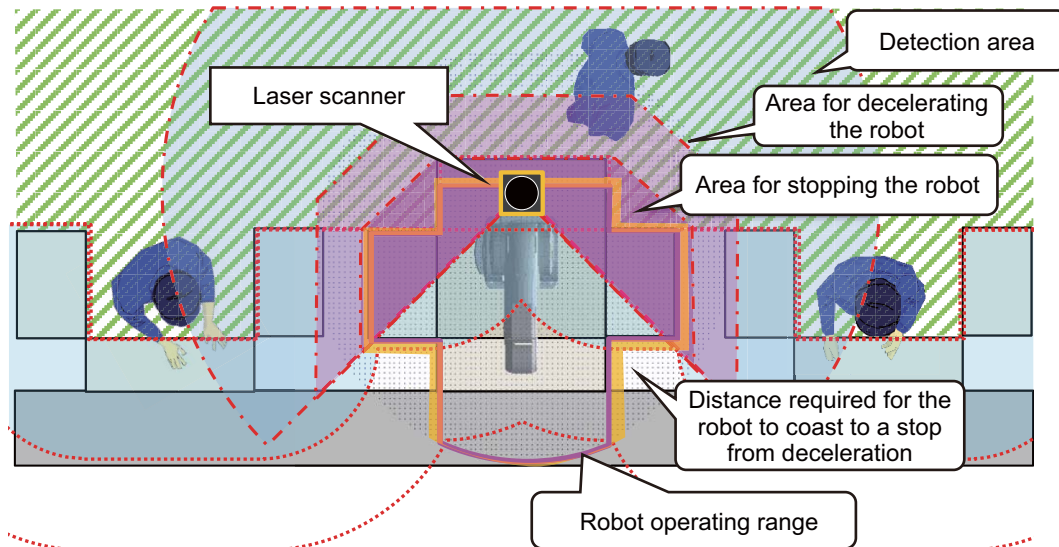
- ISO 13855 (Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body)

Requirements for protective equipment that detects humans (such as light curtains, laser scanners, and pressure sensitive mats)

- IEC/TS 62046 (Safety of machinery — Application of protective equipment to detect the presence of persons)

Using Safety Speed Monitoring (SSM)

- Using Safety Speed Monitoring (SSM)



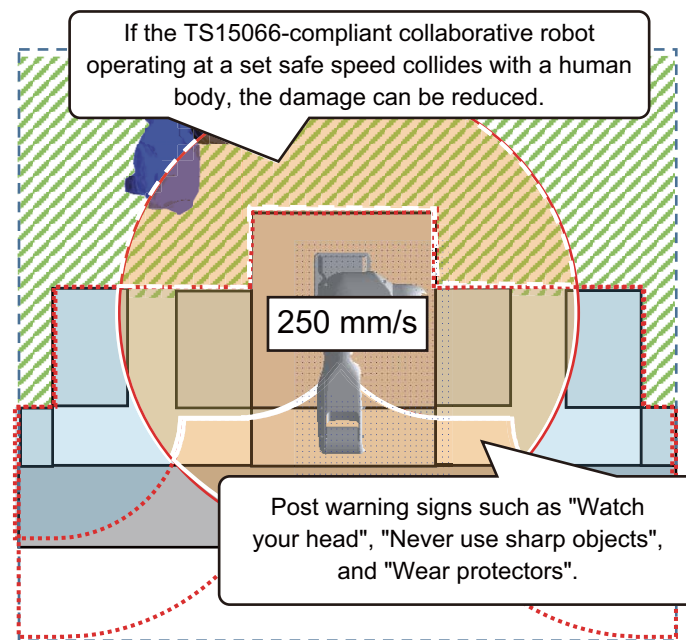
SSM is a safety precaution written in TS15066 for working with a collaborative robot. Safety sensors such as laser scanners monitor the distance between humans and the robot, and the robot decelerates or stops according to the conditions. As the same as SRMS, the robot cannot stop at the position where a stop command is given to the robot, and therefore the coasting distance must be taken into account. However, SSM can reduce the robot speed beforehand, shortening the coasting distance. (Generally, coasting distance depends on how fast the robot moves when the robot starts stopping.) Furthermore, as the same as SRMS, consider the time taken for the safety sensor to give a stop command after a human has been detected, and the speed of humans walking toward the robot after they enter the monitoring range. The areas indicated in the figure above are examples. Set areas according to the usage.

