Manual Version 1.6
Software Version 2.5

Doosan Robot

A0509 | A0509S | A0912 | A0912S

Installation Manual

DOOSAN

Preface

Thank you for choosing this Doosan Robotics product. Before installing the product, please read through this manual and follow the instructions for each installation process provided in this manual. The contents of this manual are current as of the date this manual was written, and product-related information may be modified without prior notification to the user.

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While the information in this manual is reliable, Doosan Robotics is not responsible for any damage that occurs due to errors or typos. The contents of this manual may be modified according to product improvement without prior notification.

This is a detailed manual for a specific software version of the robot. For details of updated manuals, refer to the Robot LAB website (https://robotlab.doosanrobotics.com/).

Open Source Software License Information (OSS)

The software installed in this product was developed based on free/open source software.

Details about the free/open source software license can be found on the OSS use page on the Doosan Robotics website (www.doosanrobotics.com/kr/oss/license).

For related inquires, contact the Marketing Department of Doosan Robotics (marketing.robotics@doosan.com).

1. Safety

This chapter provides safety information the user must be aware of before installing or operating the robot. All robots have risks of high voltage, electricity and collision. Therefore, in order to minimize the risk of injuries and mechanical damage, one must observe the basic safety cautions while operating the robot and using related parts. To protect user safety and prevent property loss, make sure to read and follow the instructions carefully. The contents of the manual and specifications of the product may change for product and performance improvements.

1.1 Manual Indication Conventions

To communicate safety precautions related to the use of the product, the following symbols are indicated in this manual.

Symbol	Name	Description
	**Danger**	Failure to observe instructions with this symbol may result in serious accidents that could result in death or serious injury to the operator.
	**Warning**	Failure to observe instructions with this symbol may result in serious accidents that could result in death or serious injury to the operator.
	**Caution**	Failure to observe instructions with this symbol may result in product damage or cause injury to the operator.
	**Note**	This is additional information to help the user.

1.2 Safety Symbols

Among the symbols used in this manual, symbols related to user safety are as follows:

Symbol	Description
 Danger	This symbol means that immediate hazards can occur due to electrical conditions such as high voltage. Failure to observe instructions with this symbol may result in serious accidents that could result in death or serious injury to the operator.
 Danger	This symbol means that immediate hazards can occur. Failure to observe instructions with this symbol may result in serious accidents that could result in death or serious injury to the operator.
 Warning	This symbol means that potentially dangerous situations can occur due to electrical conditions such as high voltage. Failure to observe instructions with this symbol may result in serious accidents that could result in serious injury to the operator.
 Warning	This symbol means potentially dangerous situations can occur. Failure to observe instructions with this symbol may result in serious accidents that could result in serious injury to the operator.
 Caution	This symbol means dangerous situations can occur due to overheating. Failure to observe instructions with this symbol may result in serious accidents that could result in serious injury to the operator.
 Caution	The product may become damaged or the operator may be injured.

1.3 General Instructions

This chapter describes general danger and warning items related to operating the robot.

Warning

- If the robot is installed with electrical devices, install the robot referring to the Installation Manual.

Warning

- If the setting(Section 3.3.10) of the emergency stop button setting switch is different from the actual configuration, the emergency stop button may fail and cause injury to the user in an emergency situation, so check the setting condition and operation of the emergency stop button.
- If a device is installed on the tool during robot installation, make sure to use appropriate bolts.
- Suitable safety measures, such as safety fences, must be implemented to protect the staff and robot during installation.
- Do not wear loose-fitting clothes or accessories when operating the robot. If one's hair is long, make sure to tie up the hair to prevent it from getting caught between robot joints.
- Never operate a damaged robot.
- Take caution of the robot's movement when using the teaching pendant and smart pendant (A-series).
- If the teaching pendant warns the user of a critical error, immediately engage the emergency stop switch, identify the cause of the error, resolve the error and then resume robot operation. If the critical error cannot be resolved, contact the sales agent or robot supplier.
- Make sure to connect safety protection equipment to a safety interface. If such equipment is connected to a general interface, the integrity of safety functions may not be guaranteed.
- Make sure to become completely familiar with the robot user manual prior to operating the robot.
- If the robot collides with an external object, a significant impact may be generated. The impact the robot receives is proportionate to the kinetic energy, so higher speeds and high payload can generate large impacts. Make sure to maintain a safe speed and payload during operation in collaborative spaces.
- Direct teaching must only be performed in safe environments. Do not operate the robot if there are sharp edges or jamming near the tool and its surroundings.
- Before performing direct teaching, make sure accurate inputs (tool length, weight, center of gravity) are made. If inputs are different from the tool specification, direct teaching error or malfunctioning can occur.
- To ensure user safety, joints may operate at a certain speed or higher, or the maximum speed of the TCP may be limited during direct teaching. If the limit is exceeded, the protective stop function activates.

- Enable/disable the direct teaching function when the robot has completely stopped. If the direct teaching function is enabled/disabled during robot operation, malfunctions may occur.
- If the robot axis must be rotated when the robot is not operated, it can be rotated at a torque greater than 400 Nm.
- Modifying the robot without prior approval may cause critical breakdowns and accidents.

Caution

- Operating the robot and control box for an extended period of time generates heat. Do not touch the robot with bare hands after operating for an extended period of time. Before performing work that requires touching the robot, such as tool installation, leave the robot for more than 1 hour after turning off the power of the control unit to cool down the robot.

Caution

- Do not expose the robot to powerful magnetic fields. It may cause damage to the robot. .

1.4 Product Usage

This is an industrial product designed specifically for purposes of transferring and assembling objects by attaching components to products using tools, and it must be operated in the conditions specified in its specifications.

This product features special safety functions designed for the purpose of collaborating with human operators, and it operates with human operators without specific boundaries. Conduct work with the system only when all applications, including the tool, workpiece, boundary and other equipment, are confirmed to have no harm.

The following uses are considered inappropriate because they exceed the boundaries of the product's intended purpose. Doosan Robotics will not be held responsible for any damage and malfunctioning of the robot, property losses and injuries to users due to such inappropriate uses.

- Use in an environment with potential explosions
- Use in applications related to medicine and human lives
- Use in transporting humans and animals
- Use without risk assessment
- Use in locations where the performance and operation environment specifications are not met
- Use in environments with insufficient safety functions
- Use of the robot as a step to stand on
- Use in environments where electromagnetic waves are generated at levels greater than the IEC standard, such as welding

1.5 Risk Assessment

One of the most important aspects of a system integrator is risk assessment. Risk assessment is legally mandatory in most countries. In addition, safety assessment of robot installation changes according to the overall system integration method, so it is impossible to perform risk assessment solely with the robot.

In order to perform risk assessment, the administrator overseeing the overall system establishment must install and operate the robot according to ISO12100 and ISO10218-2. In addition, the administrator can refer to the technical specification, ISO/TS 15066.

Risk assessment must consider the overall work process in terms of the overall life cycle of the robot application. Key objectives of risk assessment are as follows:

- Robot setting and work teaching for robot operation
- Troubleshooting and maintenance
- Proper robot installation

Before supplying power to the robot arm, make sure to perform a risk assessment. Setting appropriate safety settings and identifying the need for additional emergency stop buttons and other protective measures are parts of risk assessment.

Identifying appropriate safety settings is a critical aspect of developing a collaborative robot application. For more information, refer to the corresponding chapter of the manual.

Some safety functions are designed specifically for collaborative robot applications. These functions can be set up through safety function settings, and they are optimized for responding to specific risks identified through the risk assessment performed by the integrator.

The safety functions of the collaborative robot can be set up in the safety setting menu, and they offer the following features:

- Force and power limitation: Limits the stopping force and pressure of the robot in case of collisions between the robot and a worker
- Momentum limitation: Limits the energy and impact load by reducing the speed of the robot when a collision between the robot and a worker occurs
- Joint position and TCP limitation: Limits robot movement to prevent moving towards specific body parts of users such as the neck or head
- TCP and tool pose limitation: Limits certain areas or characteristics of a tool and workpiece to minimize related risks (i.e., limits the movement of sharp edges of workpieces aimed at users)
- Speed limitation: Limits robot movement to stay at low speed in order to secure time for the user to avoid a collision before a collision between the robot and a worker occurs

Applying appropriate safety settings is considered to be the same as fixing the robot to a specific location and connecting it to a safety-related I/O. For example, setting password protection can prevent unauthorized safety setting changes by individuals not approved by the system integrator.

Key items to note when performing risk assessment of the collaborative robot application are as follows:

- Severity of individual potential collisions
- Probability of individual potential collision occurrence
- Probability of individual potential collision avoidance

If the robot is installed on a non-collaborative robot application that cannot sufficiently remove risks using its internal safety functions (e.g., use of dangerous tool), the system integrator must decide to install additional protection devices during risk assessment (e.g., use of protection devices capable of protecting the integrator during installation and programming).

1.6 Potential Risks

- Jamming fingers between the robot base and mount
- Jamming limbs between the Link 1 and Link 2 (between joint 3 (J3) and joint 4 (J4))
- Joint 1,2 (J1, J2) and Joint 5,6 (J5,J6) Jamming
- Penetration of skin by sharp edges or surfaces of the tool
- Penetration of skin by sharp edges or surfaces of objects in the operating space of the robot
- Contusion caused by robot movement
- Bone fracturing due to movement between heavy payload and hard surface
- Accidents that occur due to loosening of bolts securing the robot arm or tool
- Object falls from the tool due to inappropriate grip or sudden power shortage
- Accidents that occur due to mistaking an emergency stop button of different equipment
- Errors that occur due to unauthorized safety parameter modification

1.7 Validity and Responsibility

This manual does not provide information about the design, installation and operation methods of robot applications integrated with other systems. In addition, this manual does not provide information that may influence the safety of the integrated system.

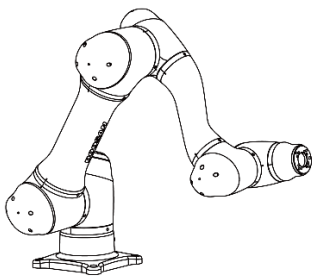
The system administrator must install the robot in a way that observes various safety requirements according to the related national standards and regulations. In addition, the staff in charge of integrating and managing the robot in a system must guarantee that all related national safety legislation and regulations are observed. The entity or user of the final system in which the robot is integrated has the following responsibilities, and such responsibilities are not limited to the items listed below.

- Risk assessment of the system with the robot integrated
- Installation and removal of safety devices according to the outcome of the risk assessment performed
- Confirmation of whether the system is properly designed, set up and installed
- Establishment of system operation and instructions
- Management of suitable safety settings in the software
- Prevention of users modifying safety devices
- Validity check of design and installation of integrated system
- Indication of contact information or important notifications related to use and safety
- Provision of technical documents including various manuals
- Provision of information on standards and legislation applied: http://www.doosanrobotics.com/

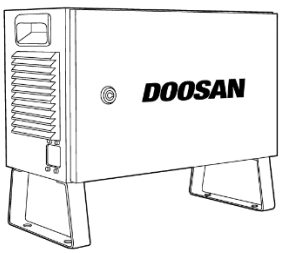
Compliance with the safety requirements in this manual does not mean all risks can be prevented.

2. Product Introduction

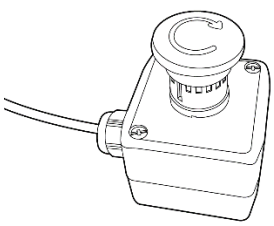
2.1 Component Check



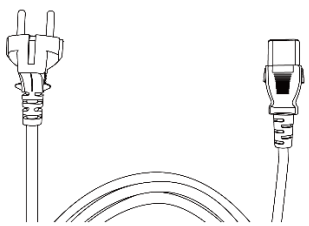
Robot (including connection cables)*



Control Box*



Emergency Stop Button*

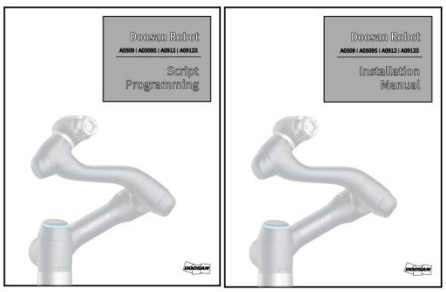


Control Box Power Cable

Teach Pendant**

Smart Pendant**

Laptop (for DART Platform installation, not included)



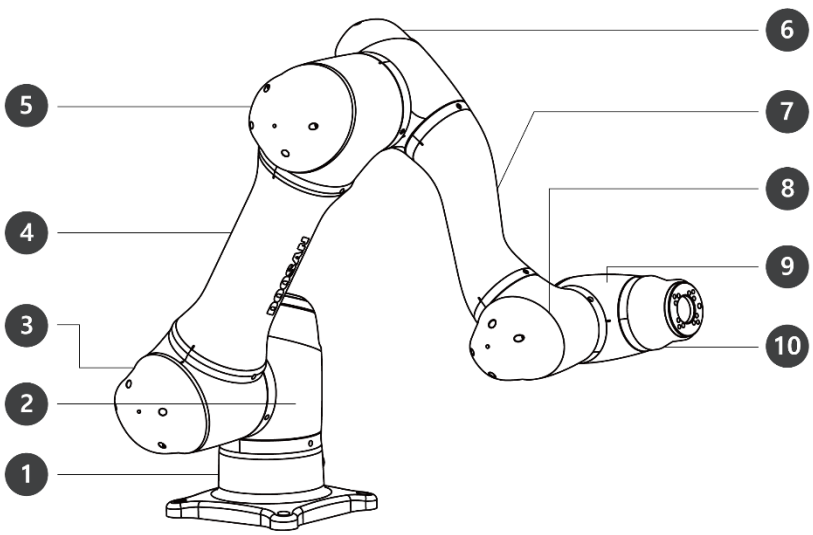
Manual*

Note

- Components may vary depending on the robot model.
- Items are indicated as standard items (*) and optional items (**, sold separately)
- The laptop is not included in the package, and it is necessary when installing the DART Platform.

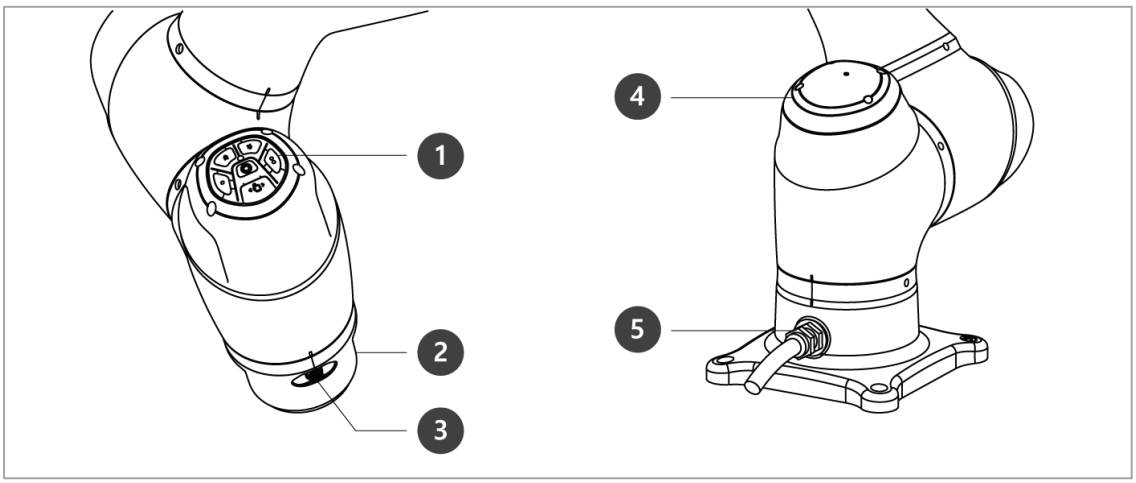
2.2 Names and Functions

2.2.1 Robot



- **Names of Parts**

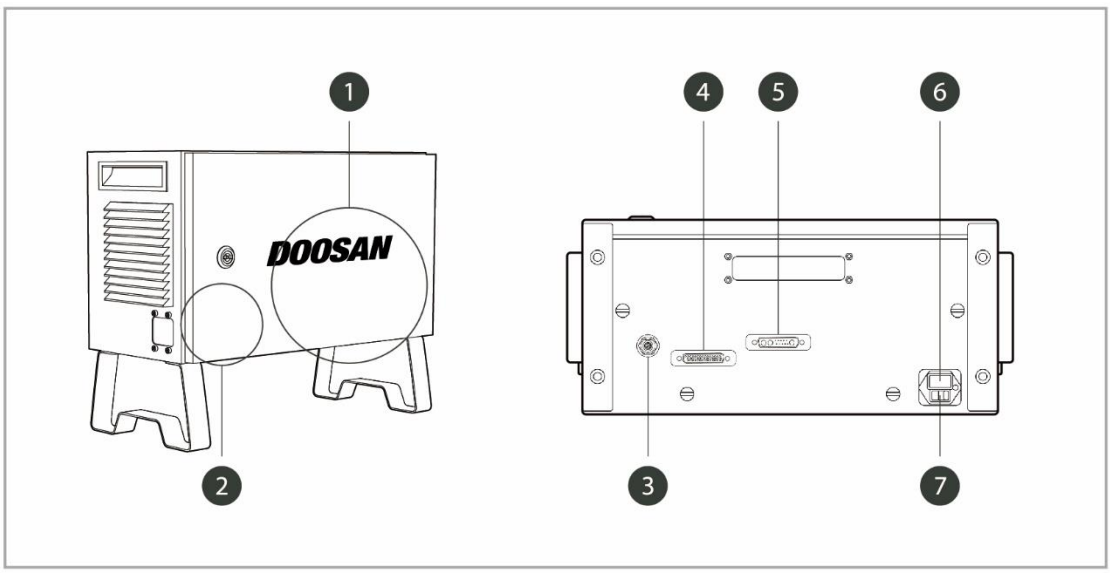
No.	Name	No.	Name
1	Base	6	J4
2	J1	7	Link2
3	J2	8	J5
4	Link1	9	J6
5	J3	10	Tool flange



- **Key Features**

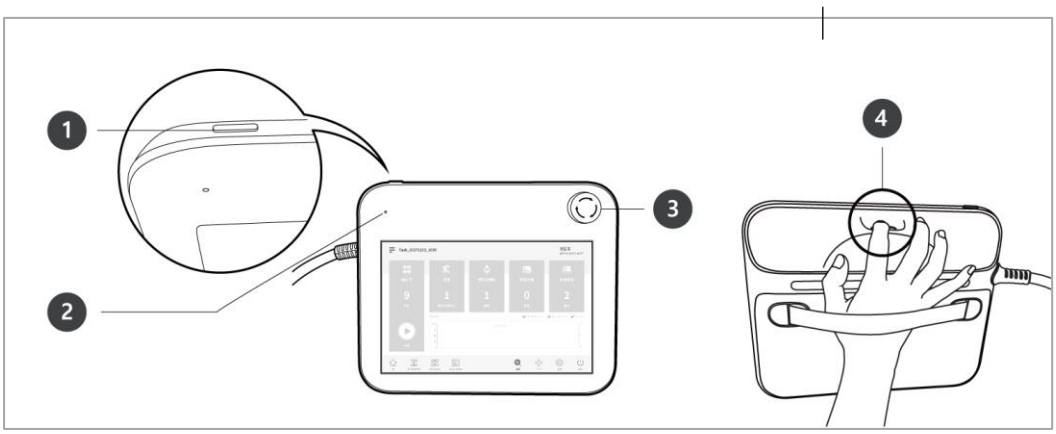
No.	Item	Description
1	Cockpit	Controller used for direct teaching.
2	Tool flange	Area to install tools.
3	Flange I/O	I/O port for tool control. (Digital input 2ch, output 2ch)
4	LED (1-axis)	Displays the robot status with different colors. For more information about robot status, refer to the “0 **Status and Flange LED** Color for Each Mode.”
5	Connector	Used for supplying power to and communication of the robot.

2.2.2 Control box



No.	Item	Description
1	I/O connection terminal (internal)	Used to connect the control box or peripherals.
2	Emergency stop button setting switch	To use the Teach Pendant, Smart Pendant, or Emergency Stop buttons, the switch must be set to match the actual configuration.
3	Emergency stop button and smart pendant connection terminal	Connects the emergency stop button or smart pendant cable to the control box.
4	Teach pendant cable connection terminal	Used to connect the teach pendant cable to the control box.
5	Robot cable connection terminal	Used to connect the robot cable to the control box.
6	Power connection terminal	Used to connect the control box power supply.
7	Power switch	Used to turn ON/OFF the main power of the control box.

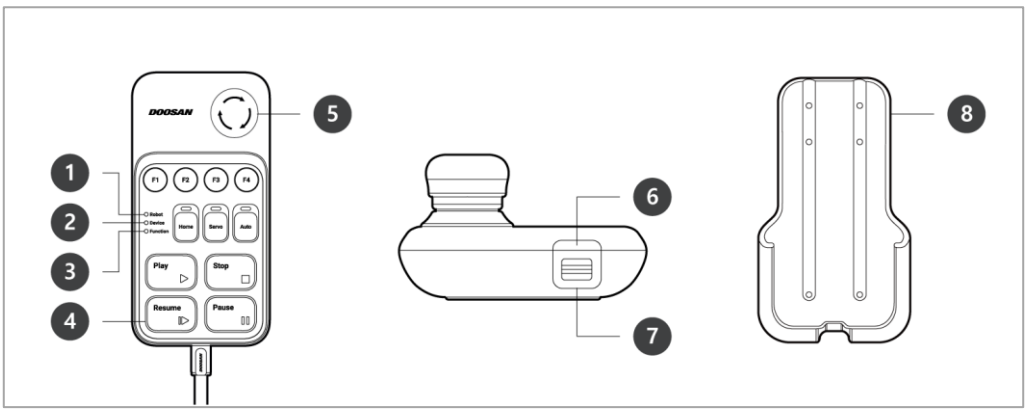
2.2.3 Teach pendant



No.	Item	Description
1	Power button	Used to turn ON/OFF the main power of the teach pendant.
2	Power LED	Turns ON when power is supplied.
3	Emergency Stop Button	In case of an emergency, press the button to stop robot operation.
4	Hand guiding button	Press and hold the button to move the robot freely into a desired pose.

※ The teach pendant is not a standard item but an optional item, so it must be purchased separately

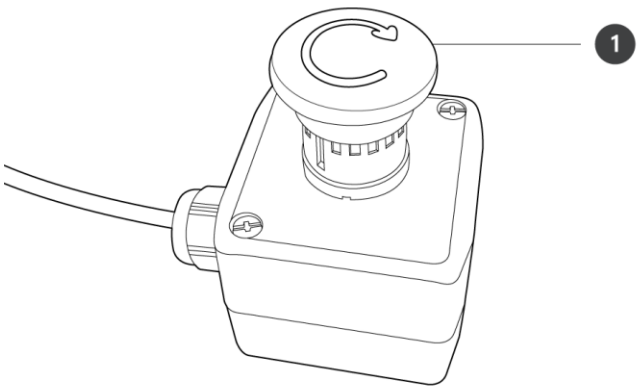
2.2.4 Smart Pendant



No.	Item	Description
1	Robot LED	Used to indicate the robot status by displaying the same color as the robot status LED to the user.
2	Device LED	Used to indicate whether the system entered smart pendant mode.
3	Function LED	Pressing four input signal buttons (F1-F4) lights the LED, indicating the press status.
4	Buttons	There are a total of 11 buttons including four input signal buttons (F1-F4) for each function, home, servo, auto, play, stop, resume and pause.
5	Emergency Stop Button	In case of an emergency, press the button to stop robot operation.
6	Power Button	Used to turn ON/OFF the main power of the smart pendant.
7	Strap Anchor	Used to add a strap to the device.
8	Holder bracket	Install the holder bracket on a wall to store the smart pendant.

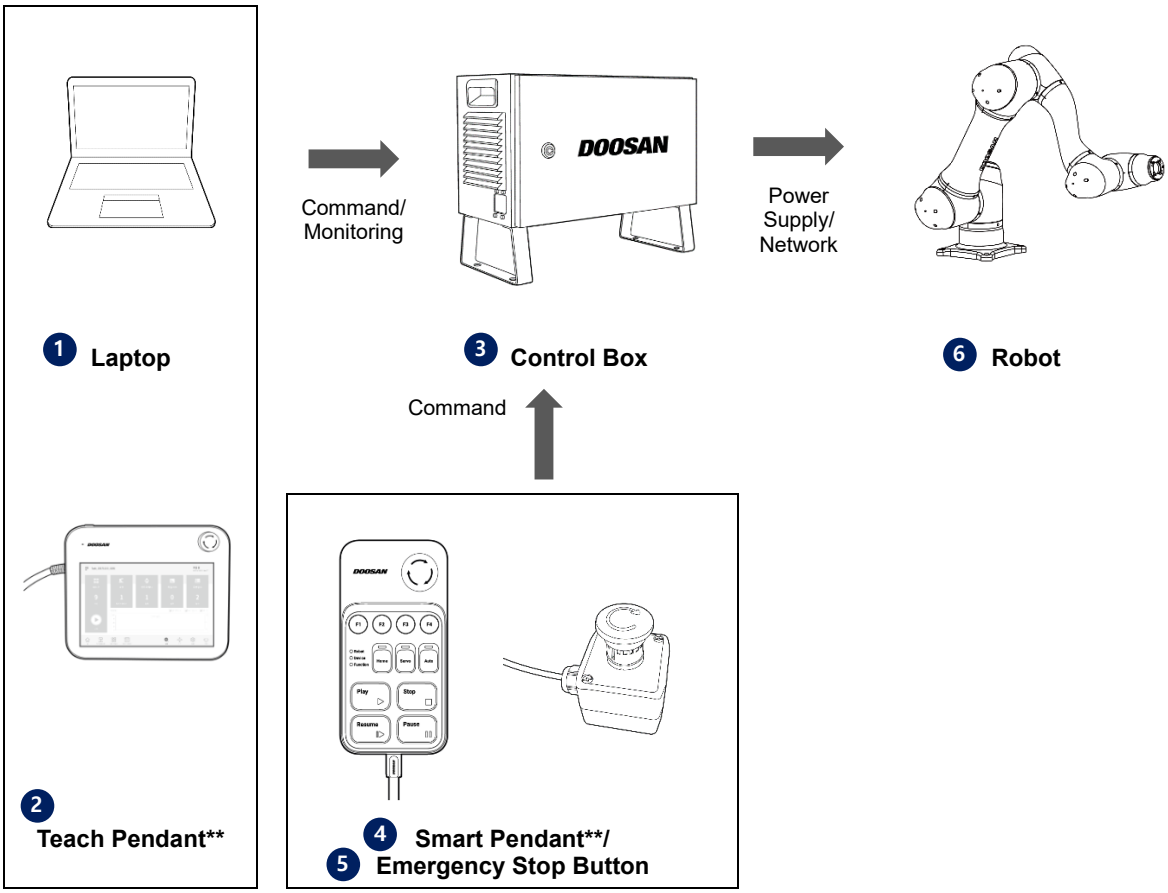
※ The smart pendant is not a standard item but an optional item, so it must be purchased separately

2.2.5 Emergency Stop Button



No.	Item	Description
1	Emergency stop button	In case of an emergency, press the button to stop robot operation.