The figure above shows the following situation: The SLP function limits the operating range, the safety input receives signals from the laser scanner when the workers enter the area for decelerating the robot and the area for stopping the robot, and then the signals activate the SLS function to decelerate the robot and the SS1/STO functions to stop the robot.

For reference standards, refer to the section of SRMS.

Using Power and Force Limiting (PFL)

- Using Power and Force Limiting (PFL)



PFL (Power and Force Limiting) is one of the precautions for collaborative operation described in TS15066. By limiting the robot energy, and adopting appropriate shapes or materials, PFL aims to make the collision force or pressure against humans smaller than the permissible force or pressure as defined for each part of the human body. Regarding PFL, our collaborative robots have the following characteristics: The upper operating speed has been set, they are light weight, they have a rounded shape, and a function to stop the robot immediately upon detection of a collision. Unlike SRMS or SSM, external safety sensors are not required, which allows collaborative operation easily. However, always note the following: The operating speed is limited, injury cannot be prevented if the robot comes into contact with a human from the neck up at any speed, and safety may not be ensured depending on the shape of the hand attached to the robot arm or workpiece if a collision occurs. The figure above shows the following situation: The SLS function keeps the robot operating speed below a certain speed to limit the robot energy, and the STR function detects collisions and the robot is stopped immediately.

Refer to the following to use Power and Force Limiting (PFL).

Upper permissible force when collisions occur

- ISO/TS 15066:2016

Also refer to the following manual.

- DGUV, Collaborative robot systems Design for systems with "Power and Force Limiting" function

Other precautions

In this chapter, to explain risk assessments briefly, hazard areas are determined using figures seen from above. In actuality, make sure to examine risk factors related to the height, such as tables, laser scanner monitoring, and possibility of a contact with a human from the neck up. Changing the way tasks are performed in the system affects the operation status of the robot and the area where humans enter accordingly. To reduce risks inherent in the system, risk assessments need to be carried out for a number of system uses. If other products that move are incorporated into the system, prevent them from colliding with humans or from humans getting stuck in them. Examine other risk factors such as charging areas and heat sources.

8.7 Setting example

For examples of setting monitoring ranges in some situations and examples of setting safety inputs and outputs, refer to "Example" in the following manual.

 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

APPENDIX

Appendix 1 Examples of safety protection device configuration

Safety protection device configuration methods

Stop functions

The following three methods are available for the stopping methods, a basic means of safety protection.

Emergency stop	An input signal is detected by the software then servo power is shut off and the mechanical brake activates to stop the robot. During operation, the servo motors will decelerate to a stop before the mechanical brake activates, so it may take some time before the robot stops completely.
Enable switch (3-position switch)	When the [T/B ENABLE] switch on the teaching pendant is enabled, releasing the switch will cause the software to detect an input signal. Servo power is then shut off and the mechanical brake activates to stop the robot. During operation, the servo motors will decelerate to a stop before the mechanical brake activates, so it may take some time before the robot stops completely.
Servo OFF	The input signal is judged by the software, the motor power is shut off, and the motor stopped. During operation, the motor will decelerate to a stop before the servo is turned OFF, so it may take some time before the stopping is completed.

The other stop functions (emergency stop, temporary stop, etc.) are used to judge the input signal by the software and stop the operation. These are used to confirm the operation status, etc., but since the power is not shut off, these do not act as stop functions for safety protection.

Safety protection functions

The following functions can be used for the safety protection devices.

Safety speed limiter	This sets the high-speed operation speed with the operation panel, etc. This function limits the speed to a safe speed.
Exclusive starting control	This prohibits the start command from a source other than the device being used.

The following functions are also available as safety protection assembled in the product. These functions are already assembled in the teaching box, and will function as safety protection functions without special consideration.

- Hold to run: This function starts operation only when the key, etc., is pressed. Operation stops when released.
- Double key pressing: This function validates the commands only when two keys are pressed simultaneously.

Safety protection measures

Measures for safety protection using the above stop functions and safety protection functions are indicated below.

Measure A: Servo OFF

Measure B: State in which emergency stop can be applied immediately (teaching pendant emergency stop, emergency stop switch inside guard, etc.)