2.3 System Configuration



- 1 Laptop: After installing the DART Platform, a work environment identical to the teach pendant can be set up.
- 2 Teach Pendant**: It is a device that manages the overall system, and it is capable of teaching the robot specific poses and setting the robot and items related to the installation of the control box and robot.
  (purchased separately as an option)
- 3 Control Box: It controls the robot's movement according to the pose or movement set by the teach pendant. It features various I/O ports that allow the connection and use of various equipment and devices.
- 4 Smart Pendant**: The robot can be easily controlled using a pendant capable of performing simple functions such as turning on the servo ON/OFF or executing/closing preset programs.
  (purchased separately as an option)
- 5 Emergency Stop Button: If a laptop is used as part of the system, it acts as the emergency stop button of the teach pendant.
- 6 Robot: It is an industrial collaborative robot that can perform transport or assembly tasks with various tools.

2.4 Product Specifications, General

M-Series	Technical Data
A0509(s)	Basic Specifications (refer to 1.5.1) Axis Specifications (refer to 1.5.2) Work Radius (refer to 1.5.3) Payload (refer to 1.5.4)
A0912(s)	

2.5 Robot Specifications

2.5.1 Basic Specifications

Model Name	A0509	A0509s[1)]	A0912	A0912s[1)]
Weight	21 kg		31 kg	
Payload within Work Radius	5 kg		9 kg	
Max. Work Radius	900 mm		1200 mm	
Number of Axes	6			
Max. TCP Speed	Over 1 m/s			
Position Repeatability (ISO 9283)	±0.03 mm		±0.05 mm	
Protection Rating	IP 54			
Noise	< 65 dB			
Installation Direction	Floor / Wall / Ceiling / Any			
Control Box and Teaching Pendant	Doosan Controller, DART Platform & Teach Pendant (Option)			
Vibration and Acceleration	10≤f< 57㎐ - 0.075 mm amplitude 57≤f≤150㎐ – 1G			
Impact	Max Amplitude : 50㎨ (5G) * Time: 30 ㎳, Pulse: 3 of 3 (X,Y,Z)			
Operating Temperature	-5 - 45℃ (268K-318K)			
Storage Temperature	-5 - 50℃ (268K-323K)			
Humidity	90% RH (non-condensing)			

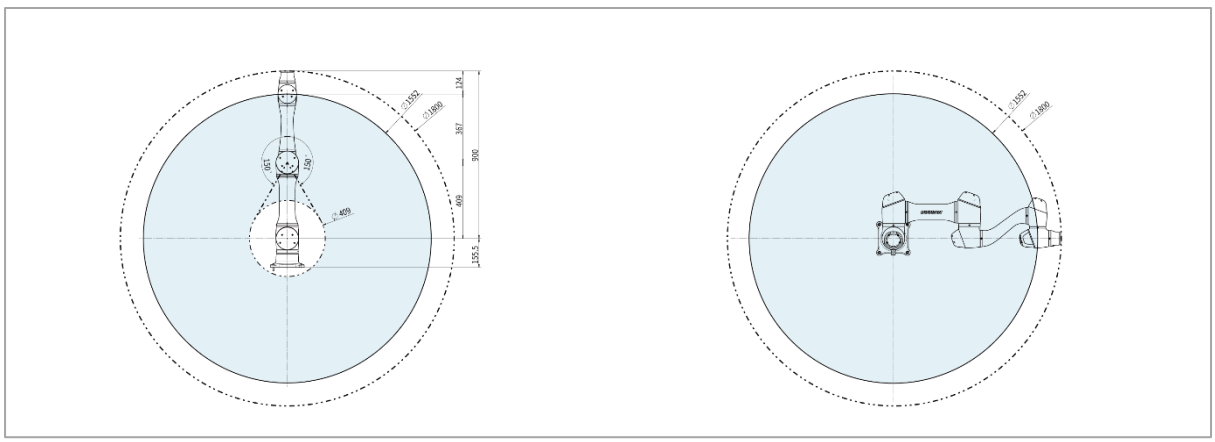
1) This is the model with an integrated Force Torque Sensor, so make sure to check the **FTS Specification**.

2.5.2 Axis Specifications

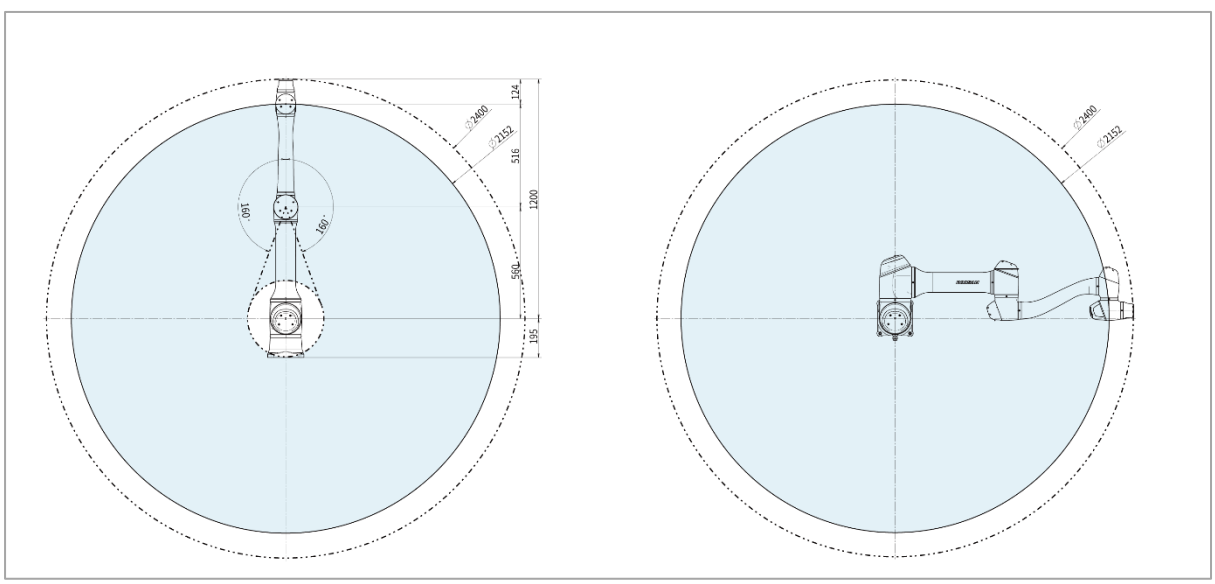
Model Name	A0509	A0509s	A0912	A0912s
Operating Angle				
J1	±360°		±360°	
J2	±360°		±360°	
J3	±160°		±160°	
J4	±360°		±360°	
J5	±360°		±360°	
J6	±360°		±360°	
Max. Speed per Axis (rated payload operation)				
J1	180 °/s		180 °/s	
J2	180 °/s		180 °/s	
J3	180 °/s		180 °/s	
J4	360 °/s		360 °/s	
J5	360 °/s		360 °/s	
J6	360 °/s		360 °/s	

2.5.3 Robot operating space

- **A0509**

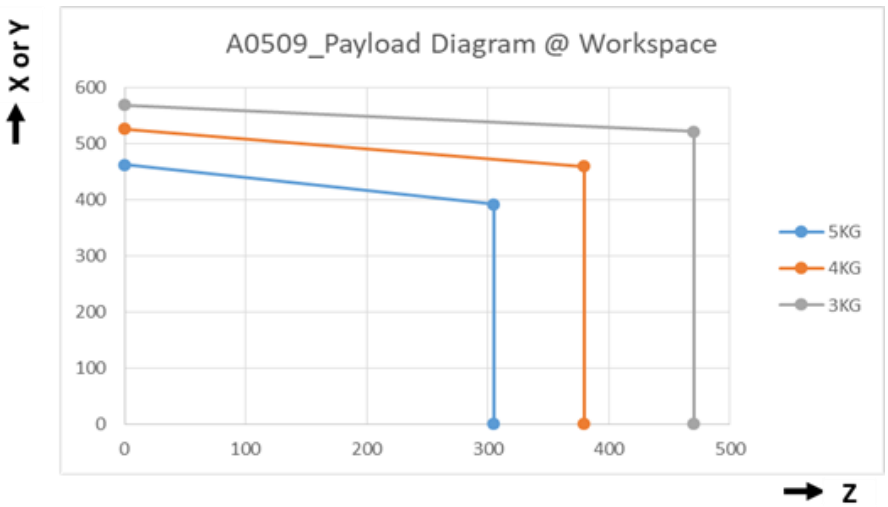


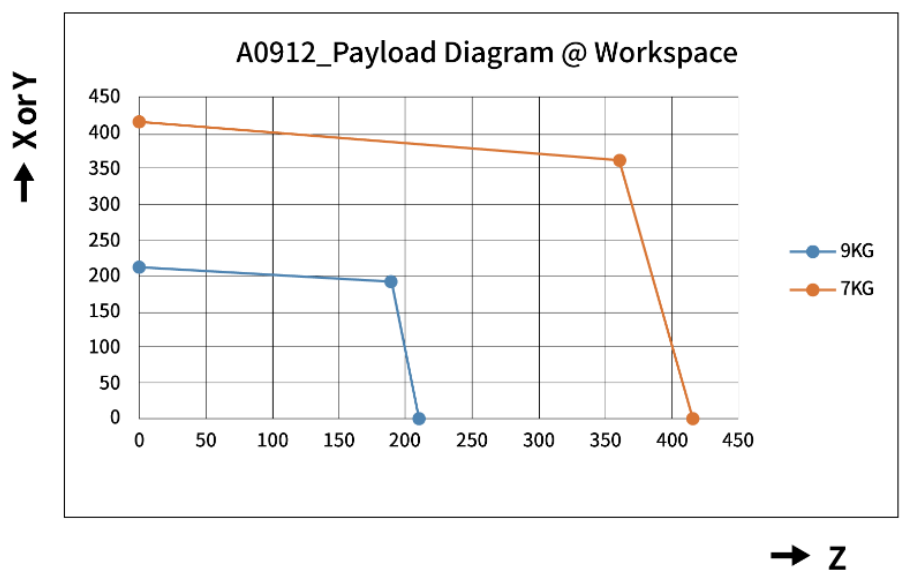
- **A0912**



2.5.4 Max. Payload within operating space

The maximum payload of the robot within its operating space changes according to the distance from the center of gravity. Payload per distance is as follows:



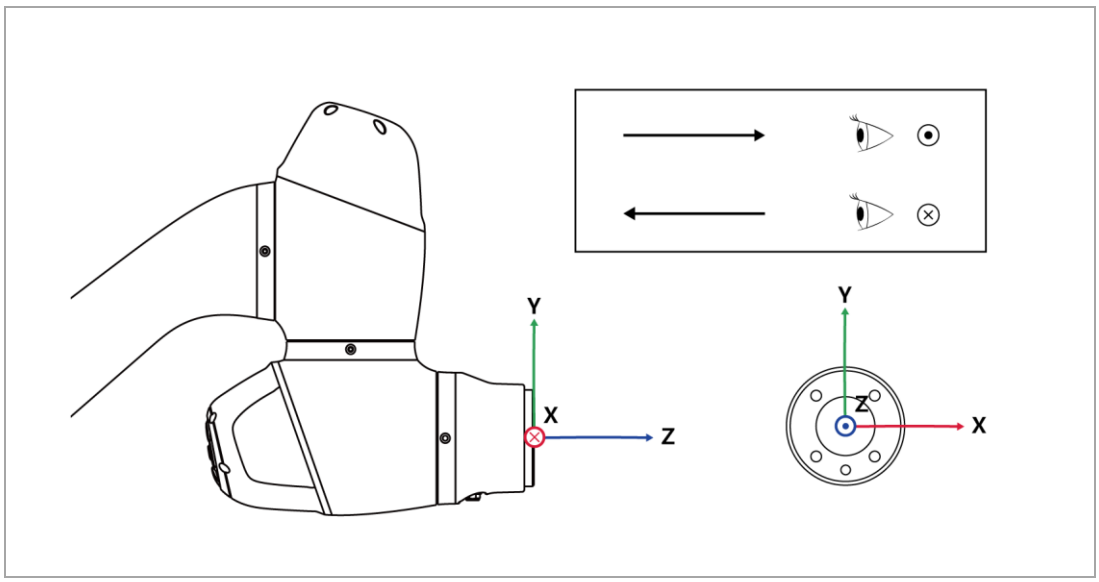


Note

- This load diagram assumes a small tool load volume. Tools with a larger volume will have greater limitations in payloads above the tool's center of gravity compared to a tool with equal weight but smaller volume, and in such cases, vibration may occur.

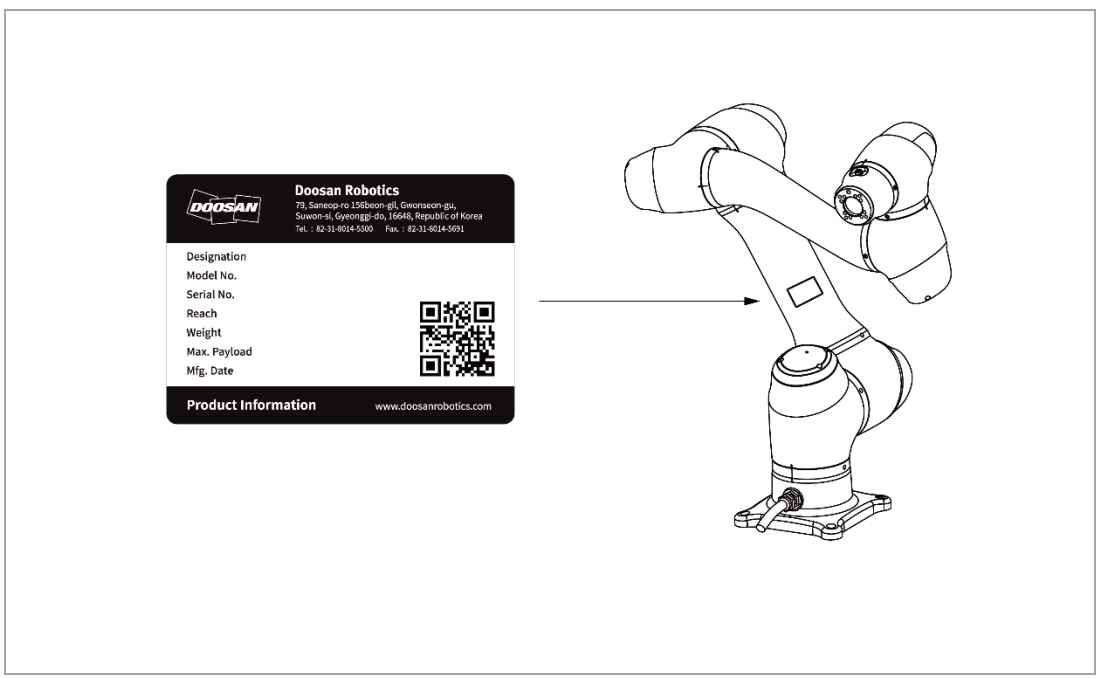
2.5.5 Tool Center Point (TCP)

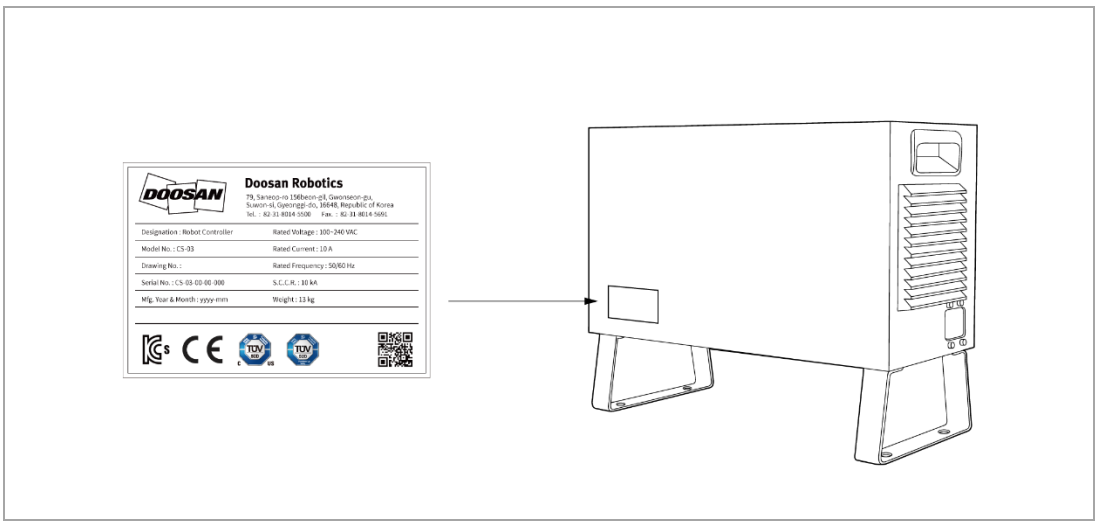
Refer to the figure below for TCP.



2.6 Nameplates and Labels

Be careful not to remove or damage labels attached to the robot and control box.




DOOSAN
Doosan Robotics
79, Sanseo-ro 156beon-gil, Gwonseon-gu,
Suwon-si, Gyeonggi-do, 16648, Republic of Korea
Tel. : 82-31-8014-5500 Fax. : 82-31-8014-5691
Designation : Robot Controller
Rated Voltage : 100~240 VAC
Model No. : CS-03
Rated Current : 10 A
Drawing No. :
Rated Frequency : 50/60 Hz
Serial No. : CS-03-00-00-000
S.C.C.R. : 10 kA
Mfg. Year & Month : yyyy-mm
Weight : 13 kg

3. Installation

3.1 Cautions during Installation

⚠ Warning

- Secure sufficient space for installation before installing the robot. If not enough space is secured, the robot may be damaged or the user may be injured.
- Safety devices to be connected to the control box must be connected to a safety contact input terminal or a configurable digital I/O set as Safety I/O using dual signals. If safety devices are connected to a regular I/O or connected using single signals, the devices cannot satisfy the required safety level.
- When connecting the power plug and and power cable to a power source, do not touch them with wet hands. This can cause electrocution or injury. The maximum payload of the robot within its operating space changes according to the distance from the center of gravity.
- To use the Teach Pendant, Smart Pendant, or Emergency Stop buttons, the switch must be set to match the actual configuration.
- If the setting (Section 3.3.10) of the emergency stop button setting switch is different from the actual configuration, the emergency stop button may fail and cause injury to the user in an emergency situation, so check the setting condition and operation of the emergency stop button.

⚠ Caution

- Ensure that the mounting bolts are completely tightened during installation. If the mounting bolts become loose, the base and robot may separate during operation, resulting in breakdowns.
- Make sure that safety measurements and robot safety setting parameters are correctly defined according to the risk assessment. If these are not established, the robot may be damaged or the user may be injured.
- Correctly set robot installation-related settings such as robot mounting angle, TCP weight, TCP offset and safety settings. If these are not established, the robot may be damaged or the user may be injured.

3.2 Installation Environment

Secure sufficient space to allow the robot to move freely. Check the operating space of the robot to ensure that the robot does not collide with external elements.

3.2.1 Installation Location Check

Before installing the robot, secure sufficient space and consider the following:

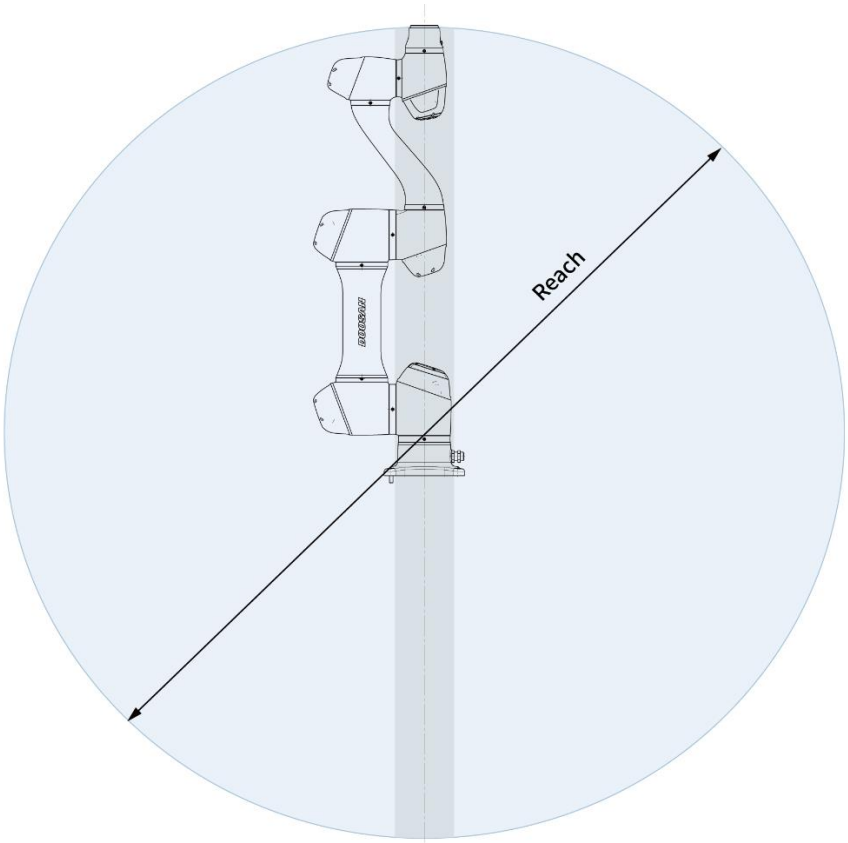
- Install the robot on a firm, even surface.
- Install the robot in a location with no water leakage and with constant temperature and humidity.
- Check whether flammable and explosive materials are near the installation location.

Caution

- Installing the robot in locations other than the recommended locations may result in reduced robot performance and product life.

3.2.2 Robot Work Area Check

Secure installation space considering the operating space of the robot. The operating space varies according to the robot model.



Note

The gray areas in the figure are areas where the robot has difficulty performing work. Within this area, the speed of tools is low but the speed of joints is high, making it difficult to conduct a risk assessment because the robot can operate inefficiently. Therefore, it is not recommended to operate the tool passing through the cylindrical section on the top and bottom of the base.

3.3 Hardware Installation

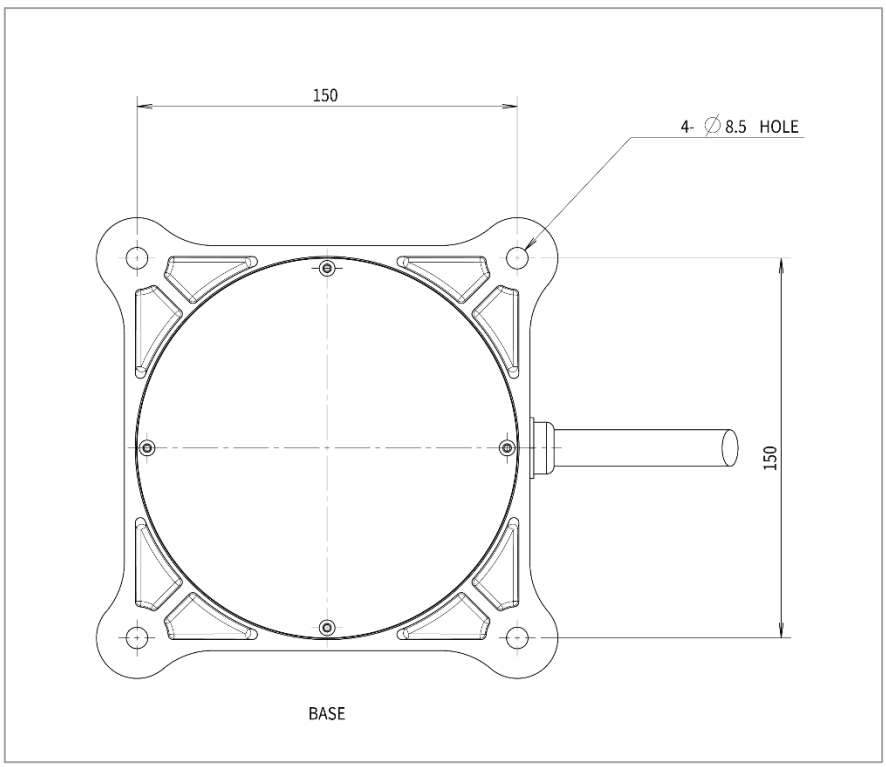
Install the robot, control box and teach pendant, the key components of the system in the work area, and supply power to them before operating the robot. The installation of each component is as follows:

3.3.1 Securing the Robot

Use M8 bolts in the four 9.5 mm holes in the robot base to secure the robot.

- It is recommended to use a tightening torque of 20 Nm to tighten the bolts.

  Use a Φ5 place marker pin to accurately install the robot in a fixed location.



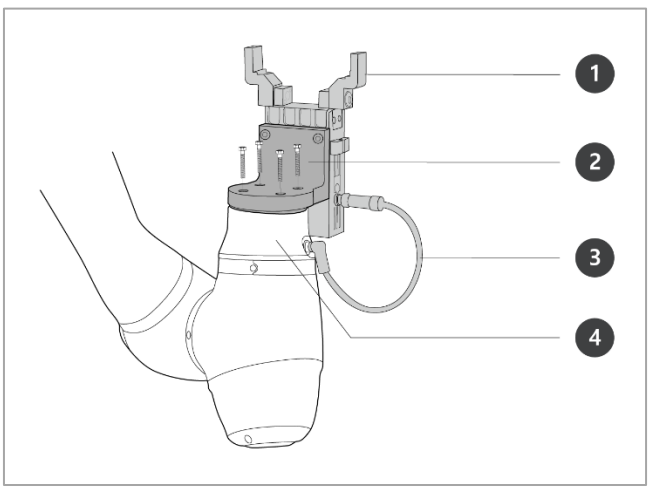
Robot base drawing, use four M8 bolts. Unit [mm]

Warning

- Tighten the bolts all the way to prevent loosening during robot operation.
- Install the robot base on a solid surface that can withstand the load generated during operation (10 times the maximum torque and five times the weight of the robot).

- The robot will interpret robot base vibration as a collision and engage the emergency stop. Therefore, in the case of installation locations that automatically shift position, do not install the robot base in a location with high movement acceleration.
- Mount the robot arm in a specific location using appropriate methods. The mounting surface must be solid.
- The robot will be damaged if it comes in contact with water for an extended period of time. Do not operate the robot in conditions where it can get wet or under water.

3.3.2 Connecting the Robot and Tool



No.	Item
1	Tool
2	Bracket
3	Cable
4	Tool flange

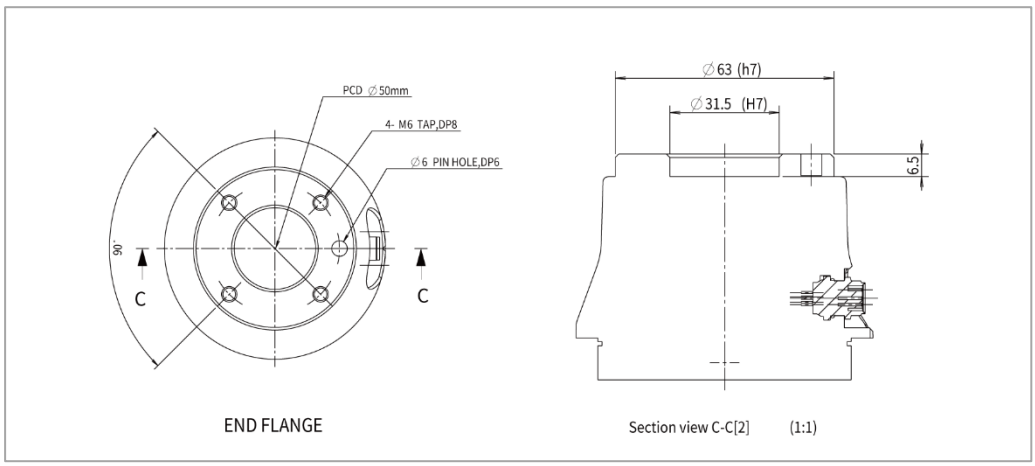
1 Use four M6 bolts to secure the tool on the tool flange.

- It is recommended to use tightening torque of 9 Nm to tighten the bolts.
- Use a Φ6 place marker pin to accurately install the robot in a fixed location.

2 Connect the necessary cables to the tool I/O after the tool is secured.

Note

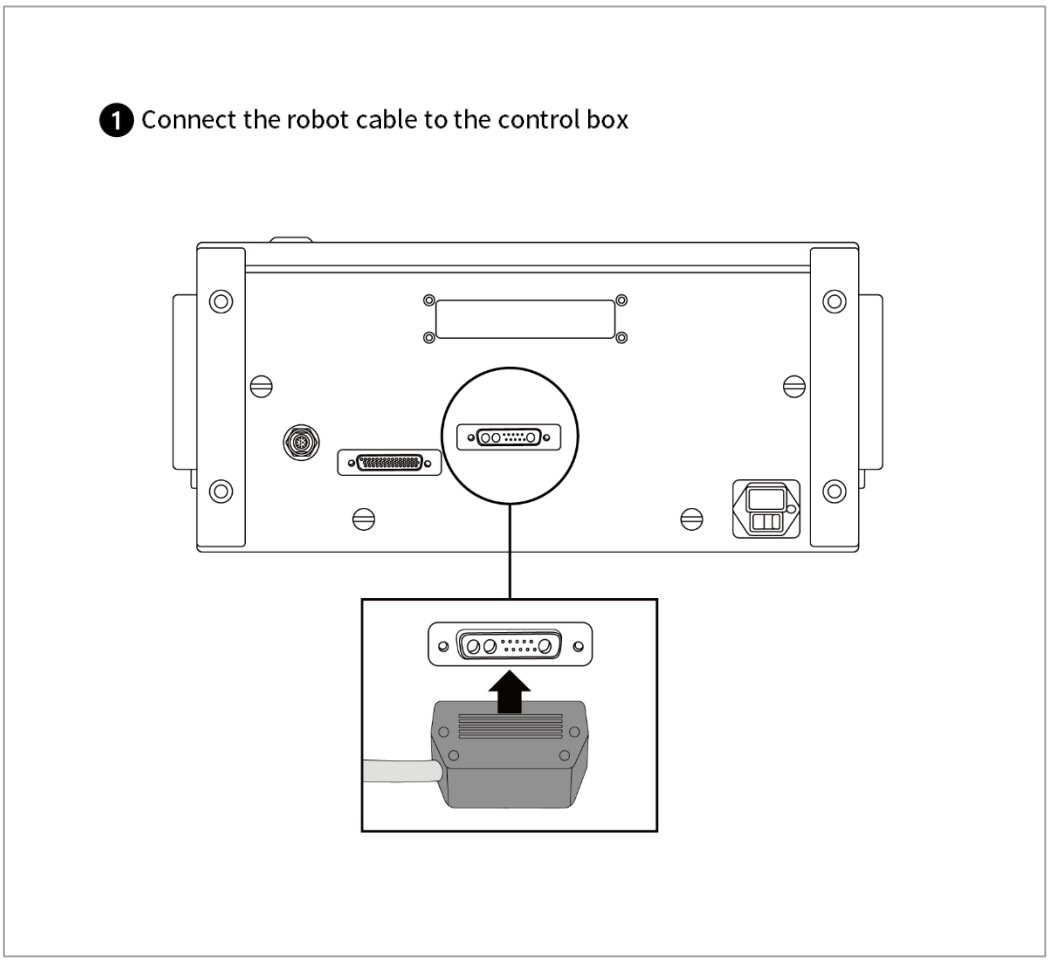
Methods of securing the tool may vary according to the tool. For more information about tool installation, refer to the manual provided by the tool manufacturer.



Tool output flange, ISO 9409-1-50-4-M6

3.3.3 Connecting the Robot and Control Box

Push the robot cable connected to the robot into the corresponding control box connector until a click is heard to prevent the cable from becoming loose.

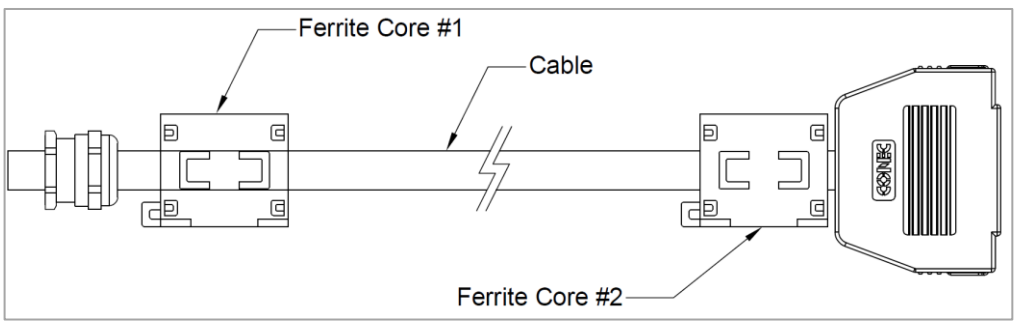


Caution

- Do not disconnect the robot cable when the robot is turned on. This can cause damage to the robot.
- Do not modify or extend the robot cable.
- When installing the control box on the floor, secure at least 50 mm of space on each side of the control box to enable ventilation.
- Make sure that connectors are properly connected before turning on the control box.

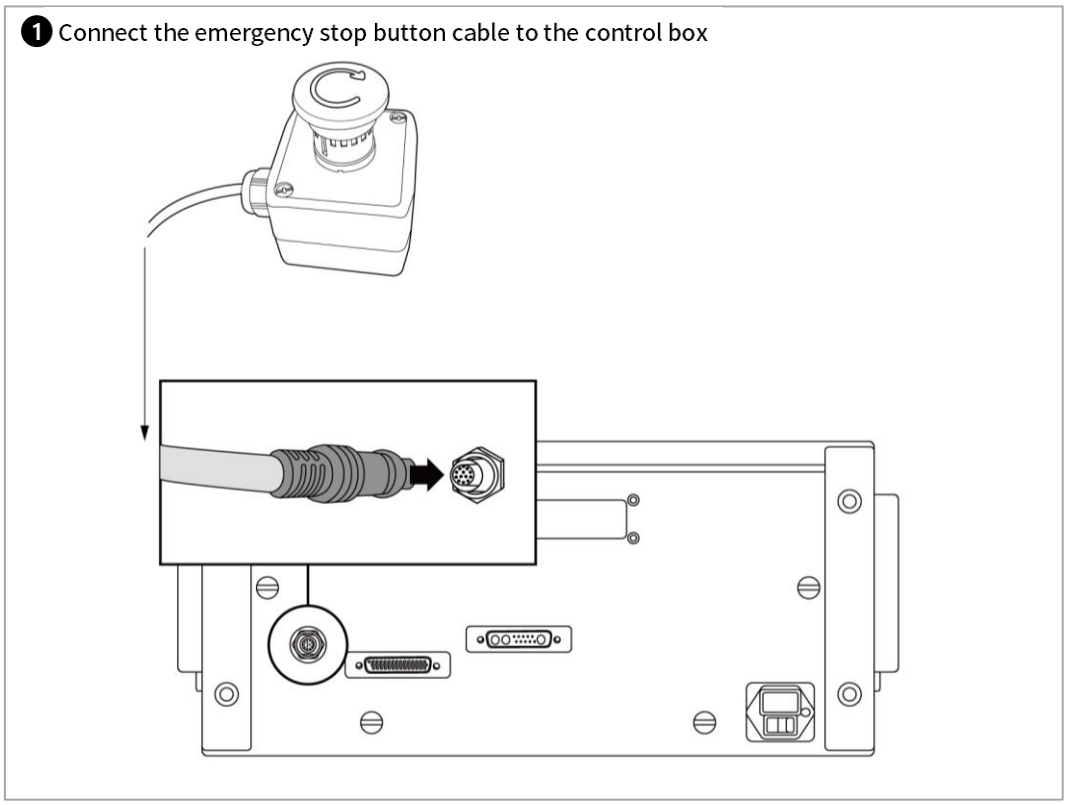
Note

- When configuring the system, it is recommended to install a noise reducer to prevent noise influence among devices and system malfunctioning.
- If the control box is affected by the noise generated by electromagnetic waves, it is necessary to install a ferrite core to ensure normal operation. The installation location is as follows:



3.3.4 Connecting the Control Box and Emergency Stop Button

Connect the emergency stop button cable to the corresponding control box connector and install a screw lock by turning it clockwise to prevent the cable from becoming loose.



Warning

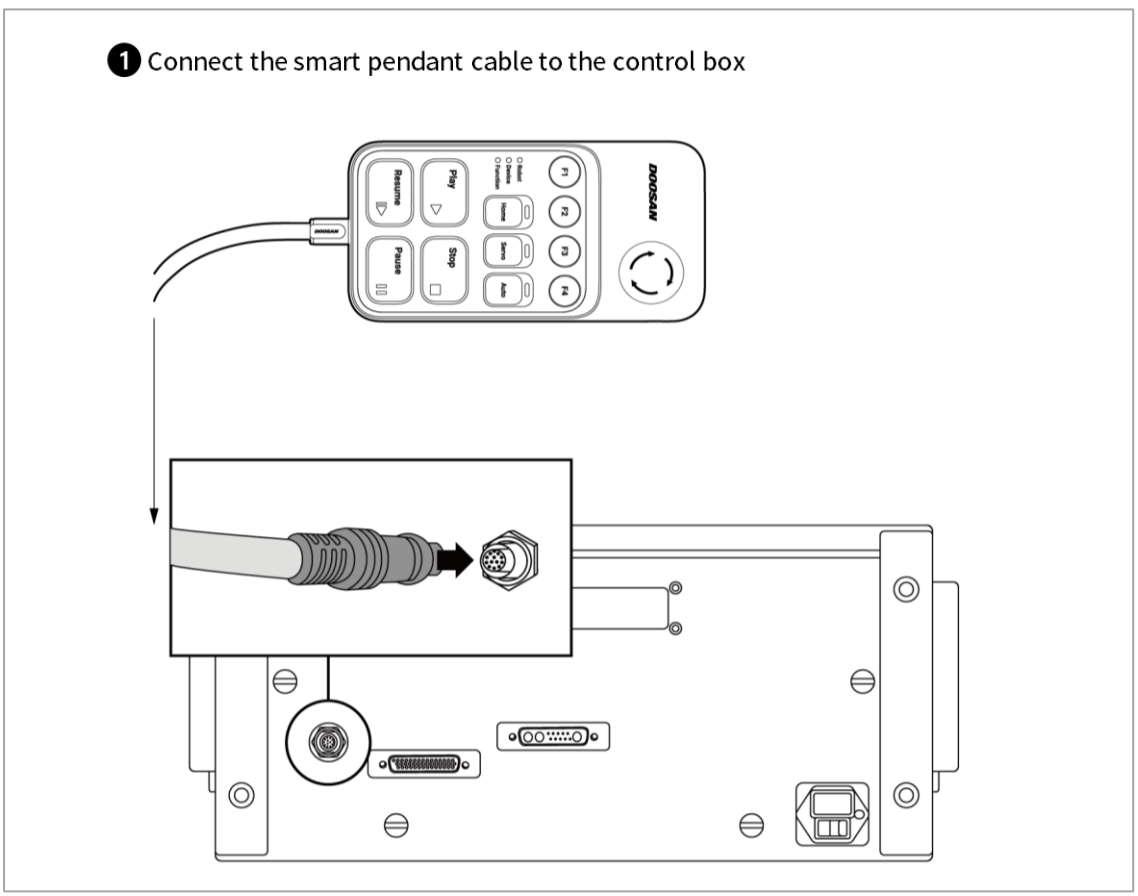
- If the setting(Section 3.3.10) of the emergency stop button setting switch is different from the actual configuration, the emergency stop button may fail and cause injury to the user in an emergency situation, so check the setting condition and operation of the emergency stop button.

Caution

- Make sure to check the connector shape before connecting the cable.
- If the emergency stop button is used, be careful not to trip on the connecting cables.
- Be careful not to allow the control box, emergency stop button and cable to come in contact with water.
- Do not install the control box and emergency stop button in a dusty or wet environment.
- The control box and emergency stop button must not be exposed to dust conditions exceeding IP40 ratings. Be especially careful in environments that have conductive dust.
- Do not disconnect the emergency stop button cable during robot operation.

3.3.5 Connecting the Control Box and Smart Pendant

Connect the smart pendant cable to the corresponding control box connector and install a screw lock by turning it clockwise to prevent the cable from becoming loose.



Warning

- If the setting(Section 3.3.10) of the emergency stop button setting switch is different from the actual configuration, the emergency stop button may fail and cause injury to the user in an emergency situation, so check the setting condition and operation of the emergency stop button.

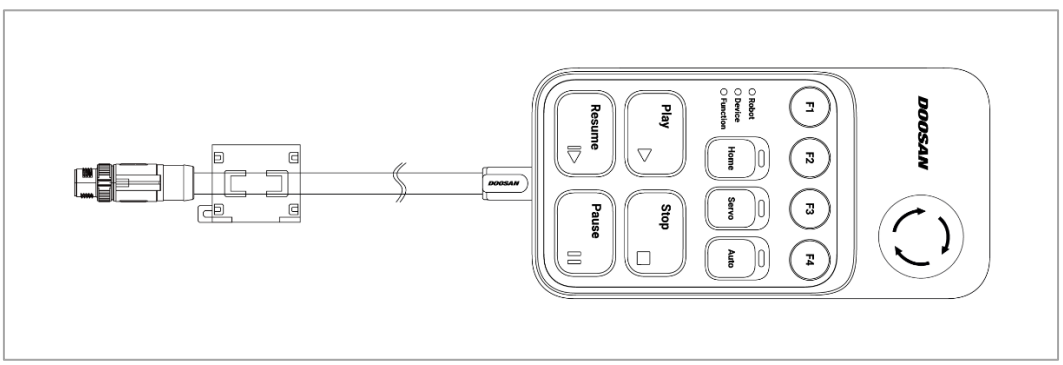
Caution

- Make sure to check that the pins of the cable end are not damaged or bent before connecting the cable.
- If the smart pendant is used by hanging it on the wall or on the control box, be careful not to trip on the connecting cables.
- Be careful not to allow the control box, smart pendant and cable to come in contact with water.
- Do not install the control box and smart pendant in a dusty or wet environment.

- The control box and smart pendant must not be exposed to dust conditions exceeding IP20 ratings. Be especially careful in environments that have conductive dust.
- Ensure that the smart pendant cable curvature is greater than the minimum curvature radius (120 mm).

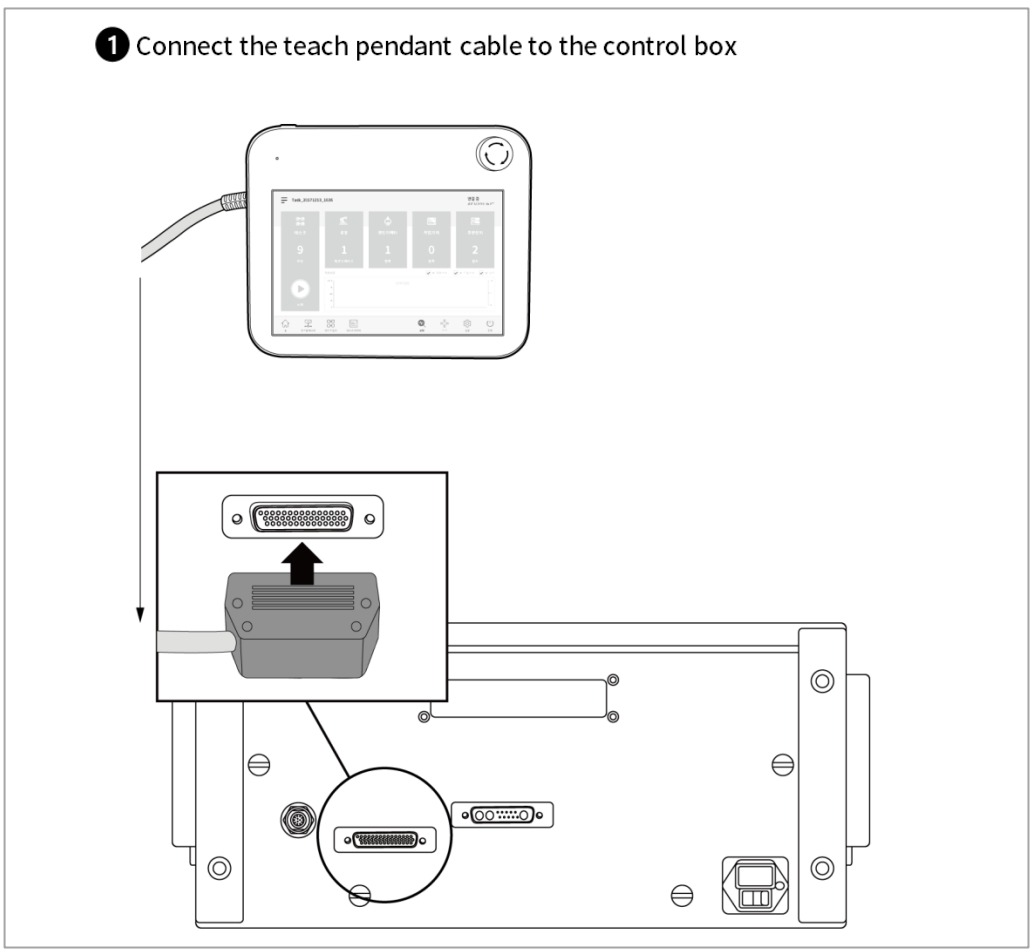
Note

- When configuring the system, it is recommended to install a noise reducer to prevent noise influence among devices and system malfunctioning.
- If the smart pendant is affected by the noise generated by electromagnetic waves, it is necessary to install a ferrite core to ensure normal operation. The installation location is as follows:



3.3.6 Connecting the Control Box and Teach Pendant

Push the teach pendant cable into the corresponding control box connector until a click is heard to prevent the cable from becoming loose.



Warning

- If the setting(Section 3.3.10) of the emergency stop button setting switch is different from the actual configuration, the emergency stop button may fail and cause injury to the user in an emergency situation, so check the setting condition and operation of the emergency stop button.

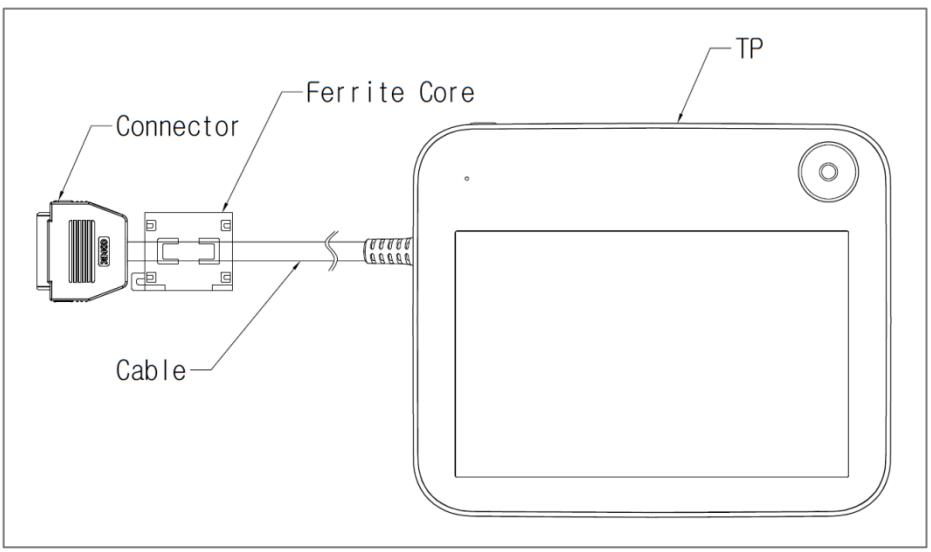
Caution

- Make sure to check that the pins of the cable end are not damaged or bent before connecting the cable.
- If the teach pendant is used by hanging it on the wall or on the control box, be careful not to trip on the connecting cables.
- Be careful not to allow the control box, teach pendant and cable to come in contact with water.

- Do not install the control box and teach pendant in a dusty or wet environment.
- The control box and teach pendant must not be exposed to dust conditions exceeding IP30 ratings. Be especially careful in environments that have conductive dust.

Note

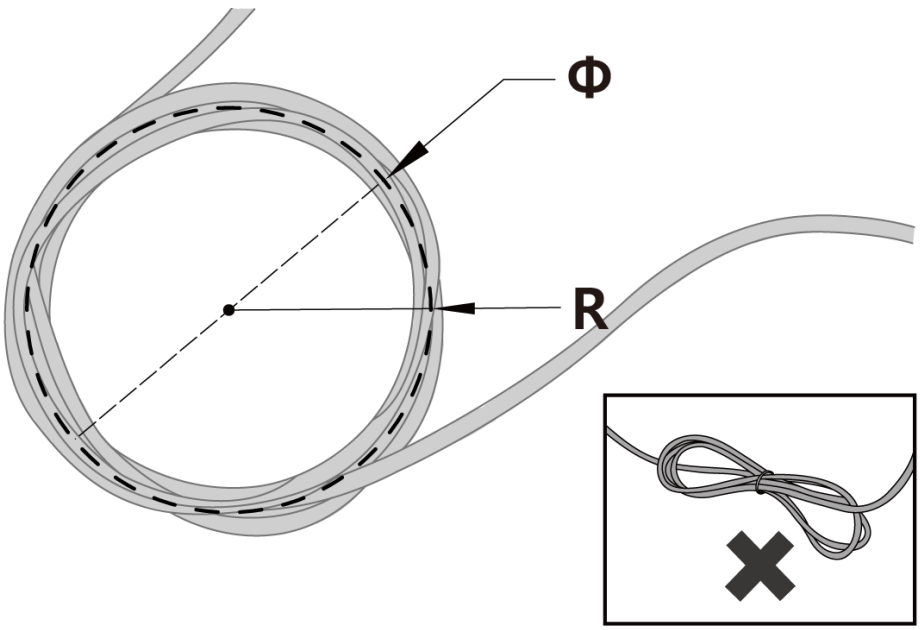
- When configuring the system, it is recommended to install a noise reducer to prevent noise influence among devices and system malfunctioning.
- If the teach pendant is affected by the noise generated by electromagnetic waves, it is necessary to install a ferrite core to ensure normal operation. The installation location is as follows:



3.3.7 Routing of Cables

Ensure that the cable curvatures are greater than the minimum curvature radius. The minimum curvature radius of each cable is as follows:

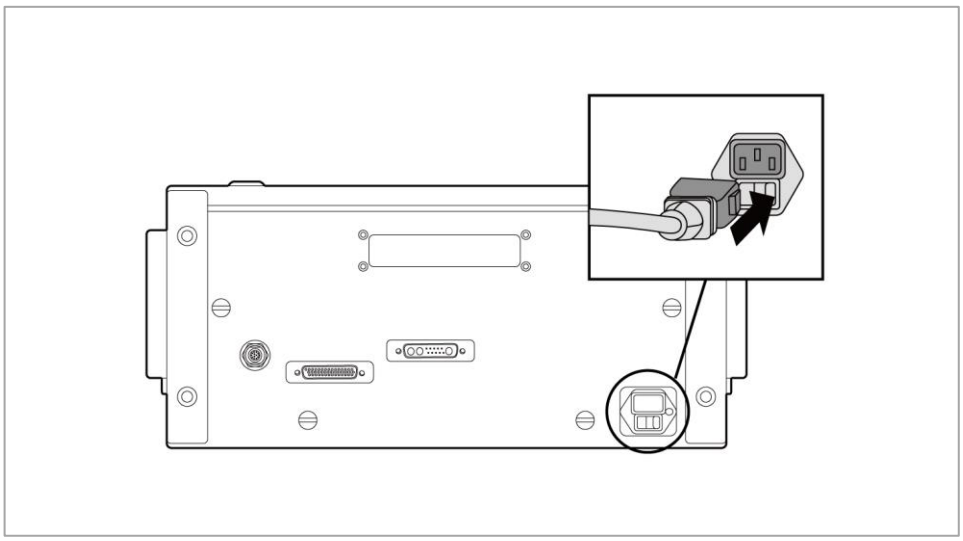
Cable	Minimum Curvature Radius (R)
Teach pendant cable	120 mm
Robot cable	120 mm
Smart pendant cable	100 mm
Emergency stop button cable	100 mm



3.3.8 Supplying Power to the Control Box

To supply power to the control box, connect the power cable of the control box to a standard IEC power outlet.

- Use a cable with a standard power plug that matches the outlet of country of use.
- Push the plug completely into the corresponding control box connector to prevent the cable from becoming loose. Connect a standard IEC C14 plug and corresponding IEC C13 cord (refer to below) to the control box.



Warning

- After connecting the power cable, make sure that the robot is properly grounded (electronic ground connection). Establish a common ground for all equipment in the system with an unused bolt related to the ground symbol inside the control box. The ground conductor must satisfy the maximum current rating of the system.
- Protect the input power of the control box using a circuit breaker.
- Do not modify or extend the robot cable. It can cause a fire or control box breakdown.
- Make sure that all cables are properly connected before supplying power to the control box. Always use the original cable included in the product package.