Measure C: Safety speed limiter, exclusive starting control (teaching pendant enable, manual mode, etc.)

Movable range	Operation status	Drive source shut off	Measures
Outside	During automatic operation	Not shut off	Signaling of operation start Provision of fences and enclosures
Inside	During teaching, etc.	Shut off <u>Measure A</u>	Indication that work is in progress
		Not shut off	Measures to stop operation immediately, etc. <u>Measure B</u> and <u>Measure C</u>
	During inspections, etc.	Shut off <u>Measure A</u>	Indication that work is in progress with operation stopped, etc.
		Not shut off	Measures to stop operation immediately, etc. <u>Measure B</u> and <u>Measure C</u>

A

Examples of safety protection device configuration

For information on constructing safeguards, refer to the following manuals.

 RV-5AS-D Standard Specifications (BFP-A3727)

 Instruction Manual: Controller Setup and Maintenance (BFP-A3731)

Appendix 2 Glossary of terms (according to ISO 10218: 1992)

For a glossary of terms related to collaborative operation, refer to "Terms" in the following manual.

📖 Collaborative Robot: Detailed explanations of functions and operations (BFP-A3735)

Precautions

Safeguarded space

Guards (safety fences) separate workspaces for humans and industrial robots. Safeguarded spaces have almost the same function as guarded areas. In collaborative operation, even if guards are not used, robots are allowed to be operated in workspaces where humans work. This means guards are not always used in every robot system.

The term "safeguarded space" used in this manual has the following meanings: workspaces separated by guards for humans and robots, and areas or spaces monitored by safety protection devices such as laser scanners, light curtains, or safety mats. A safeguarded space is not always the maximum space for robot operation. A safeguarded space may indicate an area larger than the maximum space.

That is because a certain time is required for safety sensors to detect humans and then for robots to become safe even if a collision occurs. Safety sensors must detect humans before they reach areas where a collision may occur.

A

- Arm (primary axis)

An arm is a series of links and joints for end-effector positioning.

- Automatic mode (Refer to ISO/TR 8373: 1988, 5.3.8.1.)

Operating mode in which the robot control system can operate according to the task program.

D

- Dangerous situation/movement

A situation or movement that may injure humans

E

- Enabling device

A manually operated device that allows robot operation only while the switch is held in a predetermined position.

G

- Guard

A mechanical barrier used to protect humans. Depending on their construction, guards may be called a variety of things such as casting, cover screens, fences, doors, enclosures, or barriers.

H

- Hold-to-run control

A control which allows robot movements only when a button is manually actuated and stops the movements when the button is released.

I

- Interlock (for safeguarding)

An interlock is a feature that makes the state of robots, peripheral control systems, drive systems, guards, and safety devices mutually dependent.

L

- Local control

A state of the robot in which the robot can be operated from the control panel installed to the robot system or teaching pendant.

- Lockout/tagout

The placement of a lock and tag in the "on" or "off" position of the energy isolating device.

Remarks: The energy isolating device or the peripheral devices being controlled shall not be operated until the removal of the lock and tag.

M

- Manipulating industrial robot (Refer to ISO/TR 8373: 1988, 3.3.)

An automatically controlled, reprogrammable, multipurpose manipulative machine with 3 or more axes. In industrial automation applications, robots may be fixed in place or mobile.

Remarks: The meanings of the terms used in the above definition are as follows.

Reprogrammable: Programmed motions or auxiliary functions can be changed without physical alteration.

Multipurpose: Capable of being adapted to a different application with physical alterations. Alteration of the mechanical structure or control system except for changes of programming cassettes, ROMs, or others.

- Manual mode

Operating mode in which the robot is under the control of the operator and that excludes other modes.

- Maximum space

The space which can be swept by the moving parts of the robot (defined by the manufacturer) and the space which can be swept by the end effector and the workpiece.

- Mode selector switch

The switch that changes controller modes between MANUAL mode and AUTOMATIC mode. The input terminal status in each mode is as follows.

Controller mode	Input terminal
MANUAL (during teaching)	Open
AUTOMATIC (during automatic operation)	Close

P

- Person

Any individual including personnel.

- Personnel

Those who are specially employed and trained to use and maintain robot systems.

- Presence sensing device

A device for detecting intrusion of humans into the specified plane area or space.