Note

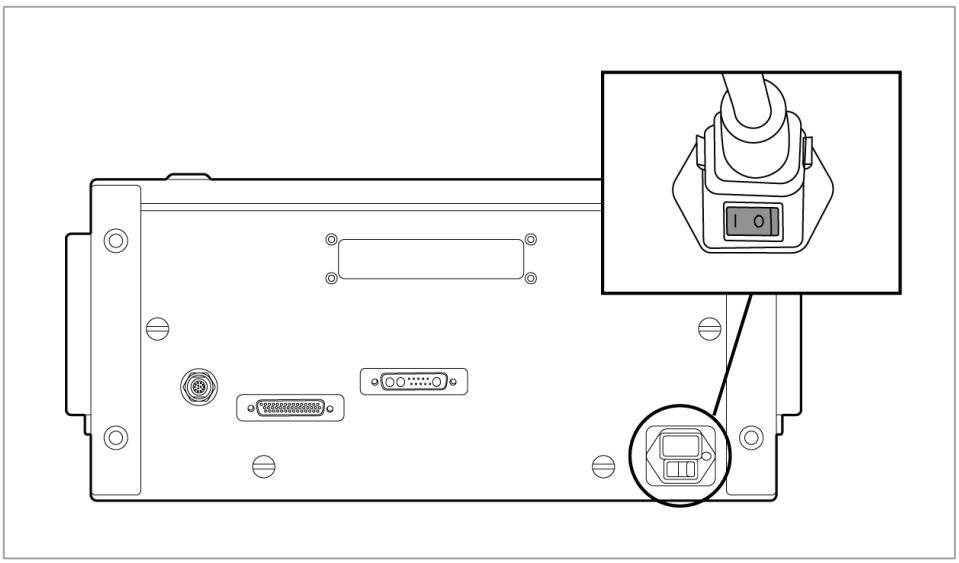
- When configuring the system, it is recommended to install a power switch that can turn off power to all devices in the system at once.
- The power supply must satisfy minimum requirements such as ground and circuit breakers. The electrical specifications are as follows:
- If the input voltage is less than 180V, the robot's movement may be limited according to the load and motion.

Parameter	Specifications
Input Voltage	100 – 240 VAC
Input Power Fuse (@100-240V)	15 A
Input Frequency	50 – 60 Hz

3.3.9 System Power-Up

Press the power button located on the bottom of the control box.

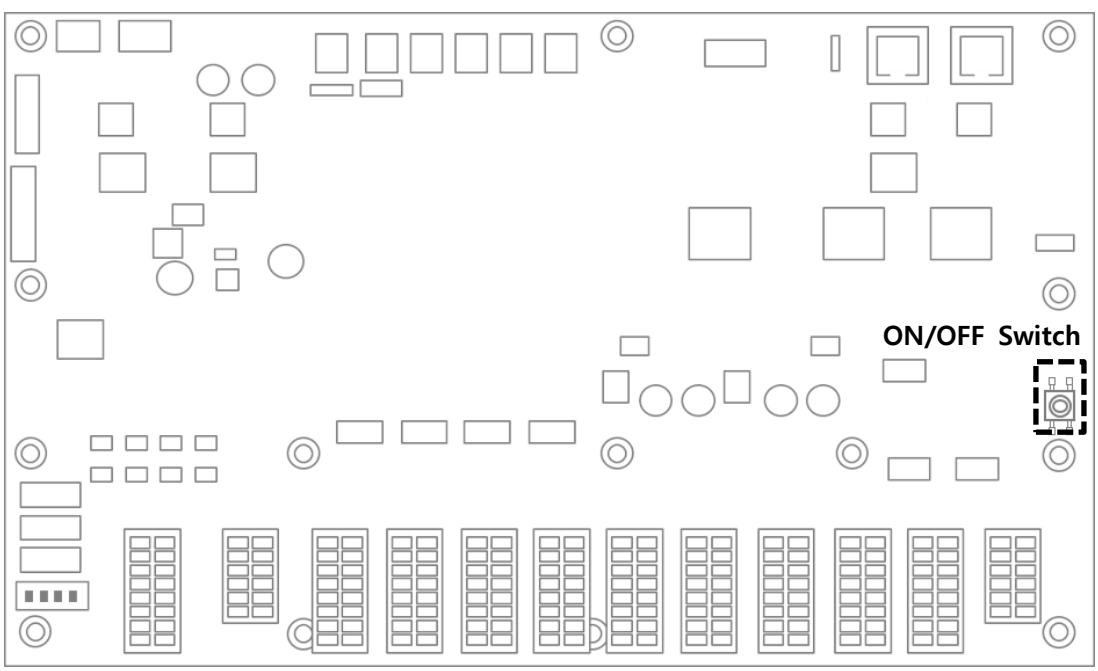
- Power is supplied to systems including the robot, control box, teach pendant and smart pendant.

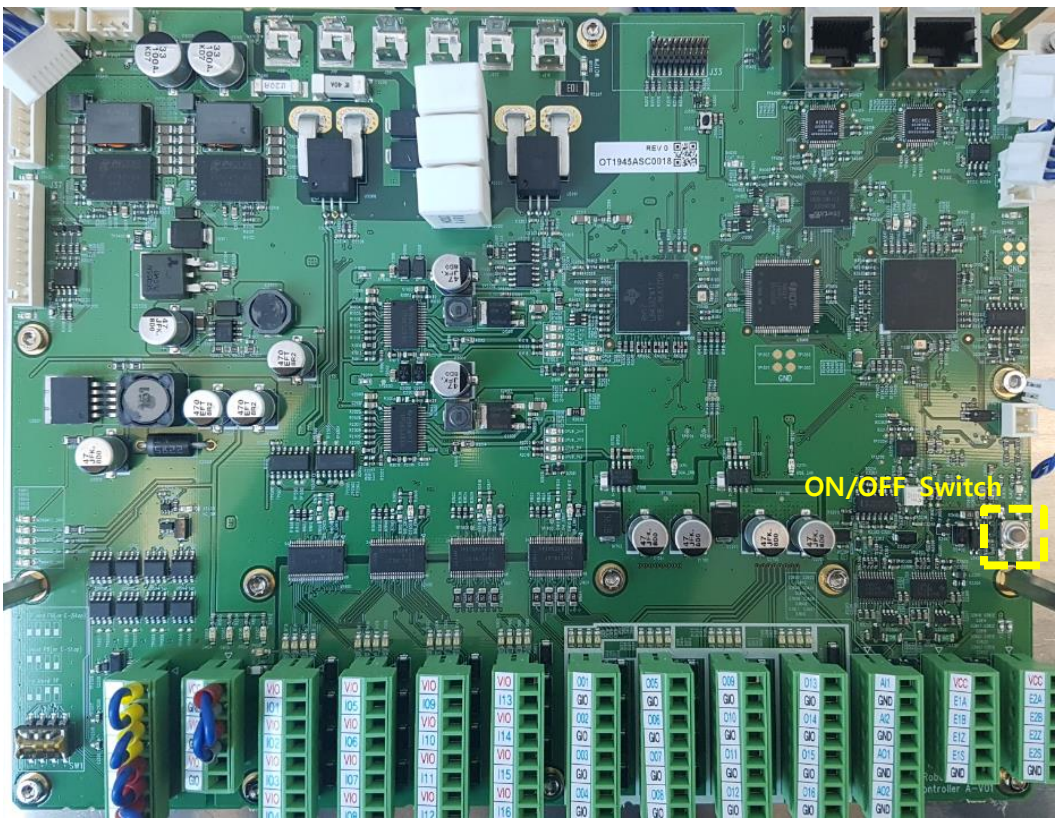


[PC Power ON/OFF when only E-STOP Box is available - Standard Item]

Open the control box door, and press and hold the power button located below the bottom right of the Safety board.

- To turn off the power, press and hold the button.

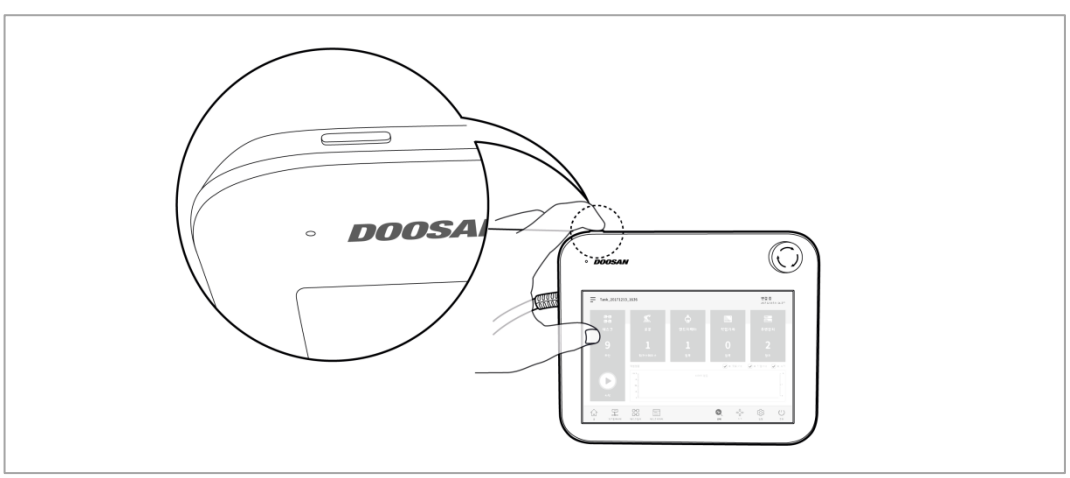




[PC Power ON/OFF when Teach Pendant is used - Optional Item]

Press and hold the power button located on the top left of the teach pendant.

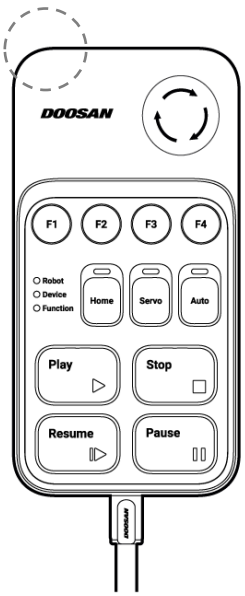
- To turn off the power, press and hold the button.

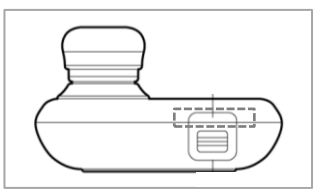


[PC Power ON/OFF when Smart Pendant is used - Optional Item]

Press and hold the power button located on the top left of the smart pendant.

- To turn off the power, press and hold the button.





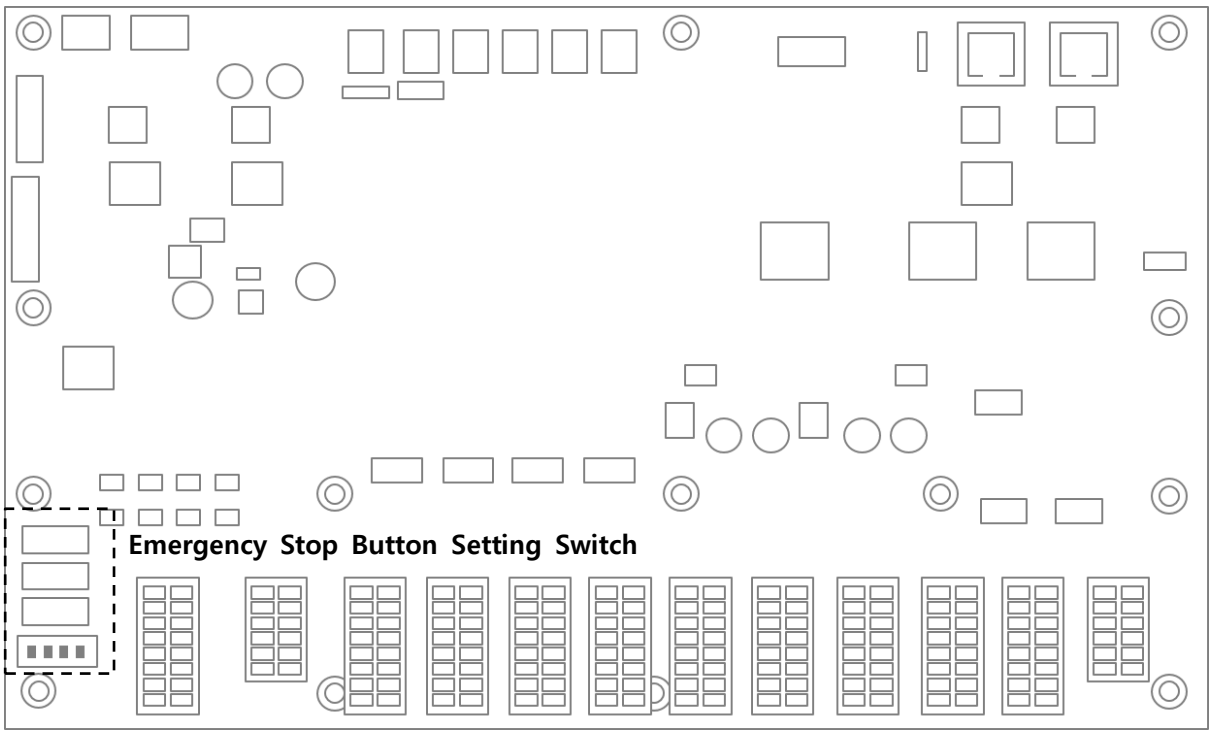
Note

If a system does not power up, check the power switch located on the bottom of the control box.

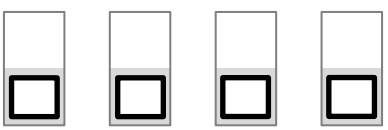
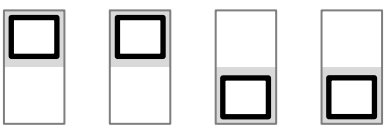
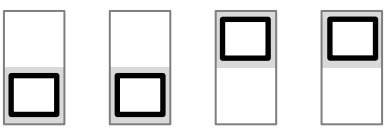
3.3.10 Emergency Stop Button Setting Switch

Configure the emergency stop button setting switch on the Case according to components and additional components before connecting and starting up the product. If the setting is not configured according to the guide, the robot will not operate properly.

The emergency stop button setting switch is located on the bottom left of the board inside the control box door (refer to below).



Configure the setting according to the components as follows. Upon first receiving, the setting is configured as Case 1.

Case 1	1.Teach Pendant(O), Smart Pendant(O) 2.Teach Pendant(O), Emergency Stop Button(O) 3.All use	On Off	
Case 2	1.Smart Pendant(O), Teach Pendant(X) 2.Emergency Stop Button(O), Teach Pendant(X)	On Off	
Case 3	Teach Pendant(O), Smart Pendant(X), Emergency Stop Button(X)	On Off	

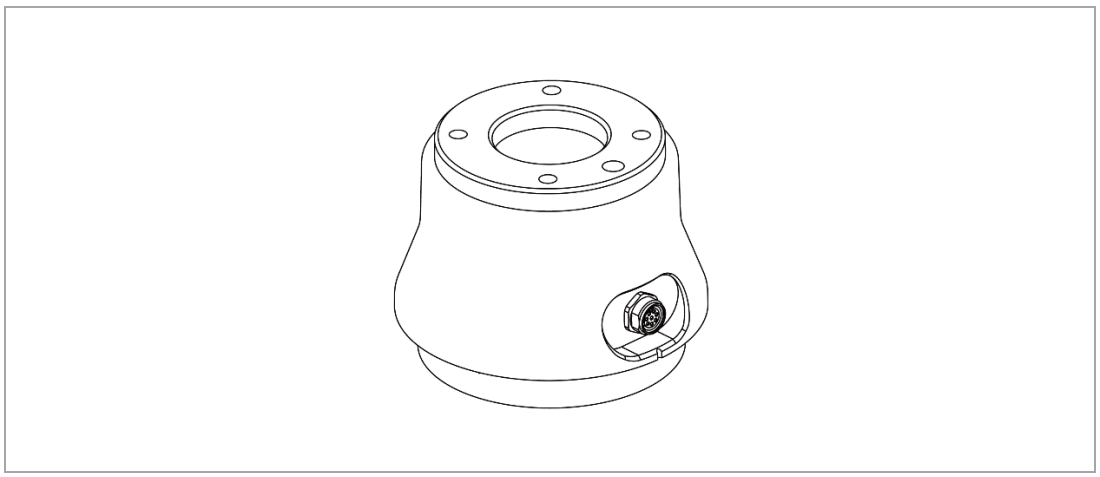
Warning

- . If the setting of the emergency stop button setting switch is different from the actual configuration, the emergency stop button may fail and cause injury to the user in an emergency situation, so check the setting condition and operation of the emergency stop button.

4. Interface

4.1 Flange I/O

The end flange cover of the robot has one M8 spec 8-pin connector, and refer to the figure below for the location and shape.

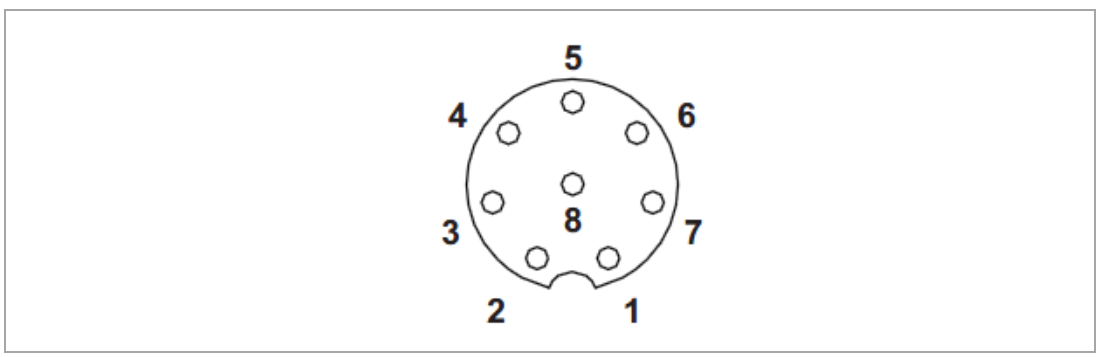


The connector supplies power and control signals necessary to operate the gripper or sensors embedded within specific robot tools. The following are sample industrial cables (equivalent cables can be used):

- ▪ Phoenix contact 1404178 (Straight)
- ▪ Phoenix contact 1404182 (Right Angle)

The pin map of each connector is as follows:

- **Schematic Diagram**



The I/O functions provided through X1 connector are different from each other, and refer to the table below for detailed I/O settings.

- ▪ X1 Setting (Digital I/O, RS 485)

No	Signal
1	RS485 A
2	RS485 B
3	Digital Output 1
4	Digital Output 2
5	+24V
6	Digital Input 2
7	Digital Input 1
8	GND

Internal power of the flange I/O is set to 24V, and refer to the table below for detailed power specifications during I/O connection.

Parameter	Min	Typ	Max	Unit
Supply voltage	-	24	-	V
Supply current	-	2	3	A
Digital output	-	2	-	EA
Digital input	-	2	-	EA

Warning

- Set up the tool and gripper so that they do not cause any hazards when power is cut off. (E.g., workpiece falling from the tool)
- The No. 5 terminal of each connector outputs 24V at all times while power is supplied to the robot, so make sure to cut the power supply to the robot when setting up the tool and gripper.

4.1.1 Flange Digital Output Specifications

Flange digital output is a PNP specification, and photo coupler output is set up in the output.

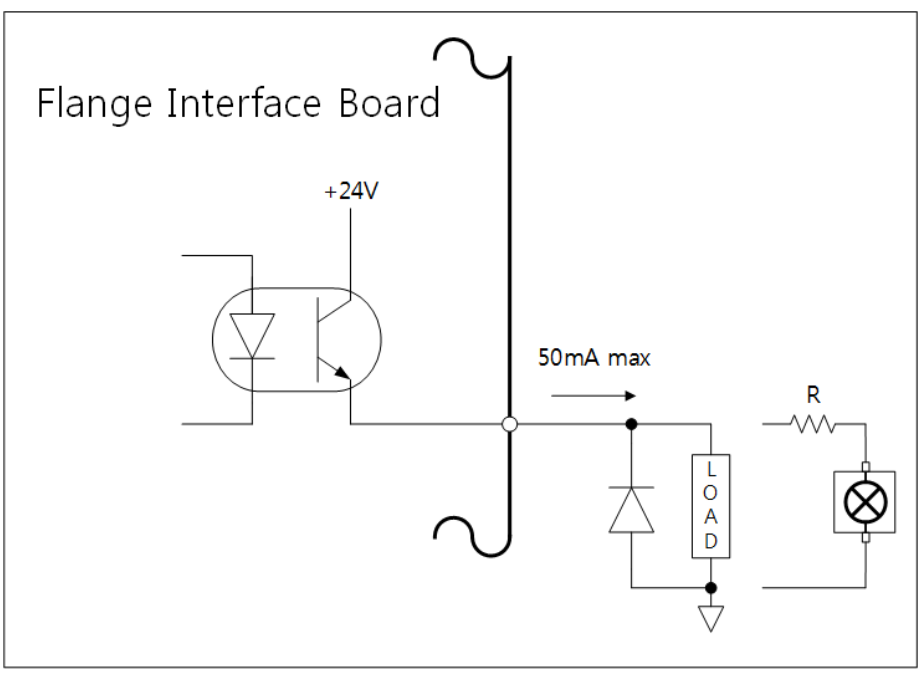
The corresponding output channel becomes +24V when digital output is activated. The corresponding output channel is open (floating) when digital output is deactivated.

The electrical specifications of the digital output are as follows:

Parameter	Min	Typ	Max	Unit
Voltage when driving 10mA	23	-	-	V
Voltage when driving 50mA	22.8	-	23.7	V
Current when driving	0	-	50	mA

Caution

- Digital output is not subject to current limitation. Ignoring the specifications above during operation may cause permanent damage to the product.
-
- The figure below is an example of a digital output setup, so refer to it while connecting the tool and gripper. Make sure to disconnect the power from the robot when setting up the circuit.



4.1.2 Flange Digital Input Specifications

Flange digital input features a photo coupler input.

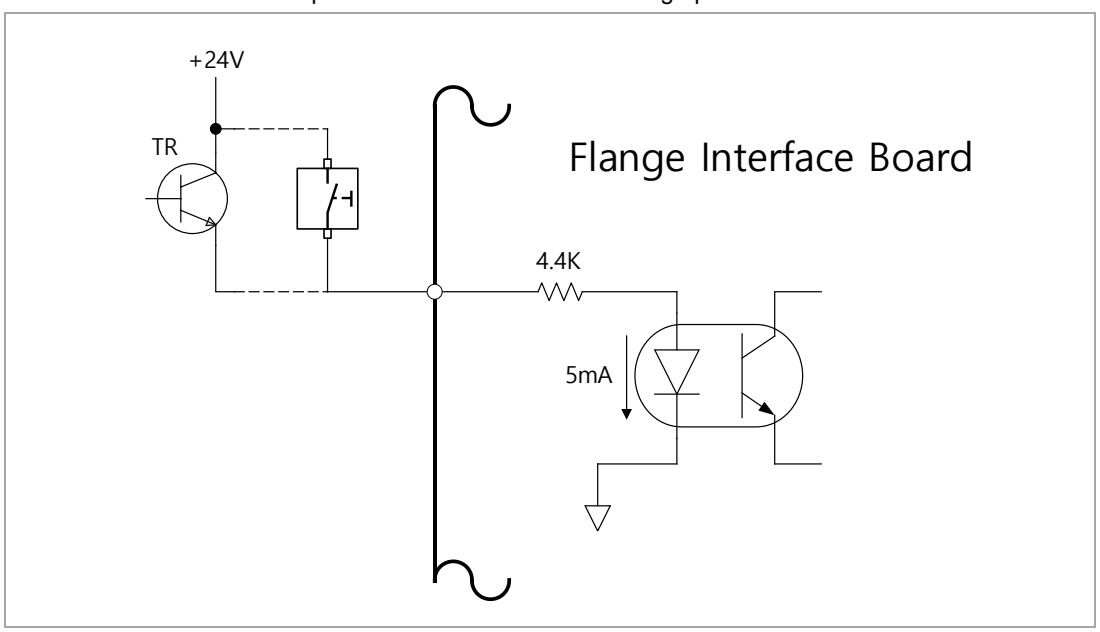
The current based on 24V input is limited to 5mA by internal resistance.

The electrical specifications of the digital input are as follows:

Parameter	Min	Typ	Max	Unit
Input voltage	0	-	26	V
Logical high	4.4	-	-	V
Logical low	0	-	0.7	V
Input resistance	-	4.4k	-	Ω

The figure below is an example of a digital input setup, so refer to it while connecting an input device.

Make sure to disconnect the power from the robot when setting up the circuit.

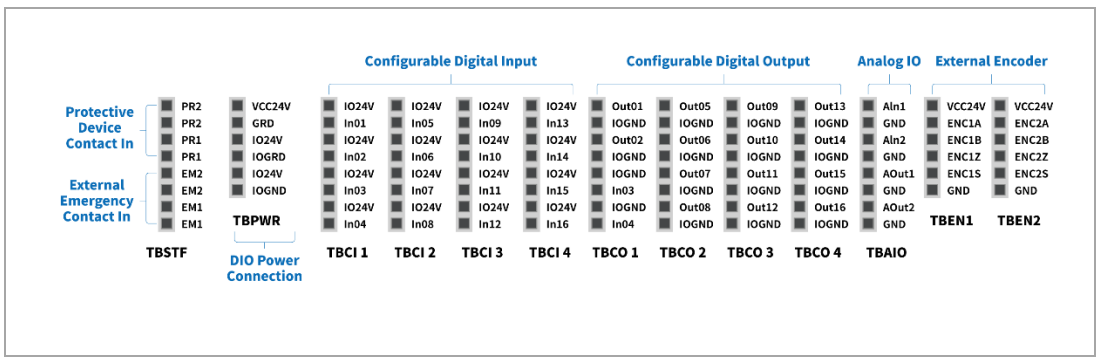


4.2 Control Box I/O Connection

In addition to the robot and teach pendant, various external equipment can be connected to the control box through the control box I/O terminal. Various peripherals such as safety devices, including emergency stop switch, light curtain and safety mats, and devices required during robot work cell setup including pneumatic solenoid valves, relays, PLCs and conveyor belt encoders can be connected. The control box I/O consists of the following six units:

- Terminal Block for Safety Contact Input (TBSFT): Used to connect devices required for emergency stopping and protective stopping
- Terminal Block for Digital I/O Power (TBPWR):
- Configurable Digital IO Block (TBCI1- 4, TBCO1– 4): Used to connect peripherals required for robot operation
- Terminal Block for Analog I/O (TBAIO):
- Terminal Block for Encoder Input (TBEN1, TBEN2)

The figure below depicts the electric interface layout of the control box interior.



Caution

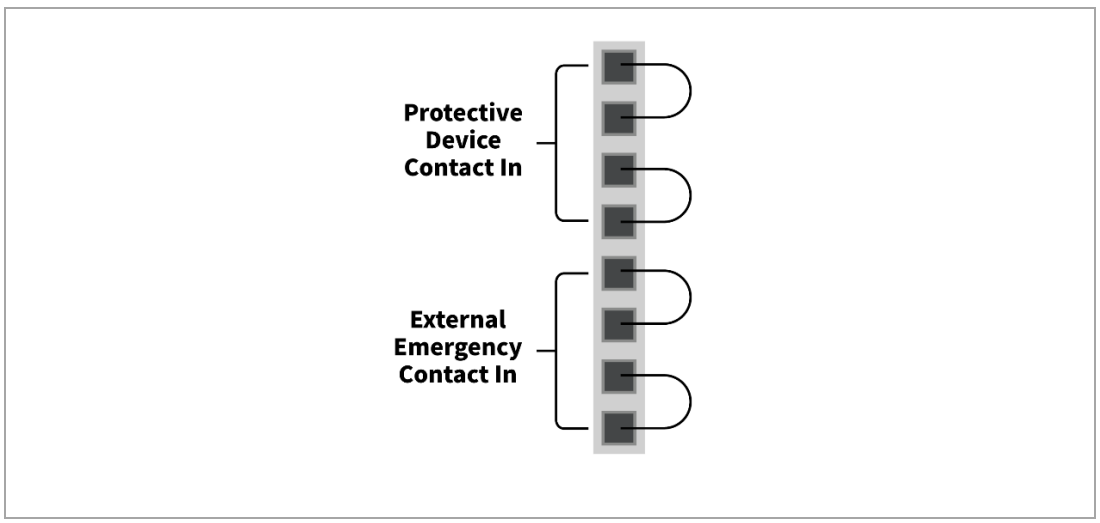
- Turn off the power when connecting terminals to the control box I/O to prevent product damage and breakdown.
- Doosan Robotics will not compensate any product damage caused by inappropriate terminal connection or user negligence.
- Make sure to turn off the external power source when turning off the control box power.

4.2.1 Setting the Terminal Block for Contact Input (TBSFT)

The safety I/O of the control box consists of dual contact input terminals for connecting safety devices. These terminals are categorized into two group depending on their use.

- Two pairs of external emergency contact in on the bottom: Used to connect devices required for emergency stopping such as external emergency switch.
- Two pairs of protective device contact in on the top: Used to connect devices for protective stopping such as light curtain and safety mat.

If no external safety device is connected, connect each contact input as follows:



The external safety device signal recognized by the safety controller depending on the normally closed contact status, where all four contact inputs are normally closed, is as follows:

Contact Status	EM1 contact	EM2 contact	PR1 contact	PR2 contact
Close	Normal	Normal	Normal	Normal
Open	Emergency Stop	Emergency Stop	Protective Stop	Protective Stop

Warning

- Do not connect the safety signal to regular PLCs that are not safety PLCs. Failure to do this will result in inappropriate operation of the safety stop function, which can cause severe injury or death to the user.
- If any of the contacts are open, the robot will stop operation according to the safety stop mode setting, and the LED on the right side of the TBSFT lights up. EMGA (Red), EMGB (Red), PRDA (Yellow), PRDB (Yellow)

Note

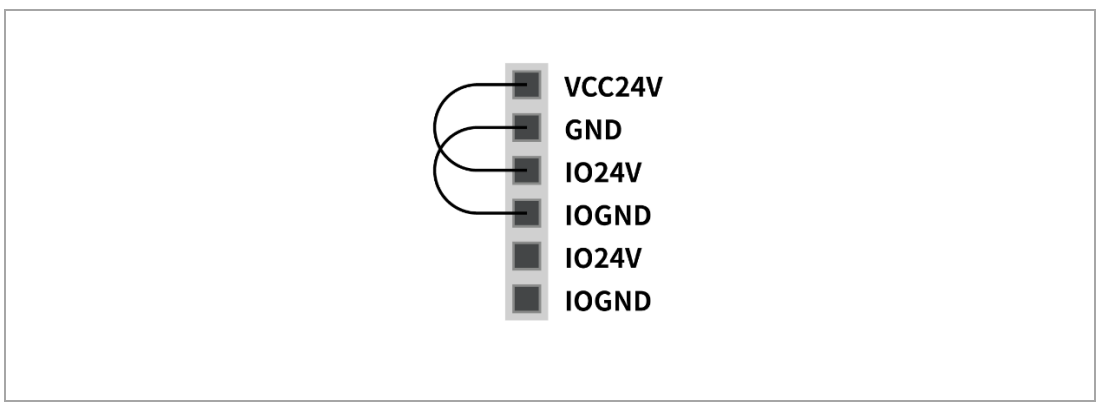
- EMGA : Emergency Stop channel A(EM1) LED
- EMGB : Emergency Stop channel B(EM2) LED
- PRDA : Protective Stop channel A(PR1) LED
- PRDB : Protective Stop channel B(PR2) LED

Caution

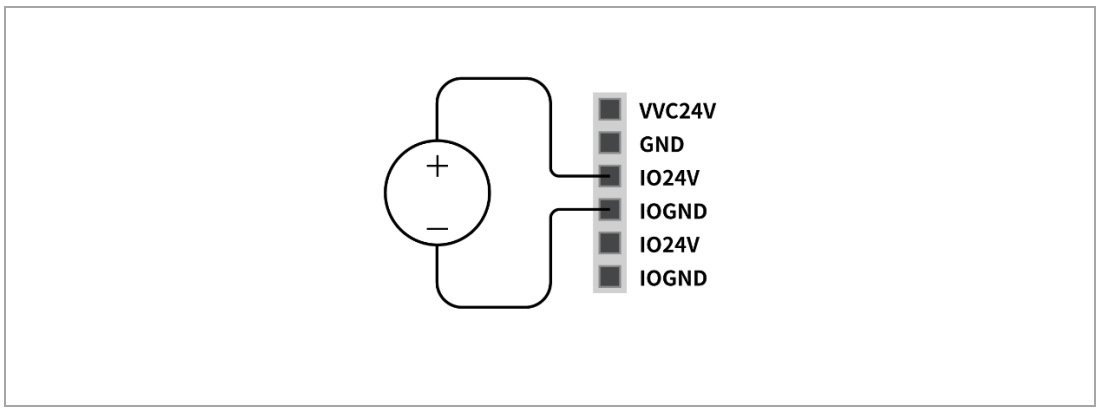
- To check for connection losses and connection shortages, this terminal must be connected to devices that output a safety signal as contacts. To connect peripherals that output safety signals as voltages to the safety controller, refer to the description for the Configurable Digital I/O Terminal Block.

4.2.2 Setting the Digital I/O Power Terminal (TBPWR)

VIO and GIO are power terminals used for the safety controller digital I/O located in the front of the control box, and are separated from the VCC24V and GND that supply SMPS inside the control box. If the user uses a current of 2A or less for the configurable digital I/O, and if there is no insulation for the connected I/O device and control box, the internal power supply of the control box can be used as the I/O power supply, as shown in the figure below. (factory default setting)



If a current greater than 2 A is required, separate the VCC and GND. It will be necessary to connect a separate external power source (24V) using VIO and GIO terminals.



When VIO power is supplied, the IOPW (green) LED on top of the TBPWR lights up.

Caution

Make sure to turn off the external power source (SMPS) when turning off the power for the control box.

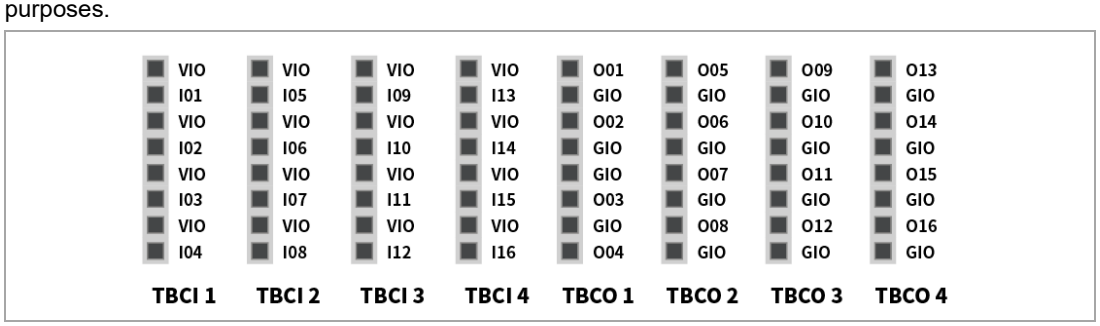
Note

If a current greater than 2A is connected to the VCC and GND of TBPWR, the fuse in front of the terminal power output shorts to ensure the safety of the control box internal system connected to the same SMPS.

If a current greater than 2A is required for the configurable digital I/O, make sure to connect an external power source (24V) to VIO and GIO.

4.2.3 Setting the Configurable Digital I/O (TBCI1 - 4,TBCO1 - 4)

The digital I/O of the control box consists of 16 inputs and 16 outputs. They are used to connect peripherals required for robot control or are set as a dual safety I/O to be used as safety signal I/O purposes.



The electrical specifications of the configurable digital I/O are as follows:

Terminal		Parameter	Specifications
Digital Output	**[Oxx]**	**Voltage**	0 - 24 V

Terminal		Parameter	Specifications
	[Oxx]	**Current**	0 - 1 A
	[Oxx]	**Voltage Drop**	0 - 1 V
	[Oxx]	**Leakage Current**	0 - 0.1 mA
Digital Input	**[Ixx]**	**Voltage**	0 - 30 V
	[Ixx]	**OFF Range**	0 - 5 V
	[Ixx]	**ON Range**	11 - 30 V
	[Ixx]	**Current**	2 – 15 mA

Caution

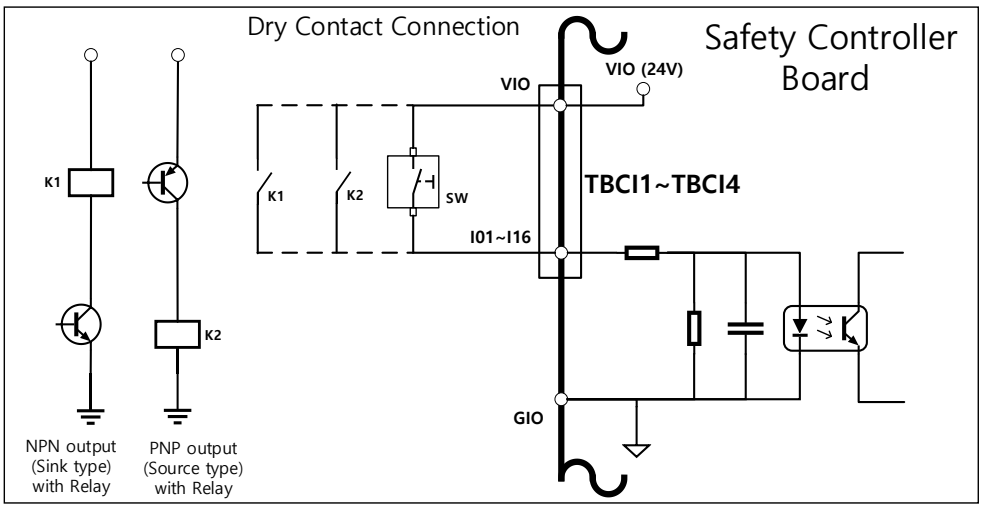
- The VIO (IO 24 V) and GIO (IO GND) terminals, which can be used as power supplies for digital I/O, are separated from the external power supply terminal VCC (24 V) and the GND on the safety I/O circuit. Use caution, as the diagnostic functions of the robot will detect errors if the internal power supply is connected as a digital I/O power supply through the terminal block for digital I/O power (TBPWR) and if the 24 V power is not supplied to the VIO and GIO terminals through an external power supply, the configurable digital I/O will not work and operating power to the robot will be shut off.

If the configurable digital I/O is used as a general digital I/O, various low current operations such as solenoid valves for voltage and signal exchanges with PLC systems or peripherals can be performed. The following is how to use the configurable digital I/O:

[Digital Input]

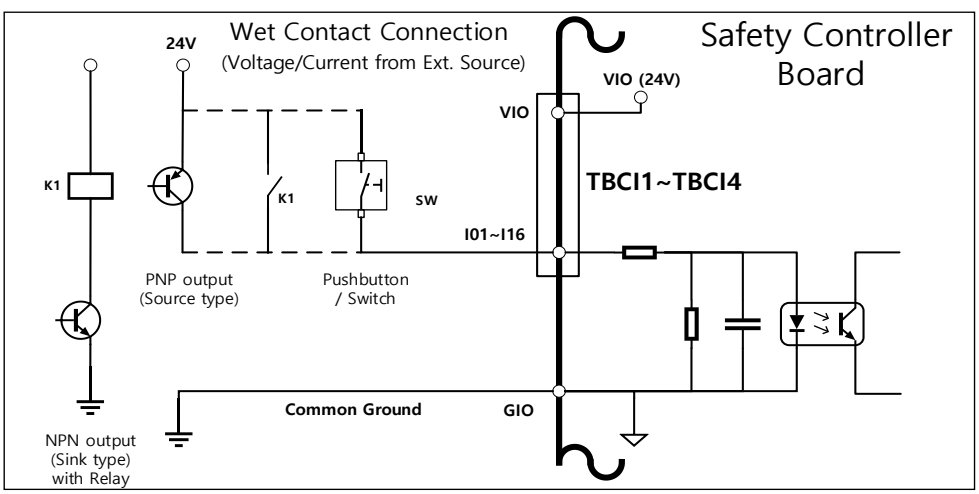
- If dry contact input is received

  This is a method of connecting a switch or contact between the VIO terminal of terminal blocks TBCI1-TBCI4 and Ixx terminals. The output of the external device only acts on the open/close of the contact through the relay, so it is electrically insulated from external devices.



- If wet contact input is received

It receives voltage type signals from external devices. If the output of the target device is source type, it receives a voltage of 24V/0V as input. If the output of the target device is sink type, a relay can be added to receive voltage of 24V/0V as input. Because voltage input requires a reference, the external devices and the external power supply must be connected to a common ground.

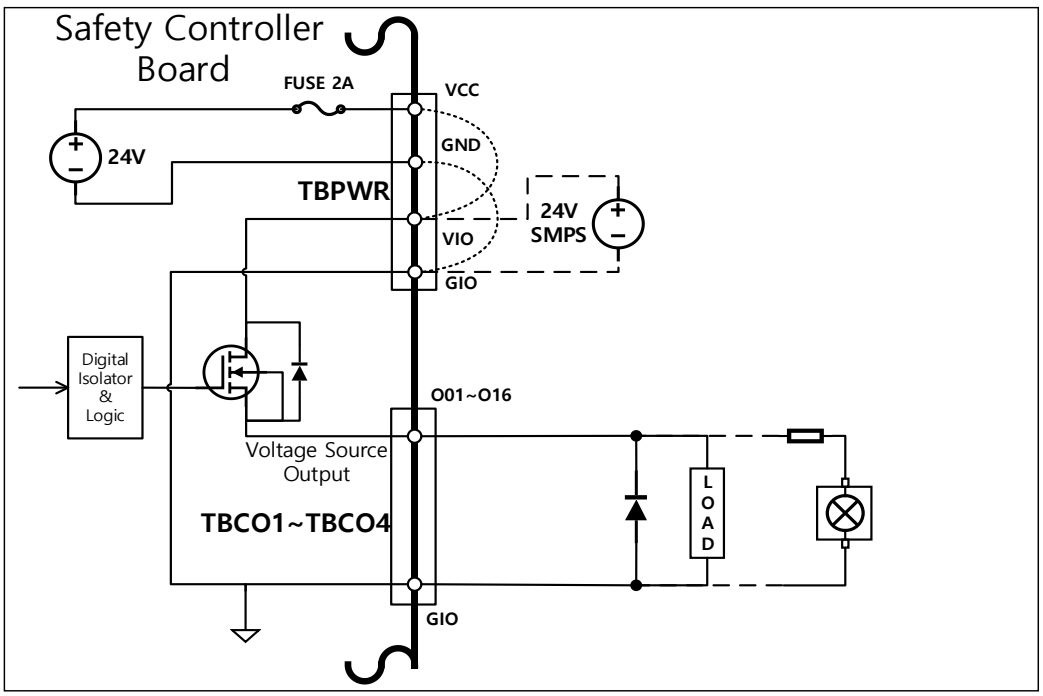


[Digital Output]

- If a simple load is operated

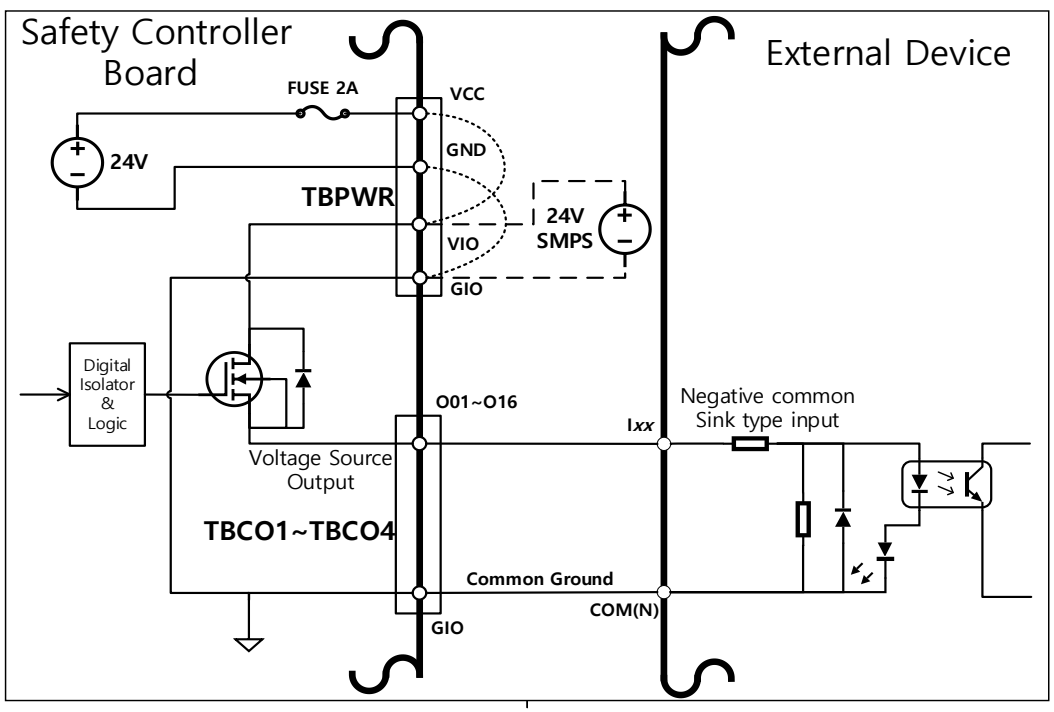
This is a method of connecting loads between the O01-O16 terminals of the TBCO1-TBCO4 terminal blocks and the GIO terminal.
Each terminal is capable of outputting a maximum of 1A, but the overall current may be limited according to the calorific value and load.

If digital I/O power (VIO/GIO) is supplied through the internal power supply as in the factory default setting, up to 2A of VIO current can be used. If a total current greater than 2A is required, remove the connection between the digital I/O power supply (VIO/GIO) of the Terminal Block for Digital I/O Power (TBPWR) and the internal power supply (VCC/GND), and an external power supply must be connected.



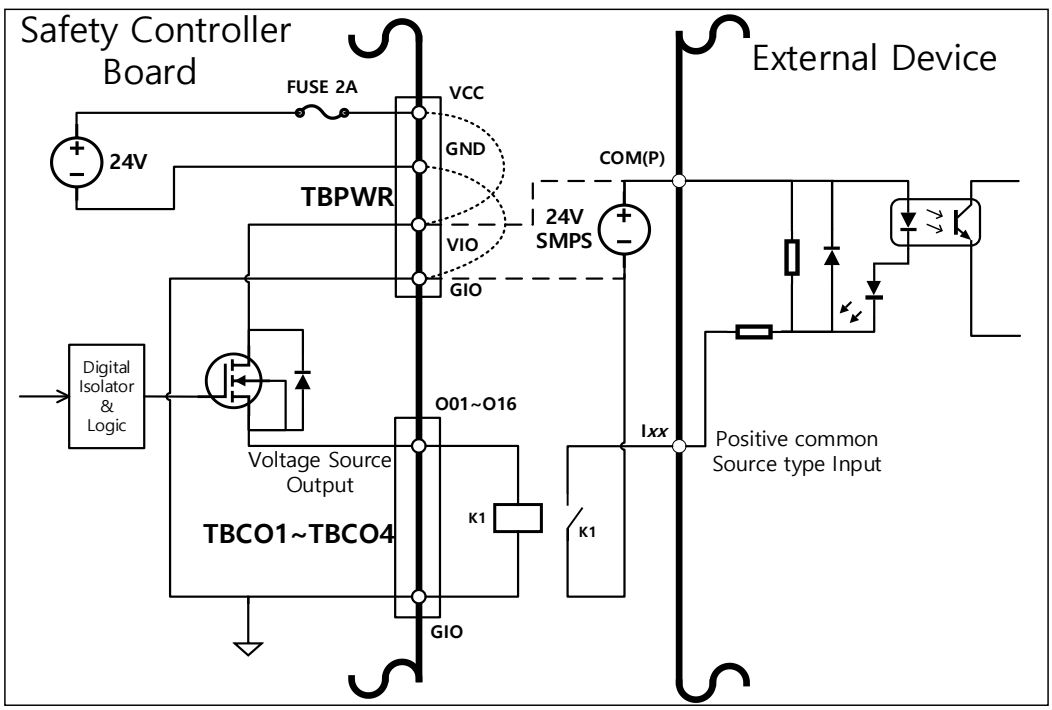
- If a negative common & sink type input device is connected

  If digital I/O output is connected to a sink type input device, connect the Oxx terminals of TBCO1-TBCO4 terminal blocks to the input terminal of the external device, and connect the GIO to the negative common of the external device to establish a common ground.



- If a positive common & source type input device is connected

Connect a relay between the Oxx terminal of TBCO1-TBCO4 terminal blocks and GIO terminal to supply input signals as contacts to the external device. If necessary, an external power supply can be connected to the external device.



Caution

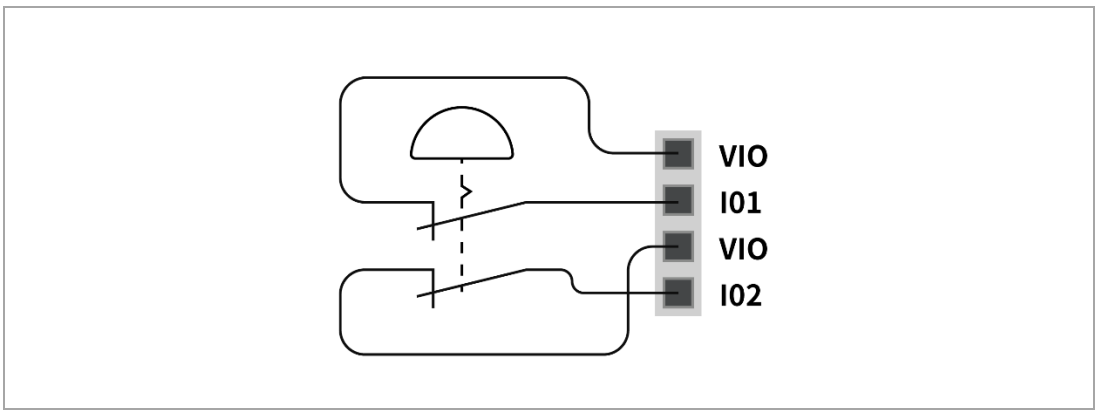
- General digital I/O devices can stop at any time due to a control box power shortage, self-diagnosis error detection and work program settings. Therefore, perform risk assessment before setting up a robot workcell, and if additional risks such as a workpiece falling, ignoring digital input or synchronization error due to incorrect recognition, make sure to implement additional safety measures.
- The general digital I/O is a single connection type I/O and any short circuits or breakdown can result in the loss of safety functions, so it cannot be used for safety purposes. If the connection of a safety device or safety-related I/O is required, make sure to set the corresponding terminal as a dual safety I/O on the teach pendant.

If the configurable digital I/O is used as safety I/O, two neighboring I/O terminals, such as O01 & O02, … , O15 & O16, I01 & I02, ... I15 & I16, can use identical safety signals to form a dual safety I/O.

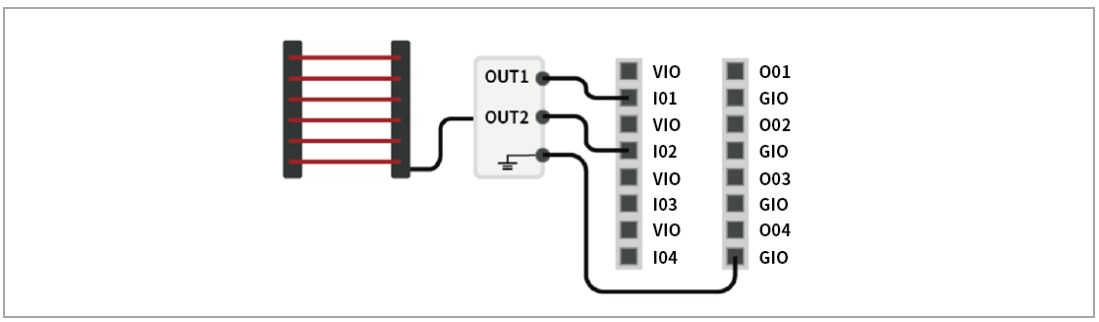
While the Safety Contact Output Terminal (TBSFT) can only be connected with contact type signals, input set as safety I/O can connect with both contact and voltage type signals Output set as safety I/O outputs voltage signals, but it can also output contact type signals by adding an external relay.

The following is an example of connecting a safety device for operation.

- Connecting an emergency switch (contact signal) as a safety input terminal



- Connecting a light curtain (voltage signal) as a safety input terminal (common ground)



4.2.4 Setting Analog I/O Terminal (TBAIO)

The control box features two analog I/O terminals that can be set to voltage mode or current mode. It can output voltage/current through an external device operated using analog I/O or receive signals from sensors outputting analog voltage/current.

To ensure maximum input accuracy, observe the following:

- Use shielded or twisted pair cables.
- Connect the cable shield to the ground terminal inside the control box.
- Current signal is relatively less sensitive to interference, so use devices operating in current mode for analog I/O terminals. Current/voltage input mode can be set by the software.