Remarks: Presence sensing devices include but are not limited to light screens, electromagnetic fields, pressure sensitive devices, ultrasonic detection devices, infrared detection devices, and image processing systems.

- Programmer (Refer to ISO/TR 8373: 1988, 3.9.)

A person who is qualified to prepare the task program.

R

- Restricted space (Refer to ISO/TR 8373: 1988, 5.5.3.)

The portion of the maximum space restricted by limiting devices. The devices establish limits which will not be exceeded in the event of any foreseeable failure or malfunction of the robot system.

Remarks: Includes the maximum distance that the robot can travel after the limiting device is actuated.

- Risk

A combination of the probability of occurrence of damage and the degree of the damage.

- Robot system (Refer to ISO/TR 8373: 1988, 3.6.)

A system composed of the following parts.

a. Mechanical structure (including mobile function, if applicable)

b. Power supply and control system

c. End effector

d. Any equipment, devices, or sensors required for the robot to perform tasks

e. Any communication interface that operates and monitors the robot, equipment, or sensors However, these peripheral devices are supervised by the robot control system.

S

- Safe operation speed

A pre-determined speed set by robot suppliers which allows for humans to avoid or stop any dangerous movements that the robot may make. (A speed below 250 mm/s at the mechanical interface is preferable.)

- Safe working procedure

A procedure to reduce the possibility of injury during tasks.

- Safeguarded space

An area protected by safety protection devices.

Remarks: Safeguarded spaces include restricted spaces.

- Safeguarding

Measures to protect humans by using guards, devices, or following safe working procedures.

- Safety protection device

A guard or device to protect humans from danger.

T

- Teaching pendant (Refer to ISO/TR8373: 1988, 6.8.)

A portable device used for teaching programs to or operate robots by connecting it to the control system.

- Troubleshooting

An act to methodically find the cause that a robot system has failed to perform tasks or function as intended.

W

- Warning

Indicates factors that may cause damage to humans or affect their health.

Appendix 3 Supplementary explanation of symbols

Symbol	Name	Description
	Caution, risk of electric shock	Can cause electric shock. Stop the primary power source before operation.
	Protective earth (ground)	Ensure the device is grounded to prevent electric shock, static electricity, unwanted electromagnetic interference and to improve noise resistance.

REVISIONS

Revision date	*Manual No.	Description
April 2020	BFP-A3733	First edition
July 2020	BFP-A3733-A	Changed the cautions regarding unpacking.
October 2020	BFP-A3733-B	Added notes to "SAFETY INSTRUCTIONS FOR USING ROBOT SYSTEMS".
September 2021	BFP-A3733-C	Corrected the explanation of electromagnetic noise in "2.1 Operating environments". Corrected other mistakes and changed some sections.
April 2023	BFP-A3733-D	Corrected "2.3 Safety-related control system performance and conforming standards". Corrected other mistakes and changed some sections.
June 2023	BFP-A3733-E	Corrected "2.3 Safety-related control system performance and conforming standards".
April 2024	BFP-A3733-F	Revised "Appendix 1 Examples of safety protection device configuration".

This manual confers no industrial property rights or any rights of any other kind, nor does it confer any patent licenses. Mitsubishi Electric Corporation cannot be held responsible for any problems involving industrial property rights which may occur as a result of using the contents noted in this manual.

© 2020 MITSUBISHI ELECTRIC CORPORATION

TRADEMARKS

Ethernet is registered trademarks or trademarks of Xerox Corporation in the United States.

Microsoft and Windows are trademarks or registered trademarks of Microsoft Corporation in the United States and other countries.

Adobe and Adobe Reader are registered trademarks of Adobe Systems Incorporated.

Unicode is a trademark or registered trademark of Unicode, Inc. in the United States and other countries.

The company name, system name, and product name herein are basically trademarks or registered trademarks of their respective owners.

In some cases, trademark symbols such as [™] or [®] are not specified in this manual.

BFP-A3733-F(2404)MEE

mitsubishi electric corporation

HEAD OFFICE: TOKYO BLDG., 2-7-3, MARUNOUCHI, CHIYODA-KU, TOKYO 100-8310, JAPAN
NAGOYA WORKS: 1-14, YADA-MINAMI 5-CHOME, HIGASHI-KU, NAGOYA 461-8670, JAPAN

Specifications subject to change without notice.