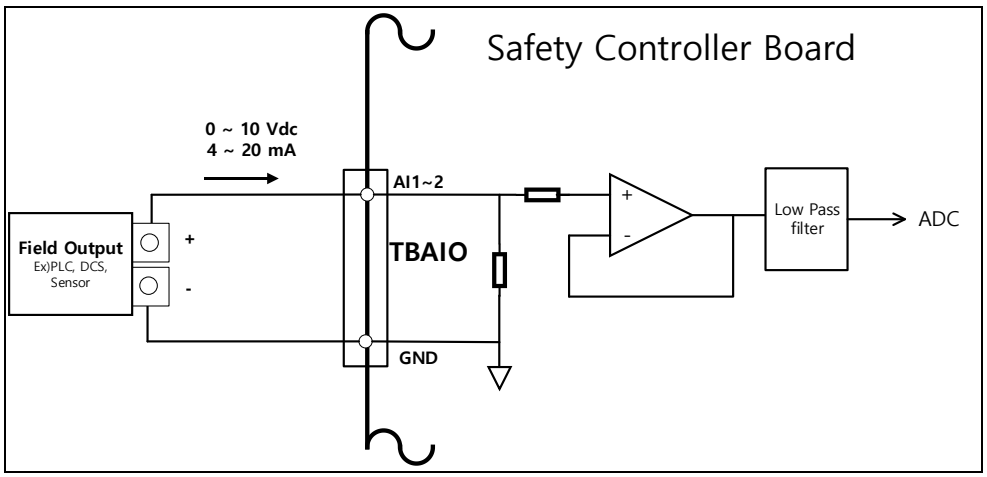
The electrical specifications of the analog I/O terminal are as follows:

Terminal		Parameter	Specifications
Current mode analog input	**[AIx-GND]**	**Voltage**	-
	[AIx-GND]	**Current**	4 - 20 mA
	[AIx-GND]	**Resistance**	250 ohm
	[AIx-GND]	**Resolution**	12 bit
Voltage mode analog input	**[AIx-GND]**	**Voltage**	0 - 10 V
	[AIx-GND]	**Current**	-
	[AIx-GND]	**Resistance**	1M ohm
	[AIx-GND]	**Resolution**	12 bit
Current mode analog output	**[AOx-GND]**	**Voltage**	-
	[AOx-GND]	**Current**	4 - 20 mA
	[AOx-GND]	**Resistance**	50M ohm
	[AOx-GND]	**Resolution**	16 bit
Voltage mode analog output	**[AOx-GND]**	**Voltage**	0 - 10 V
	[AOx-GND]	**Current**	-
	[AOx-GND]	**Resistance**	1 ohm
	[AOx-GND]	**Resolution**	16 bit

- Voltage/current input

It receives voltage or current signals from an external device between the AIx terminal of the TBAIO terminal block and GND terminal. If the output of the device is a voltage signal, it receives a signal of 0-10Vdc. If the output of the device is a current signal, it receives a signal of 4-20mA.

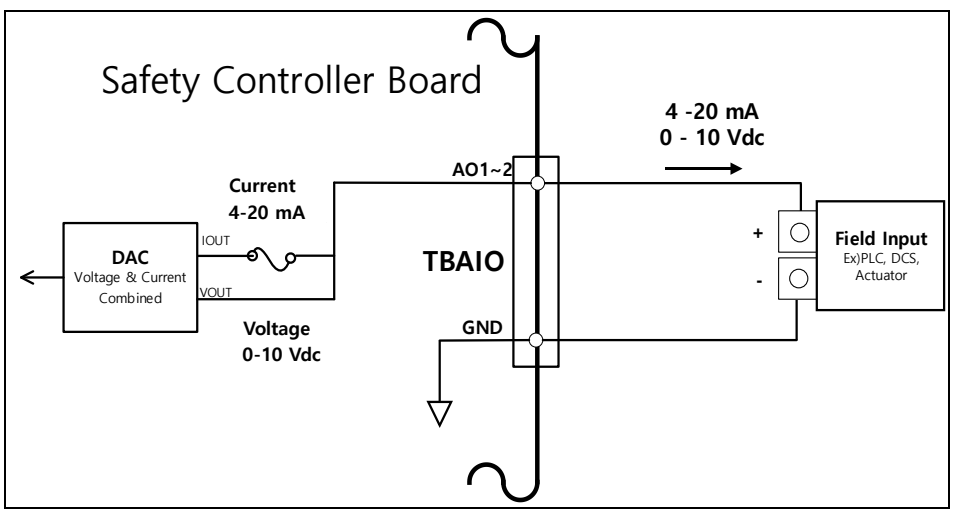
※ Depending on the output signal (voltage/current) of the device, it is necessary to set the control box analog input as “Voltage” or “Current” on the teach pendant.



- Voltage/current output

It supplies voltage or current signals to an external device between the AOx terminal of the TBAIO terminal block and GND terminal. If the input of the device is a voltage signal, it supplies a signal of 0-10Vdc. If the input of the device is a current signal, it supplies a signal of 4-20mA.

※ Depending on the input signal (voltage/current) of the device, it is necessary to set the control box analog output as “Voltage” or “Current” on the teach pendant.



4.2.5 Setting Encoder Input Terminal (TBEN1, TBEN2)

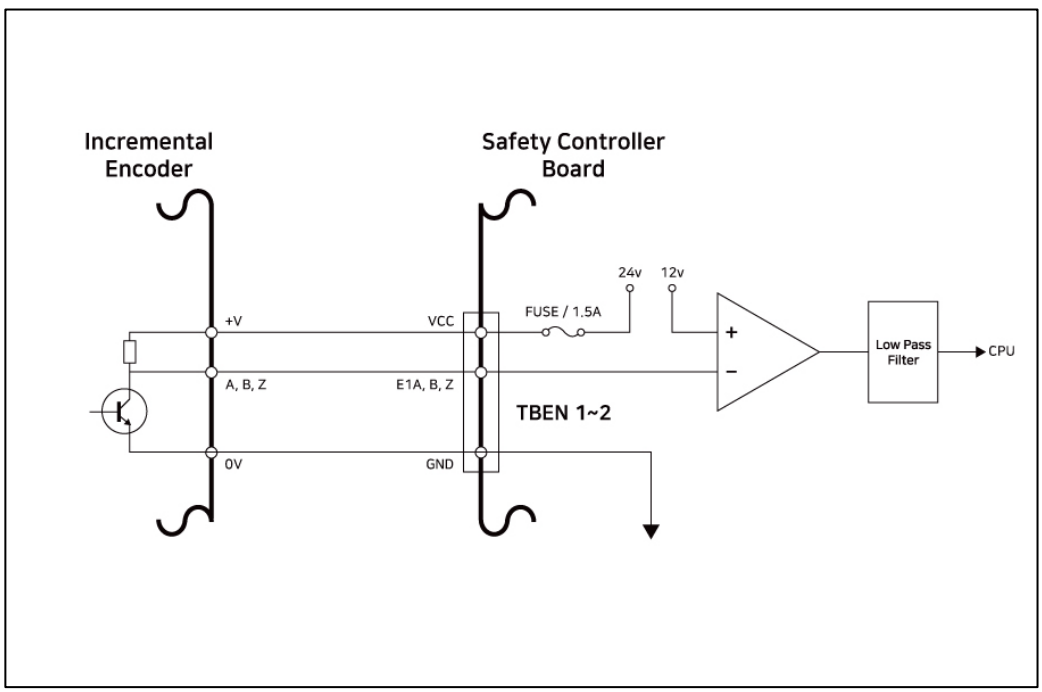
The control box has two TBEN terminals that allow the input of external encoders.

They support A, B and Z phases as inputs, and perform counts based on 12Vdc.

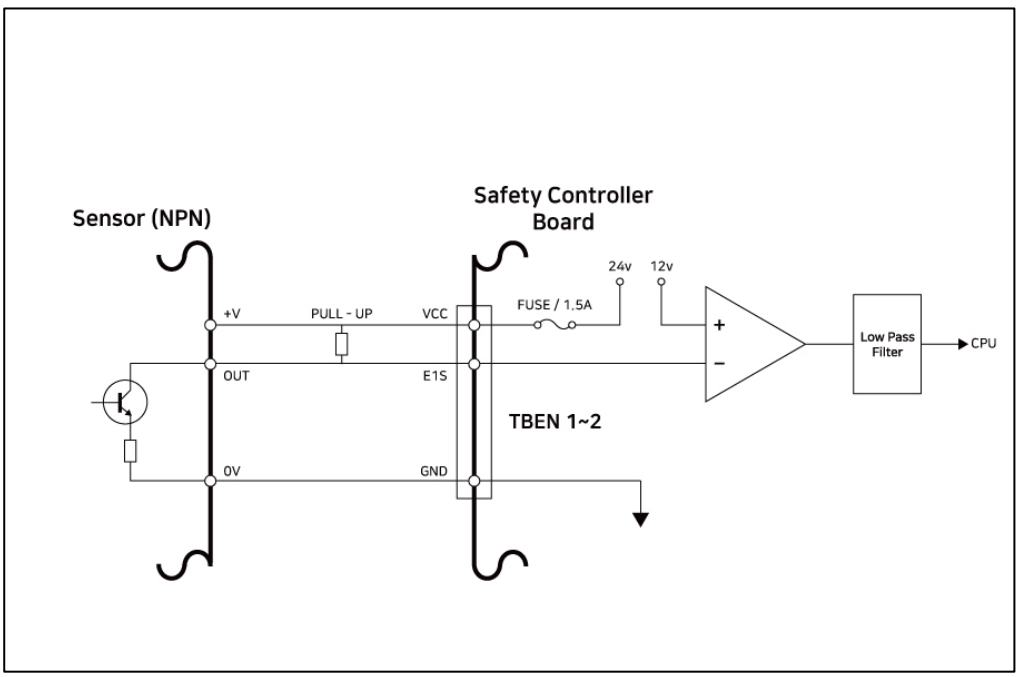
In addition, S phase can be used as the conveyor's Start sensor.

The figure below shows a sample encoder and sensor configuration, so refer to it while establishing connections.

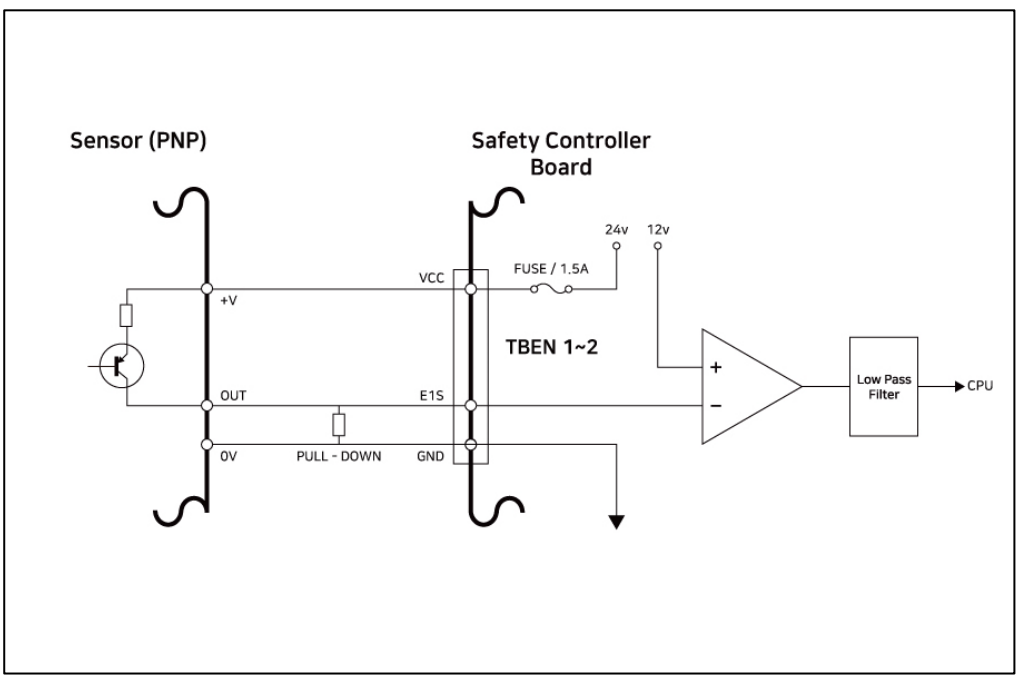
- To ensure maximum input accuracy, observe the following: Use shielded, twisted pair cables to reduce noise.
- Connect the cable shield to the ground terminal inside the control box.
- Connecting Incremental Encoder A, B, Z phase



- In the case of S phase inputs, connect a pull-up or pull-down resistance according to the sensor type to prevent floating.
- Connecting NPN Sensor



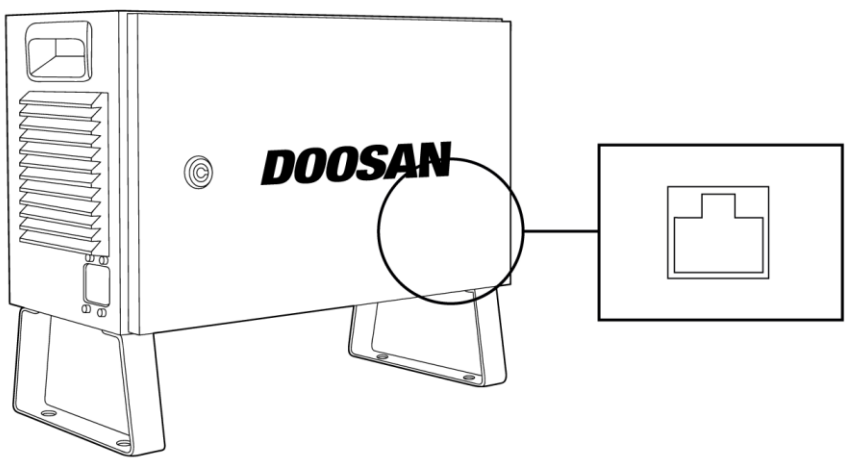
- Connecting PNP Sensor



4.3 Network Connection

Laptops, TCP/IP equipment, Modbus equipment and vision sensors can be connected to the network connector terminal inside the control box.

Connecting the cable to the network connection terminal will connect the network (refer to the figure below).



4.3.1 Connecting External Devices - Vision Sensor

The robot can be connected with a vision sensor (2D camera for object position measurement), and vision sensor measurements can be transferred to the robot through a network to link with commands of the robot.

- **Vision Sensor Setting**

  - Communication Connection Setting

Connect the LAN ports of the devices and apply TCP/IP communication to transfer vision sensor measurements to the robot. (Refer to LAN port connection 4.3 Network Connection) Set the IP address of the vision sensor to the TCP/IP 192.168.137.xxx band to allow TCP/IP communication.

  - Vision Work Setting

To perform object position measurement, it is necessary to have an image input and vision teaching of the target object using the vision sensor. Refer to the dedicated vision work setting program provided by the vision sensor manufacturer.

  - Measurement Data Format Setting

To use vision sensor measurement data in robot work, it is necessary to perform vision-robot

coordinate calibration, and this must be performed using the vision sensor setting program before initiating work. The vision sensor measurement data must be transferred using the following format setting:

Format	pos	,	x	,	y	,	angle	,	var1	,	var2	,	…

- pos: Separator indicating the start of measurement data (prefix)
- x: X coordinate value of the object measured using vision sensor
- y: Y coordinate value of the object measured using vision sensor
- angle: Rotation angle value of the object measured using vision sensor
- var1…varN: Information measured using vision sensor (e.g., object dimension / defect check value)

Example) pos,254.5,-38.1,45.3,1,50.1 (description: x=254.5, y=-38.1, angle=145.3, var1=1, var2=50.1)

• Robot Program Setting

Once the physical communication connection between the vision sensor and robot is completed and the vision sensor itself is set up, a program must be set up to allow the vision sensor and robot program to be linked. The Doosan Robot Language (DRL) enables the connection, communication and control of the external vision sensor, and it is possible to set up the program in Task Writer.

Details and comprehensive examples of Doosan Robot Language (DRL) external vision sensor functions are provided in the programming manual.

4.3.2 Connecting External Device – DART Platform

The DART Platform is software that runs on a Windows OS base desktop or laptop. Once you execute the DART Platform after connecting the Control Box and desktop/laptop through the LAN Port, all functions of the teach pendant can be used without a teach pendant. To establish a connection with sub-controllers within the control box, the following setup procedure is required.

• IP Address Search and Connection Setting

■ Communication Connection Setting

When a laptop is connected to the LAN port of the control box and the DART Platform is executed, the control box IP address, sub-controller version information and robot serial number required for establishing a connection are automatically searched.

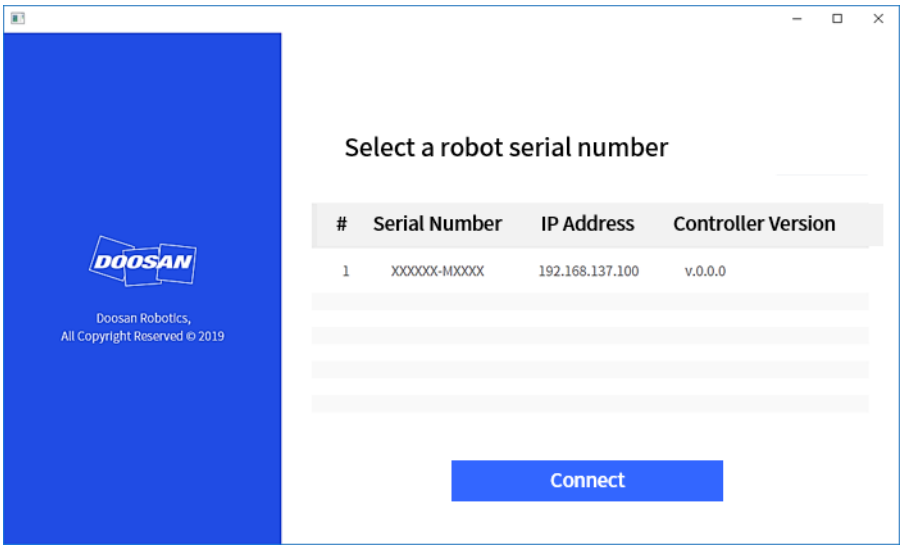
Selecting the serial number of the robot to connect will connect the DART Platform and a sub-controller, allowing the robot to be operated normally.

If there is an issue with the connection, implement the process below. If the issue is not resolved, contact the sales or service staff for assistance.

1 If the connectible control box IP address, sub-controller version information and robot serial number search results are not displayed: Press the refresh button to search again and try to connect again according to the procedure above.

2 If information is not found even after pressing the refresh button, press and hold the F3 and F4 key of the smart pendant* simultaneously for more than 3 seconds to reset to the default IP address and try to connect again according to the procedure above.

* Purchased separately as an option



4.3.3 ModbusTCP Slave Setup

The ModbusTCP Slave function of Doosan Robotics supports robot parameter monitoring, General Purpose Register (GPR) (refer to **4.3.7 Using General Purpose Register (GPR))** function.This function starts automatically when the robot controller boots up normally. Therefore, the user can use it after matching the Master IP of the robot controller with the same bandwidth.

Note

- The related I/O Table is provided as a separate file.
- Please refer to the Programming Manual for DRL to use the GPR function.

4.3.4 Expanded Protocol - PROFINET IO Device (PNIO device) Setup

The robotcontrollers of Doosan Robotics support the PROFITNET IO Device (Slave) function, which allows data modification after reading the Parameters of the robot from an external device (PROFINET IO Controller/Master). (e.g., Robot parameter monitoring, General Purpose Register (Bit, Int, Float) – refer to **4.3.7 Using General Purpose Register (GPR)**). For more information aboutPROFINET refer to www.profibus.com.

4.3.5 Expanded Protocol - EtherNet/IP Adapter (EIP adapter) Setup

The robot controllers of Doosan Robotics support the EtherNet/IP Adapter (Slave) function, which allows data modification after reading the Parameters of the robot from an external device (EtherNet/IP Scanner / Master). (e.g., Robot parameter monitoring, General Purpose Register (Bit, Int, Float) – refer to **4.3.7 Using General Purpose Register (GPR)**). For more information about EtherNet/IP, refer to www.odva.org.

4.3.6 Using Expanded Protocol

The PROFINET IO Device (PNIO device) and EtherNet/IP Adapter (EIP adapter) functions start together at controller startup, and are in connection standby state with the Master device. Therefore, in order to use the function, it is necessary to connect and set up the Master. Each Master device has different characteristics, so it is necessary to check them out.

Note

The following are descriptions of implementation characteristics of general functions for Industrial Ethernet.

- The Industrial Ethernet function of Doosan Robotics controllers does not use a separate ASIC, but implements its function based on TCP/IP, so it does not support real-time performance.
- Data output to external devices has identical markings (PNIO, EIP), but data input to the robot only has identical structures and does not link. Therefore, data output from the PNIO controller does not synchronize with output data from the EIP scanner.
- For the I/O table of PNIO and EIP, please refer to a separate document (or attachment).

4.3.7 Using General Purpose Register (GPR)

The GPR function is the memory of the PNIO device and the EIP adapter predefined by the user for use. It allows the exchange of user data between external devices and the robot.

Note

The GPR function is only provided through DRL, and the DRLs used are as follows: For more information about DRL, please refer to the Programming Manual.

- set_output_register_bit(address, val)
- set_output_register_int(address, val)
- set_output_register_float(address, val)
- get_output_register_bit(address)
- get_output_register_int(address)
- get_output_register_float(address)
- get_input_register_bit(address)
- get_input_register_int(address)
- get_input_register_float(address)

5. Robot Mode and Status

The operation modes of the robot consist of Manual Mode, where the user controls the robot directly, and Automatic mode, where the robot operates without direct user control.

5.1 Manual Mode

This is the mode in which the robot operates according to direct user control. The robot only operates when a button related to an action is pressed, and releasing the button results in stopping the corresponding action.

- In Manual Mode, the TCP movement speed is limited to less than 250 mm/s according to the Robot Safety Regulations.
- If risk assessment results indicate that a 3-position Enable Switch is necessary, the 3-position Enable Switch can be connected in the **WCM > Robot > Safety I/O** setting of the system operation program. In this case, the Enable Switch must be set in the center position to allow robot operation in Manual Mode and to turn on the servo.

In Manual Mode, it is possible to configure robot peripherals in the **Workcell Manager** or to program robot tasks in **Task Builder** and **Task Writer**, and if the robot cannot be operated normally for reasons such as the robot exceeding the safety threshold, the Recovery function can be performed to restore normal operation.

5.2 Auto Mode

This is the mode in which the robot operates without direct user control. The robot will execute the programmed task or predefined sequence with a simple operation command and without additional user input.

Task Builder or **Task Writer** can verify the programed task in virtual mode, execute it in actual operation, and perform robot tool weight and auto weight center measurement functions.

5.3 **Status and Flange LED Color for Each Mode**

Mode	Status	Description	Flange LED
Manual	Manual Ready	• This is the default status of teaching. • **Workcell Manager**, **Task Builder** and **Task Writer** can be used to configure the work condition or perform task programming. • It monitors the stop status with Safe Operating Stop (SOS).	Blue
	Jog/Move	• The jog function is used to operate the robot.	Blue Flashing
	Manual Handguiding	• The manipulator can be operated manually during teaching.	Cyan Flashing
	Recovery Ready	• Recovery in progress. • All safety functions except for axis and TCP speed monitoring are disabled during recovery. • It monitors the stop status with Safe Operating Stop (SOS).	Yellow Flashing
	Recovery Jog	• The jogs of each axis can be used to correct the exceeded safety threshold.	Yellow Flashing
	Recovery Handguiding	• The manipulator can be moved directly by hand to correct the exceeded safety threshold.	Yellow Flashing
	Safety Stop	• The system stopped due to protective stop or exceeding the safety threshold. • It monitors the stop status with Safe Operating Stop (SOS).	Yellow
	Servo Off	• The servo is turned off due to protective stop, emergency stop or exceeding the safety threshold. • It is identical to Safe Torque Off (STO).	LED Off
Others	Backdrive	• The system is operating without drive power. • During an emergency when there is no power being supplied to the manipulator, the brake can be released to allow the robot to be pushed by hand. • Use caution, as the axis will not lock by itself and will fall if the brake is not engaged again.	LED Off

Mode	Status	Description	Flange LED
Auto	Auto Ready	• The Teach Pendant UI is in the actual mode execution screen in a single work space. • Pressing the "Execute" button will execute the task program. • White is displayed for a single work area and green is displayed for a collaborative work area.	White/Green
	Auto Operating	• The task program is being executed. • White is displayed for a standalone zone and green is displayed for a collaborative zone.	White Flashing / Green Flashing
	Handguiding Ready	• The Handguiding command is executed during task program execution. • The system waits until the user presses the "Handguiding" button. • It monitors the stop status with Safe Operating Stop (SOS).	Cyan
	Handguiding	• The robot pose can be changed by pressing the "Handguiding" button. • After the robot stops, enter the Manual Guiding Stop signal through the safety IO to turn Auto Operating on and then continue executing the task program.	Cyan Flashing
	Auto-measure	• The weight center point of the end effector is measured automatically. Please note that the safety monitoring functions of the robot are disabled.	Yellow Flashing
	Safety Stop	• The system stopped due to protective stop or exceeding the safety threshold. • It monitors the stop status with Safe Operating Stop (SOS).	Yellow
	Servo Off	• The servo is off due to protective stop, emergency stop or exceeded safety threshold. • It is identical to Safe Torque Off (STO).	LED Off

6. Safety Functions

6.1 Introduction

Robots from Doosan Robotics use various safety-rated monitoring and safety-related electrical interfaces to protect users and devices, and it allows the integration of other devices and additional protection devices. The performance of each safety-rated monitoring function and interface satisfies Category 3, Performance Level d(PL d) defined by ISO 13849-1 and Hardware Fault Tolerance 1, Safety Integrity Level 2 (SIL 2) defined by IEC 62061.

Note

- Work cells must be set using the safety functions and interface according to the risk assessment performed on the corresponding robot application by the system integrator, and refer to this manual for information required for this.
- If the safety systems of the robot detect system defects such as hardware defects including emergency stop circuit shortage, position sensor damage or control communication error, stop category 0 is immediately initiated. Meanwhile, if the safety systems of the robot detect violations during safety monitoring such as pressing the emergency stop switch, protective stop signal input, detection of external impact, or physical parameters (robot position, speed, momentum) exceeding set parameters, the system stops the robot using the mode set as the stop mode setting in the safety setting menu. (select one from stop category 0, 1, 2)
- In special cases (collision detection, TCP Force Violation), a special mode that stops the robot after accepting the external force for 0.25 seconds after event occurrence can be used to avoid clamping situations where limbs are jammed between the fixated jig/workpiece and the robot. (RS1 stop mode)
- For information on the time and stopping distance until the robot comes to a full stop from the moment the above error or violation occurs, refer to Annex C. Stop Distance and Stop Time. This time must be considered as part of the risk assessment performed by the system integrator.
- The safety setting menu can set various safety functions to limit the movement of joints, robot and TCP. Here, TCP means the location of the output flange center point added by the TCP offset.

6.2 Safety-Rated Stop Function

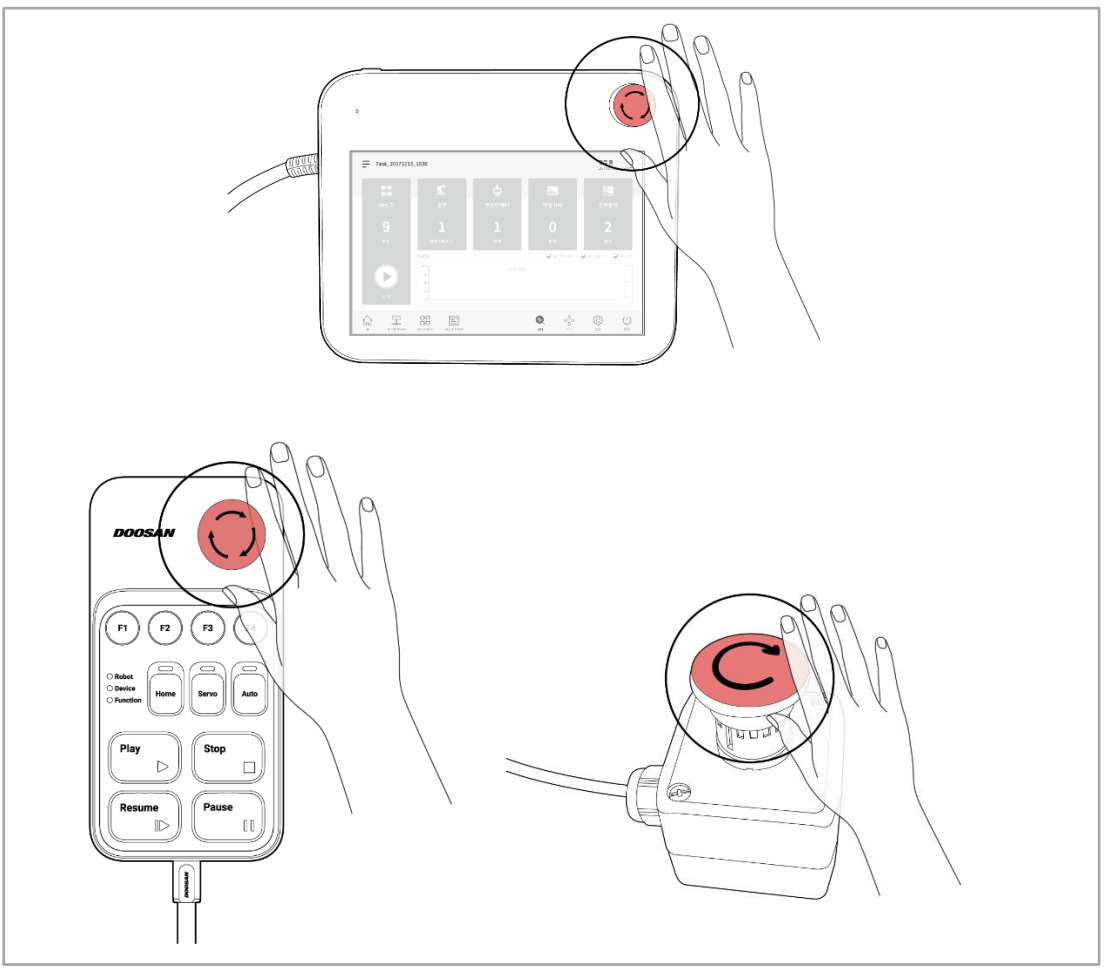
This is the stop function and stop monitoring function of Doosan Robotics, and it uses the safety function defined in IEC 61800-5-2.

Safety Function Name	Function Description and Failure Detection	PFHd	PL, SIL
STO (Safe Torque Off)	Immediately cuts off the power supply to all joint module motors, and brake engagement forces the operation to stop. (Servo Off)		
SS1 (Safe Stop 1)	All joints are stopped with the maximum deceleration possible, the power supply to the motor is cut off, and the brake is engaged to stop. (Servo Off) If deceleration is not sufficient during stopping, the method is set to STO stop.		
SS2 (Safe Stop 2)	All joints are stopped with the maximum deceleration possible, and the SOS stop monitoring function is set. If deceleration is not sufficient during stopping, the method is set to STO stop.		
SOS (Safe Operating Stop)	The current position is maintained with power supplied to the motor and the brake disengaged (Servo ON). If abnormal position change is detected, STO is set.		

Safety Function Name	Stop Triggering Event	Stop Mode	PFHd	PL, SIL
Emergency Stop	If the Emergency Stop switch of the teach pendant is pressed If the Emergency Stop switch connected to the TBSFT EM terminal is pressed	STO or SS1		
Protective Stop	If the protective device connected to the TBSFT PR terminal is activated	STO, SS1 or SS2		

6.2.1 Emergency Stop Function

The user can make use of the emergency stop button to stop the system in emergency situations. In emergency situations, press the Emergency Stop button or the Emergency Stop located on the top right of the teach pendant or smart pendant to immediately stop the system.



Note

- SS1 stop mode is set as the default setting of the emergency stop button.
- Turning the emergency stop button clockwise can release emergency stop function engagement.
- If additional Emergency Stop buttons are needed, a button can be added to the control box after a risk assessment.
- Emergency stop must not be used as a risk reduction method, but as a secondary protection device.
- If additional emergency stop buttons need to be connected, this must be determined with a robot application risk assessment. The Emergency Stop button must comply with IEC 60947-5-5.

6.2.2 Protective Stop

The robot features a protective stop function to stop the robot according to signals sent by protective devices.

For information about the protective device connection, refer to sections 4.2.1 and 4.2.3.

6.3 Safety-Rated Monitoring Function

Doosan robots feature various safety-rated monitoring functions that can be used as a risk reduction measure through risk assessment. The threshold of each monitoring function that triggers stop can be configured in the WCM>Robot>Robot Limit of the teach pendant UI.

- Joint Position Monitoring (SLP): Limits the maximum rotation angle of a joint
- Joint Speed Monitoring (SLS): Limits the maximum rotation speed of a joint
- TCP Position/Direction Monitoring: Limits and monitors TCP position/direction in an orthogonal space

  Operating Space, Standalone Workspace, Collaborative Workspace, Protected Zone,

  Tool orientation limit zone, collision detection mute zone
- TCP Speed Monitoring: Limits the maximum TCP movement speed of TCP
- TCP External Force Monitoring: Limits the external force applied to TCP
- Collision Detection: Limits the external torque applied to the robot arm and each joint
- Momentum Monitoring: Limits the maximum momentum of the robot arm
- Mechanical Power Monitoring: Limits the maximum power applied to the robot arm.

Note

- The safety threshold used for each monitoring function can be configured in the WCM>Robot>Robot Limit of the teach pendant UI.
- Safety limits is the condition where the safety-rated monitoring function triggers the stop function. When stop is completed, the position of the robot and force applied externally may differ from the configured safety threshold.

Safety Function Name	Stop Triggering Event	Stop Mode	PFHd	PL, SIL
Joint Position Limit (SLP)	If the angle of each axis exceeds the configured threshold	STO, SS1 or SS2		
Joint Speed Limit (SLS)	If the speed of each axis exceeds the configured threshold	STO, SS1 or SS2		
Joint Torque Limit (SLT)	If the torque applied to each axis exceeds the predefined threshold	STO		
Collision Detection	If the external applied to each axis exceeds the thresholds for the configured sensitivity	STO, SS1 or SS2		
TCP/Robot Position Limit	If the TCP/Robot leaves the operating space If the TCP enters the protected space	STO, SS1 or SS2		
TCP Orientation Limit	If the difference between the set direction within the Tool Orientation Limit Zone and the TCP orientation deviation exceeds the configured threshold	STO, SS1 or SS2		
TCP Speed Limit	If the TCP speed exceeds the configured threshold	STO, SS1 or SS2		
TCP Force Limit	If the external force applied to the TCP exceeds the configured threshold	STO, SS1 or SS2		
Robot Momentum Limit	If the momentum of the robot exceeds the configured threshold	STO, SS1 or SS2		
Robot Power Limit	If the mechanical power of the robot exceeds the configured threshold	STO, SS1 or SS2		

6.4 Safety-Rated I/O

The robots of Doosan Robotics feature a safety-rated input interface capable of connecting protective stop signals from safety protective devices, external emergency stop signal input and 3-position Enable Switch. They also feature a safety-rated output interface capable of outputting internal status and area information.

Safety Function Name	Function description and Failure detection	PFHd	PL, SIL
Safety IO	The redundant interface for I/O of safety-rated signals. The system stops the robot and displays error messages if a mismatch is detected between the redundant input signals or if the feedback on the redundant output signals detects a mismatch.	2.7E-8/h	PL d Cat, 3 SIL 2

7. Transportation

7.1 Cautions during Transportation

Caution

- If the robot is transported by packaging it with packaging materials, store the robot in a dry location. If the robot is stored in a location with high humidity, condensation may occur, resulting in robot defects.
- When relocating the robot, have two or more individuals hold the link area of the robot.
- The control box is moved by grasping the side handle.
- When transporting the robot or control box, make sure to maintain the proper posture. Failure to do so may result in back injury or other physical injuries.
- When transporting the robot using lifting equipment, make sure to observe all related national and regional regulations.
- Doosan Robotics does not assume responsibility for any damages or losses that occur during transportation, so make sure to transport the robot safely according to the user manual.

7.2 Pose for Robot Transportation

Set the following poses to transport the robot:

Model	J1	J2	J3	J4	J5	J6
A0509(s)	180°	0°	150°	0°	25°	0°
A0912(s)	180°	0°	160°	0°	20°	0°

7.3 Package Specifications

The box specifications for transport are as follows:

Model	Length	Width	Height
A0509(s)	755 mm	450 mm	545 mm
A0912(s)	986 mm	452 mm	545 mm

8. Maintenance

System maintenance must be performed by Doosan Robotics or a company designated by Doosan Robotics. Maintenance covers maintaining system operability and recovering system operability in the event of an issue, and it includes repair work and system diagnosis of potential issues.

When maintenance work is completed, risk assessment must be performed to confirm whether the system satisfies required safety levels. Corresponding national and regional regulations must be observed during inspection, and all possibilities related to safety must be tested.

When performing work on the robot arm or control box, the following safety procedures and warnings must be observed.

- Maintain the safety settings of the software during maintenance work.
- If a defect in a particular part occurs, replace the part with a new identical part or part approved by Doosan Robotics.
- The replaced part must be returned to Doosan Robotics.
- After completing work, resume the safety function.
- Document the repair history of the robot system and manage related technical documents.
- Disconnect the power cable and make sure other power sources connected to the robot or control box do not supply power.
- Do not connect the system to a power source during maintenance.
- Check the ground connection before supplying power to the system.
- Observe ESD regulations when disassembling robot arm or control box parts.
- Do not disassemble areas that supply power from within the control box. Power supply areas may still be charged with high voltage (up to 600V) even after the control box is turned off.
- Use caution to prevent water or dust from entering the system during maintenance.

9. Disposal and Environment

Since this system contains industrial waste materials, improper disposal can cause environmental pollution. Therefore, do not dispose of the system along with general industrial or home waste.

When disposing of all or part of the system, the relevant laws and legislation must be complied with, and contact Doosan Robotics for detailed information related to the disposal of the system.

10. Product Warranty and Responsibility

Doosan Robotics (hereinafter referred to as “Doosan” or “Manufacturer”) offers a restricted warranty as stipulated in this warranty certificate for all robot systems (collectively “Robot”) and parts of the system (excluding parts that are exceptions or restricted according to the terms and conditions below) sold through Doosan or official sales agents. The warranty stipulated by this warranty certificate is a restricted warranty, and it is the only warranty provided by the Manufacturer. All warranty items shall be handled according to the conditions listed below.

10.1 Scope of Warranty

Material and manufacturing defects of each robot and its parts (collectively, “Doosan Products”) are subject to the warranty provided by the Manufacturer. This warranty is only offered to the end user (hereinafter referred to as “Customer”). The warranty period is 1 year starting from the date the robot was installed.

The only responsibility the Manufacturer offers and the only measure the Customer can receive in terms of Doosan Products within the scope of this warranty is restricted to repairing or replacing Doosan Products with defects.

Doosan does not compensate any or all financial, operation or productions losses, any or all indirect losses such as damage to other equipment, and any or all deliberate, special or consequential losses that occur due to defects of Doosan Products.

10.2 Restrictions and Exceptions of Warranty

To maintain the warranty, thorough maintenance procedures stipulated by the Manufacturer must be observed and recorded. This warranty is void if the Manufacturer determines the following due to the user’s failure to observe the stipulated procedures.

- If a Doosan Product is inappropriately handled or used by the user
- If parts or S/W not provided by Doosan are installed
- If a Doosan Product is incorrectly repaired or maintained by an unofficial repair technician or unauthorized individuals
- If the user has modified a Doosan Product without prior approval from the Manufacturer
- If a Doosan Product is used for non-industrial or personal purposes
- If the life cycle of consumables has ended
- If the warranty claim is made after the warranty period
- If the breakdown is caused by natural disasters (fire, flood, abnormal power, etc.)

This warranty does not apply to damages caused by external circumstances the Manufacturer does not have any control over such as theft, intentional destruction, fire, natural disasters, war or acts of terrorism.

Not withstanding the exceptions or restrictions in this warranty, this warranty does not include any warranty that Doosan Product satisfies the buyer’s production standards or miscellaneous requirements, or operates without any errors or without any interruption. The Manufacturer does not assume responsibility for any uses by the buyer, and the Manufacturer does not assume any responsibility for defects other than repair or replacement, such as defects in design, production, operation and performance.

10.3 **Transfer**

This warranty is included in the warranty period, and if a Doosan robot is sold to a different individual through a private transaction, the warranty can also be transferred. However, the warranty is only valid if the Manufacturer is notified of such a transaction, and the warranty period is still in effect. The assignee of this warranty must observe all conditions stipulated in this warranty.

11. Indemnification

Doosan Robotics continues to upgrade its product reliability and performance, and has the right to upgrade the product without notification. Doosan Robotics endeavors to ensure that all contents in this manual are accurate. However, it does not assume responsibility for errors or missing information.

Annex A System Specifications

A.1 Robot

A.1.1 A0509(s)

Classification	Item	Specifications
Performance	Axis Structure	6
	Payload	5 kg
	Max. Radius	900 mm
	TCP Speed	Over 1m/s
	Repeatability	± 0.03mm
Joint Movement	J1 Range / Speed	±360° / 180°/s
	J2 Range / Speed	±360° / 180°/s
	J3 Range / Speed	±160° / 180°/s
	J4 Range / Speed	±360° / 360°/s
	J5 Range / Speed	±360° / 360°/s
	J6 Range / Speed	±360° / 360°/s
Operating Environment	Operating Temperature	-5 °C ~ 45 °C (268K-318K)
	Storage Temperature	-5 °C ~ 50 °C (268K-323K)
	Humidity	90% RH (non-condensing)
Tool Flange & Cable	Digital I/O - X1	IN-2ch / Out-2ch
	Power Supply	DC 24V/ Max. 3A
	RS 485	Support
	Cable	Teach Pendant-Controller (4.5 m) / Controller – Robot (6.0 m) Smart pendant (6.0 m)
Weight		21 kg
Mounting		Floor, Ceiling, Wall, Any
IP Rating		IP 54
Noise		< 65 dB

A.1.2 A0912(s)

Classification	Item	Specifications
Performance	Axis Structure	6
	Payload	9 kg
	Max. Radius	1200 mm
	TCP Speed	Over 1m/s
	Repeatability	± 0.05mm
Joint Movement	J1 Range / Speed	±360° / 180°/s
	J2 Range / Speed	±360° / 180°/s
	J3 Range / Speed	±160° / 180°/s
	J4 Range / Speed	±360° / 360°/s
	J5 Range / Speed	±360° / 360°/s
	J6 Range / Speed	±360° / 360°/s
Operating Environment	Operating Temperature	-5 °C ~ 45 °C (273K-318K)
	Storage Temperature	-5 °C ~ 50 °C (268K-323K)
	Humidity	90% RH (non-condensing)
Tool Flange & Cable	Digital I/O - X1	IN-2ch / Out-2ch
	Power Supply	DC 24V/ Max. 3A
	RS 485	Support
	Cable	Teach pendant (4.5 m) / Robot (6.0 m) Smart pendant (6.0 m) / Emergency stop button (6.0 m)
Weight		31 kg
Mounting		Floor, Ceiling, Wall, Any
IP Rating		IP 54
Noise		< 65 dB

A.2 Control box

Item	Specifications
Weight	13 kg
Dimensions	450x210x265 mm + Stand 100mm
Protection Rating	IP 40
Interfaces	Ethernet / USB
I/O Port – Digital I/O	16/16
I/O Port – Analog I/O	2/2
I/O power supply	DC24V
Industrial Network	ModbusTCP Master/Slave, ModbusRTU Master, PROFINET IO Device, EtherNet/IP Adapter
Rated supply voltage	100-240VAC 50/60Hz

A.3 Emergency Stop Button

Item	Specifications
Weight	0.2 kg
Dimensions	68 x 91.5 x 68 mm
Protection Rating	IP 65

A.4 Smart Pendant (Option)

Item	Specifications
Weight	0.3 kg
Dimensions	180 x 90 x 26.5 mm
Protection Rating	IP 40
Cable Length	6 m

A.5 Teach Pendant (Option)

Item	Specifications
Weight	0.8 kg
Dimensions	264 x 218 x 42 mm
Protection Rating	IP 30
Screen Size	10.1 inches i
Cable Length	4.5 m

A.6 FTS (Option)

Item	Specifications	
Load Capacity	Fx	110 N
	Fy	110 N
	Fz	110 N
	Tx	11 Nm
	Ty	11 Nm
	Tz	11 Nm
Overload Capacity	150%L.C.(Load Capacity)	
Data Rate	1000 Hz	
Operating Temperature	0 °C to 45 °C (273 K to 318 K)	

Caution

- If the load exceeds the Overload Capacity range, the measurement performance of the FTS may be degraded or be damaged.

A.7 DART Platform Installation Requirement (minimum, recommended)

The minimum installation requirements for the DART Platform are as follows:

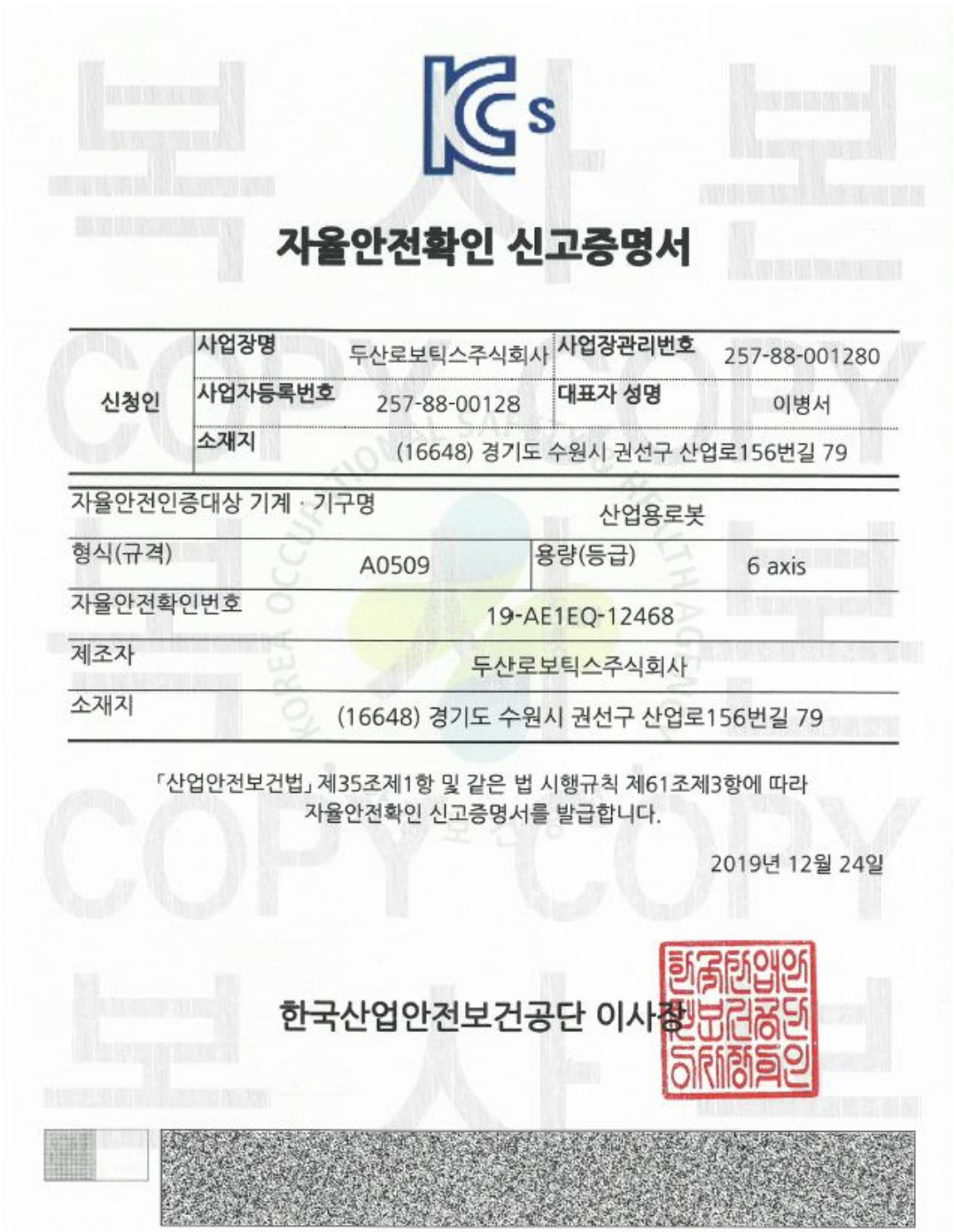
- OS: Windows 7 Enterprise Service pack1 (64 bit) or higher
- CPU: 2.20 GHz or higher
- GPU: GMA 4500 and GMA HD (Intel) or equivalent specification
- Memory: 4 GB
- Java SDK: jdk1.8.0_152 (64 bit)

The recommended installation requirements for the DART Platform are as follows:

- OS: Windows 10 Enterprise (64 bit)
- CPU: 2.80 GHz or higher
- GPU: GMA 4500 higher and GMA HD higher
- Memory: 16 GB
- Java SDK: jdk1.8.0_152 (64 bit)

Annex B Declaration and Certification

B.1 Voluntary Safety Confirmation Declaration (KCs)



KCs

자율안전확인 신고증명서

신청인	사업장명	두산로보틱스주식회사	사업장관리번호	257-88-001280
	사업자등록번호	257-88-00128	대표자 성명	이병서
	소재지	(16648) 경기도 수원시 권선구 산업로156번길 79		
자율안전인증대상 기계 · 기구명		산업용로봇		
형식(규격)		A0509	용량(등급)	6 axis
자율안전확인번호		19-AE1EQ-12468		
제조자		두산로보틱스주식회사		
소재지		(16648) 경기도 수원시 권선구 산업로156번길 79		

「산업안전보건법」 제35조제1항 및 같은 법 시행규칙 제61조제3항에 따라
자율안전확인 신고증명서를 발급합니다.

2019년 12월 24일

한국산업안전보건공단 이사장

자율안전확인 신고증명서

신청인	사업장명	두산로보틱스(주)	사업장관리번호	257-88-001280
	사업자등록번호	257-88-00128	대표자 성명	곽상철
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자율안전인증대상 기계 · 기구명	산업용로봇		
형식(규격)	A0912	용량(등급)	6 axis
자율안전확인번호	20-AE1EQ-00833		
제조자	두산로보틱스(주)		
소재지	(16648) 경기도 수원시 권선구 산업로156번길 79(고색동)		

「산업안전보건법」 제89조제1항 및 같은 법 시행규칙 제120조제3항에 따라
자율안전확인 신고증명서를 발급합니다.

2020년 02월 28일

한국산업안전보건공단 이사장

Annex C Stop Distance and Stop Time

C.1 Measurement Methods and Conditions

C.1.1 General Information

- Stop distance is the angle traveled from the moment a stop signal is generated to the moment all manipulators stop operation.
- Stop time is the time from the moment a stop signal is generated to the moment all manipulators stop operation.
- Stop distance and stop time data are provided for Joint 1, Joint 2 and Joint 3, which have large travel distances.
- The movement of an overlapping axis can cause a longer stop distance.
- Stop distance and stop time data are defined according to ISO 10218-1:2011 Annex B.

C.1.2 Stop Category:

- Stop Category 1
  The stop distance and stop time of **Joint 1 (Base) and Joint 2 (Shoulder)** are measured at 33%, 66% and 100% of the maximum speed, stretch level and load, respectively. The stop distance and stop time of **Joint 3 (elbow)** is measured at 33%, 66% and 100% of maximum speed and load. The stretch level during Joint 3 measurement is locked at maximum because of the lower arm length and completely flat wrist.

- Stop Category 0
  The stop distance and stop time of Joint 1 (Base), Joint 2 (Shoulder) and Joint 3 (Elbow) are measured at maximum speed, stretch level and load. The axes of Joint 2 and Joint 3 are parallel to each other, so an impact caused by forced stop on one part may cause a slip on the other side. The angle deviation is also measured.

Note: The measurements are the result of the worst case. Measurement may vary according to circumstances

Joint 1 measurement is performed with the rotating axis perpendicular to the ground and during horizontal movement.
Joint 2 and Joint 3 measurements are performed with the rotating axis parallel to the ground and when the robot is stopped in a downward movement vertical to the ground.

C.1.3 Pose and condition for measurements

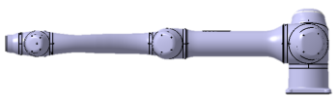
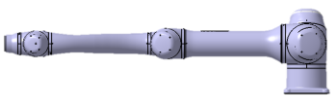
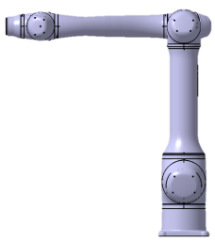
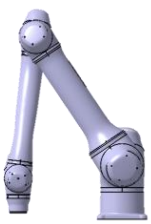
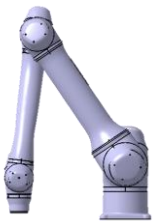
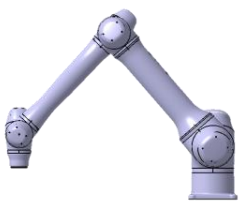
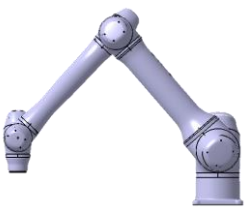
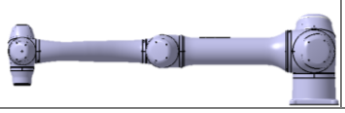
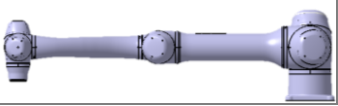
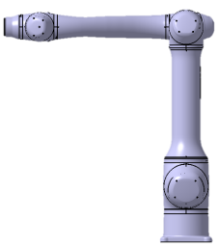
	Joint 1	Joint 2	Joint 3
100% extension Stop category 0			
33% extension Stop category 1			-
66% extension Stop category 1			-
100% extension Stop category 1			

Table C.1 the pose for 33%, 66%, and 100% of extension

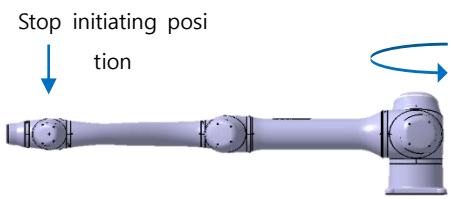
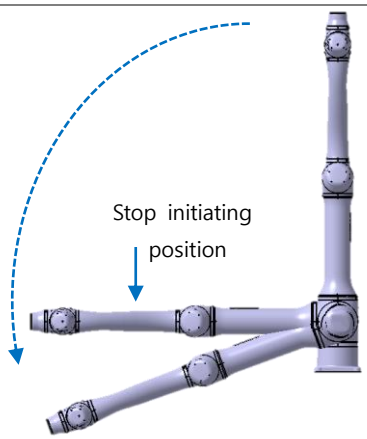
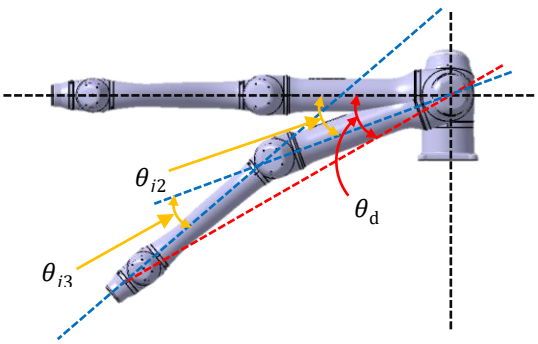
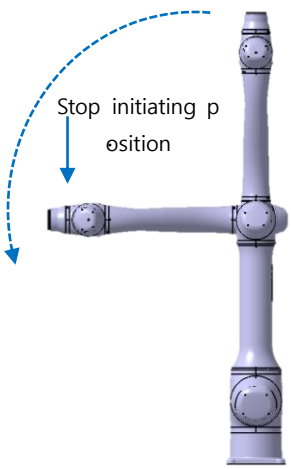
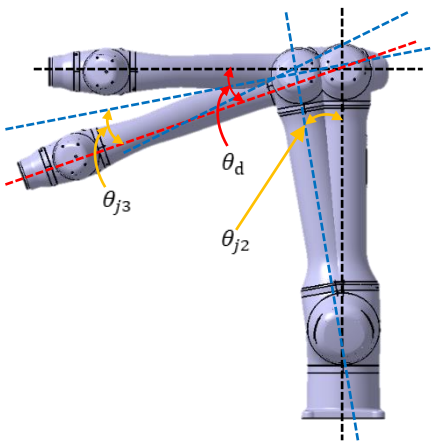
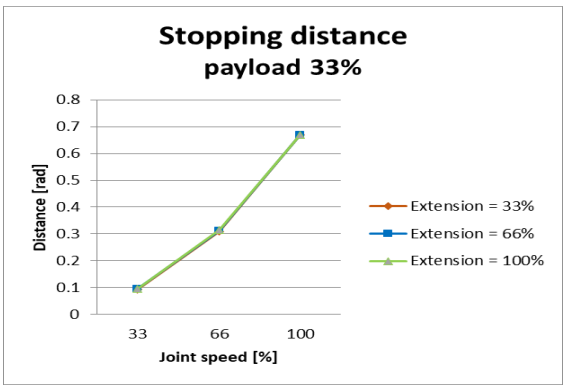
	Pose when the stop is initiated	Measured Angle
Joint1		**No slip,** $\theta_d = \theta_{j1}$
Joint2		
Joint3		

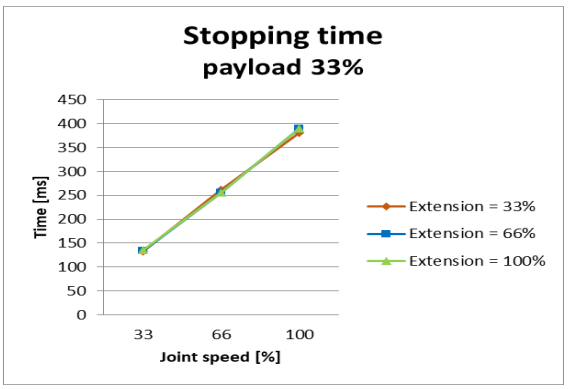
Table C.2 the pose when the stop is initiated and the measured angle (θ_d)

C.2 A0509

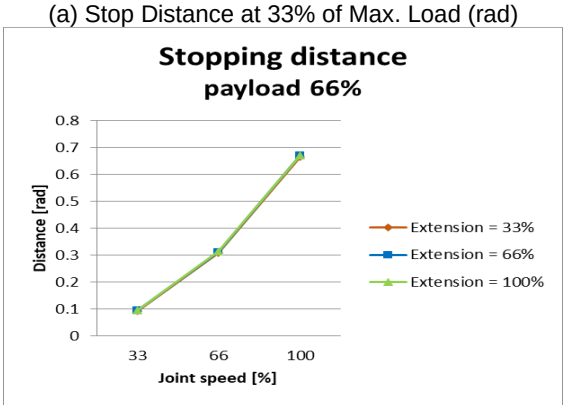
C.2.1 Stop Category 1



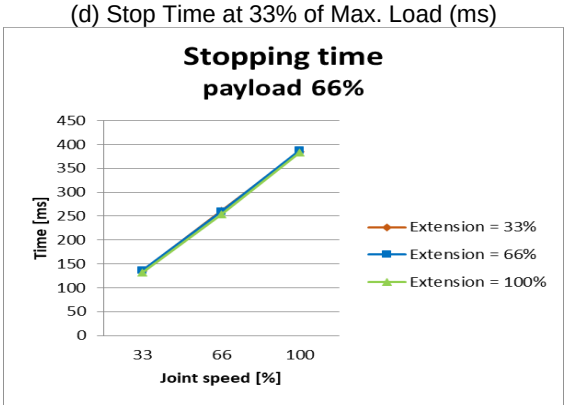
(a) Stop Distance at 33% of Max. Load (rad)



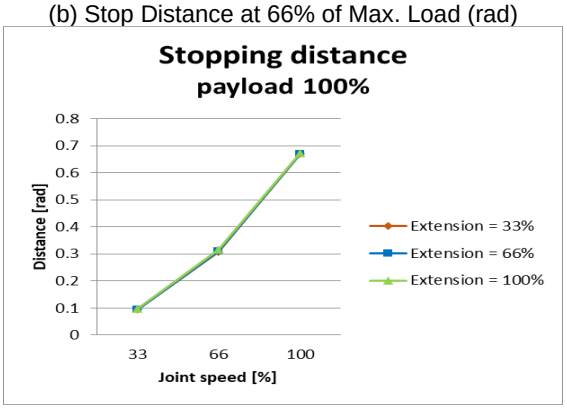
(d) Stop Time at 33% of Max. Load (ms)



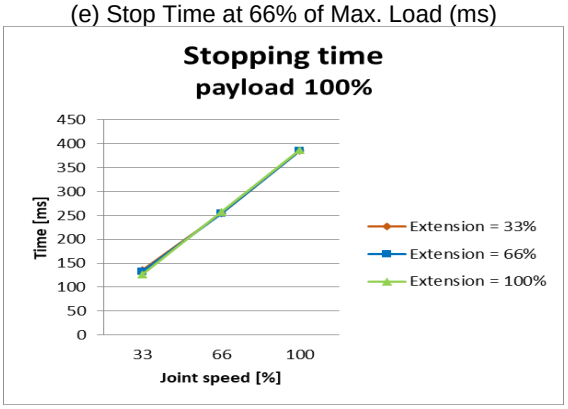
(b) Stop Distance at 66% of Max. Load (rad)



(e) Stop Time at 66% of Max. Load (ms)

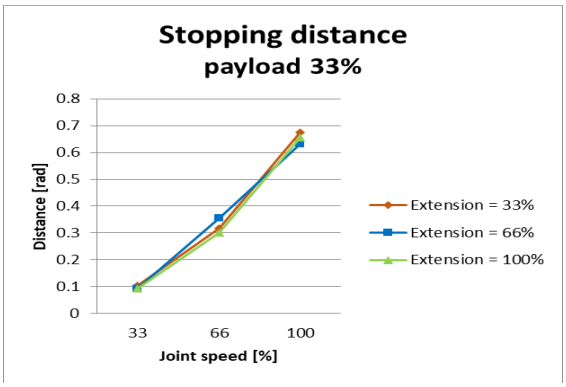


(c) Stop Distance at Max. Load (rad)

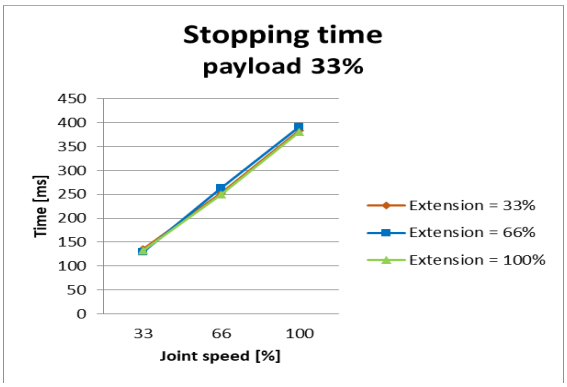


(f) Stop Time at Max. Load (ms)

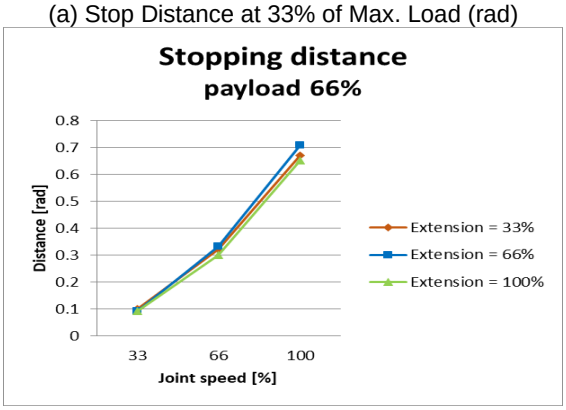
Figure C.3: Stop Distance and Stop Time of Joint 1 (Base)



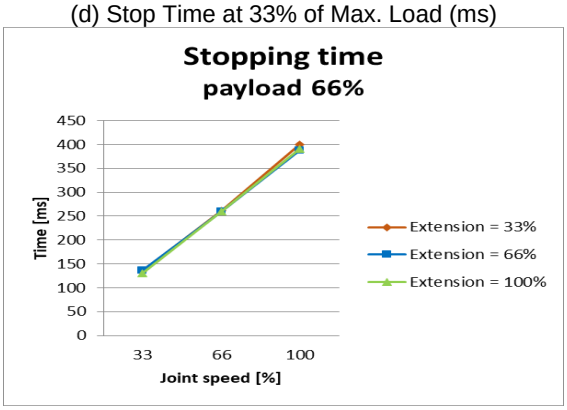
(a) Stop Distance at 33% of Max. Load (rad)



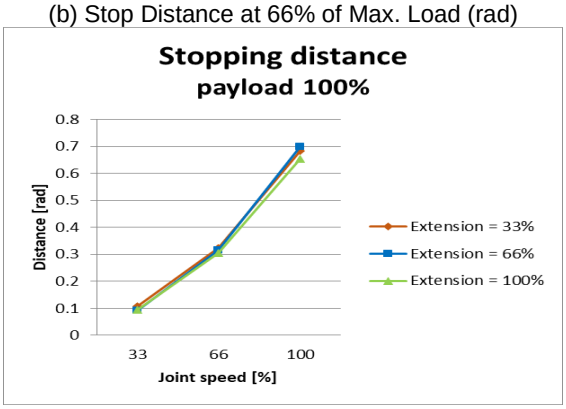
(d) Stop Time at 33% of Max. Load (ms)



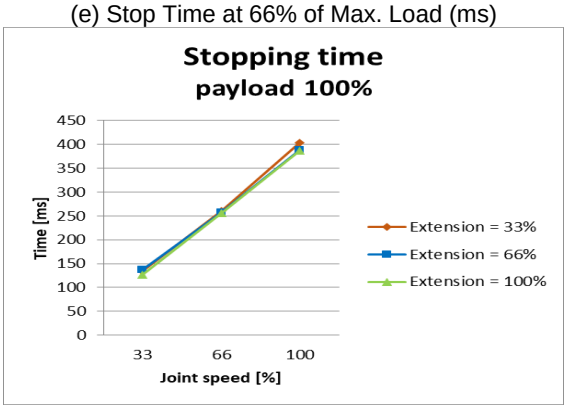
(b) Stop Distance at 66% of Max. Load (rad)



(e) Stop Time at 66% of Max. Load (ms)

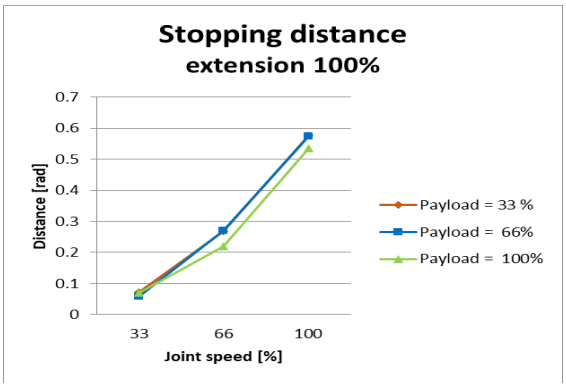


(c) Stop Distance at Max. Load (rad)

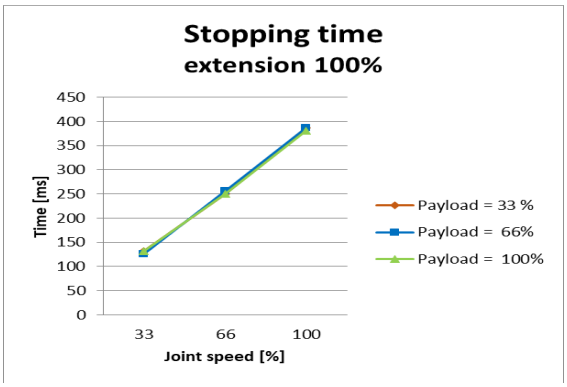


(f) Stop Time at Max. Load (ms)

Figure C.4: Stop Distance and Stop Time of Joint 2 (Shoulder)



(a) Stop Distance at Max. Stretch Level (rad)



(b) Stop Time at Max. stretch Level (ms)

Figure C.5: Stop Distance and Stop Time of Joint 3 (Elbow)

C.2.2 Stop Category 0

	Joint 1	
	Extension=100%, Speed=100%, Payload=100%	
	Stopping distance(rad)	Stopping time(ms)
Joint 1	0.286	166

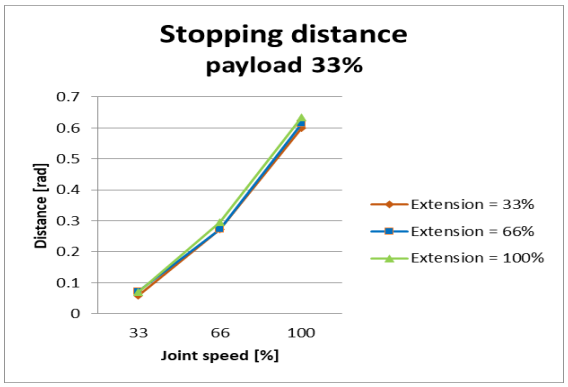
	Joint 2	
	Extension=100%, Speed=100%, Payload=100%	
	Stopping distance(rad)	Stopping time(ms)
Joint 2 (θ_{j2})	0.544	309
Joint 3 (θ_{j3})	0.0022	
Distance (θ_{jd})	0.545	

	Joint 3	
	Extension=100%, Speed=100%, Payload=100%	
	Stopping distance(rad)	Stopping time(ms)
Joint 2 (θ_{j2})	0.005	92
Joint 3 (θ_{j3})	0.163	
Distance (θ_{jd})	0.167	

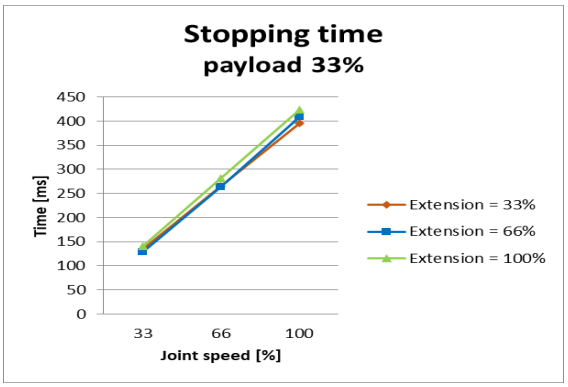
The joint 2 and joint 3 angles are refer to θ_{j2}, θ_{j3}, θ_d in table C.2

C.3 A0912

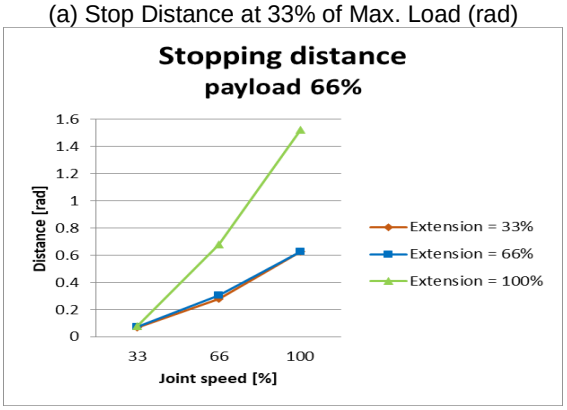
C.3.1 Stop Category 1



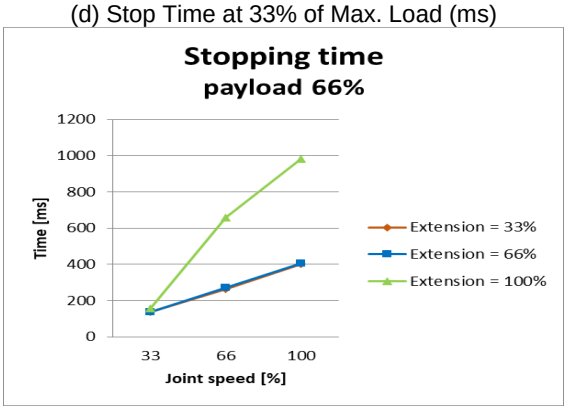
(a) Stop Distance at 33% of Max. Load (rad)



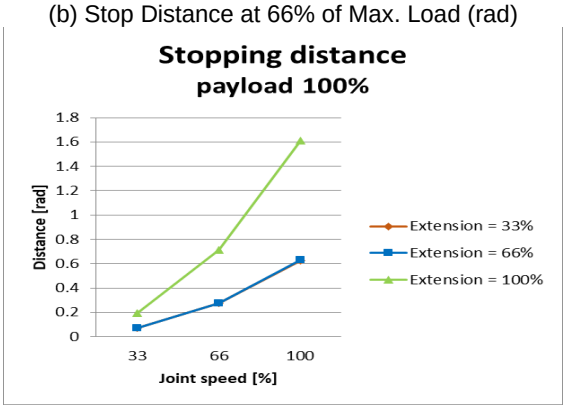
(d) Stop Time at 33% of Max. Load (ms)



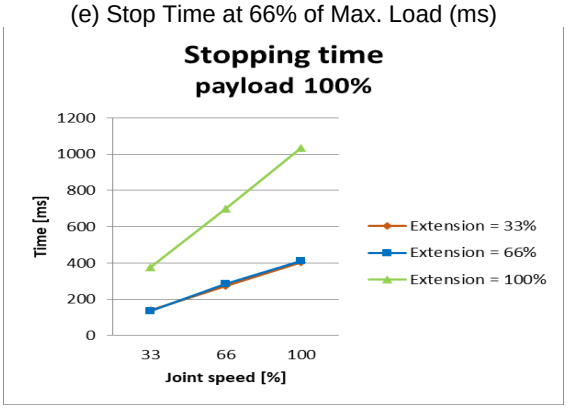
(b) Stop Distance at 66% of Max. Load (rad)



(e) Stop Time at 66% of Max. Load (ms)

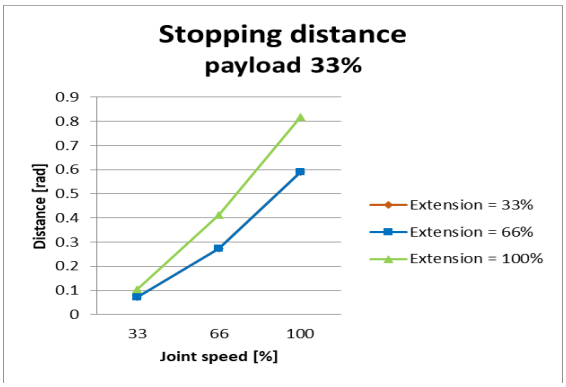


(c) Stop Distance at Max. Load (rad)

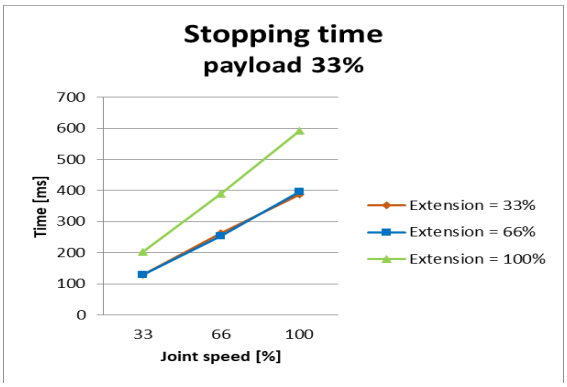


(f) Stop Time at Max. Load (ms)

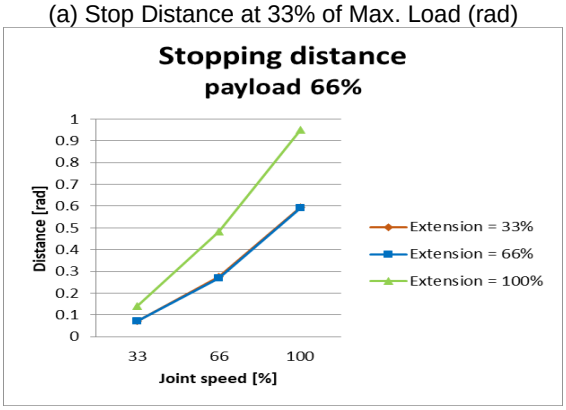
Figure C.6: Stop Distance and Stop Time of Joint 1 (Base)



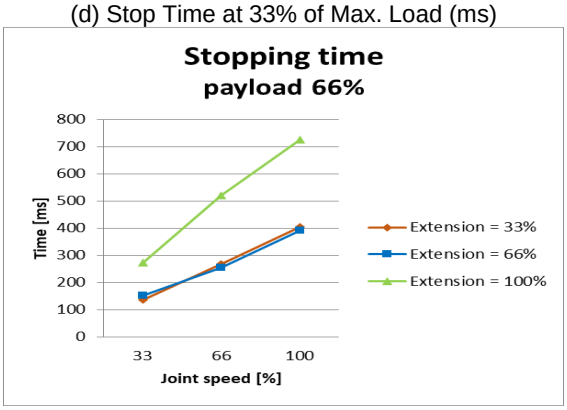
(a) Stop Distance at 33% of Max. Load (rad)



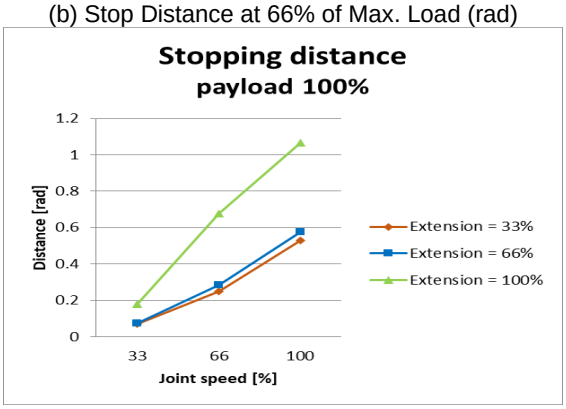
(d) Stop Time at 33% of Max. Load (ms)



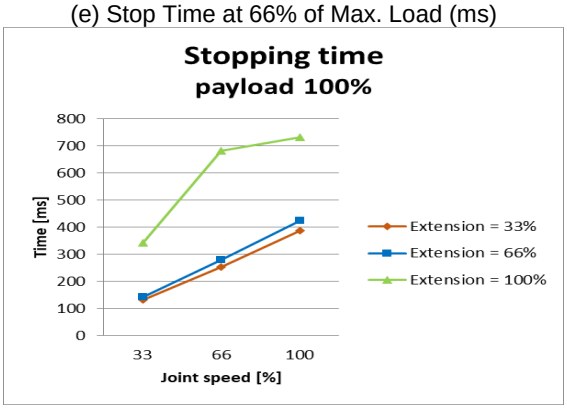
(b) Stop Distance at 66% of Max. Load (rad)



(e) Stop Time at 66% of Max. Load (ms)

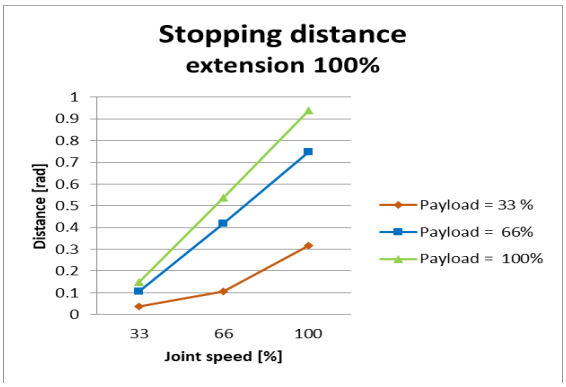


(c) Stop Distance at Max. Load (rad)

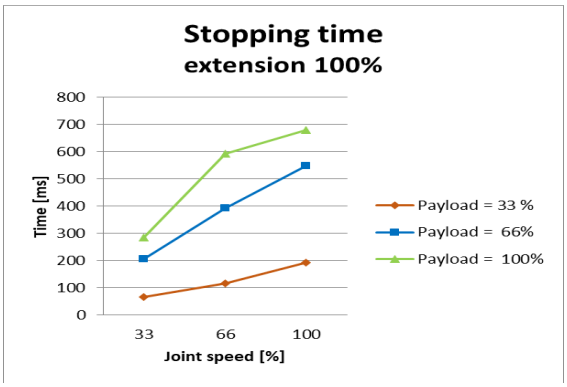


(f) Stop Time at Max. Load (ms)

Figure C.7: Stop Distance and Stop Time of Joint 2 (Shoulder)



(a) Stop Distance at Max. Stretch Level (rad)



(b) Stop Time at Max. stretch Level (ms)

Figure C.8: Stop Distance and Stop Time of Joint 3 (Elbow)

C.3.2 Stop Category 0

	Joint 1	
	Extension=100%, Speed=100%, Payload=100%	
	Stopping distance (rad)	Stopping time (ms)
Joint 1	0.4559	253

	Joint 2	
	Extension=100%, Speed=100%, Payload=100%	
	Stopping distance (rad)	Stopping time (ms)
Joint 2 (θ_{j2})	0.950	412
Joint 3 (θ_{j3})	0.001	
Distance (θ_{jd})	0.950	

	Joint 3	
	Extension=100%, Speed=100%, Payload=100%	
	Stopping distance (rad)	Stopping time (ms)
Joint 2 (θ_{j2})	0.018	187
Joint 3 (θ_{j3})	0.318	
Distance (θ_{jd})	0.329	

※ The joint 2 and joint 3 angles are refer to θ_{j2}, θ_{j3}, θ_d in table C.2

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