MAE 163B / 263B – Dynamics of Robotic System

Project No. 2

Trajectory Generation – Joint Space

MAE 163B (Undergraduate Class) – Solve Parts 1, 2

MAE 263B (Graduate Class) – Solve Parts 1, 3

Note: The following assignment is described as "open design effort" in designing trajectories for a pick and place task performed by a robotic system. There is no right or wrong way to address the problem. Every piece of information that is not described in the following technical specification is a design parameter that may affect the overall performance of the system. As an engineer an/or scientist who is assigned to design the pick and place task it is up to you to determined. In the context to designing a trajectory the best solution is the one that complies with the following constrains:

- Shortest in length
- Shortest in time (under the limitation of the joint velocities and acceleration – see spec sheet at the appendix, you may assume a max acceleration of 50 deg/s^2)
- Doesn't violet the workspace limitation of the robotic arm
- Doesn't violate the performance of the arms in terms of pick joints' velocities and and acceleration (see spec sheet in the appendix for max joint velocity, you may assume a max acceleration of 50 deg/s^2 for all the joints)
- Avoid a collision with obstacles in the field

Task description - A feeder of electronic chips presents a chip with physical dimensions of 10mm x 10mm x 2mm one at a time to the robotic system in a known position. All the chips fed by the feeder are present in exactly the same configuration (position and orientation) and at the same place one at the time. The feeder is much faster than the robotic arm and presents the chip before the arm completed its previous trajectory. The robotic arm is required to pick up the chips from the feeder and place the four chips at the corners of a PCB with the size of 100mm x 100mm. The orientations of chip is different at each one of the corners of the PCB (1,2,3,4) as indicated by the dot on the chip. The chips are rotated by 90 deg with respect to each other but share the same surface. As the arm moves between the location the gripper mast remain close on the chip and further open as it is about to grasp/release the chip. The jaws of the gripper moves with a specific speed that needs to be taken into account during the grasping and releasing actions.

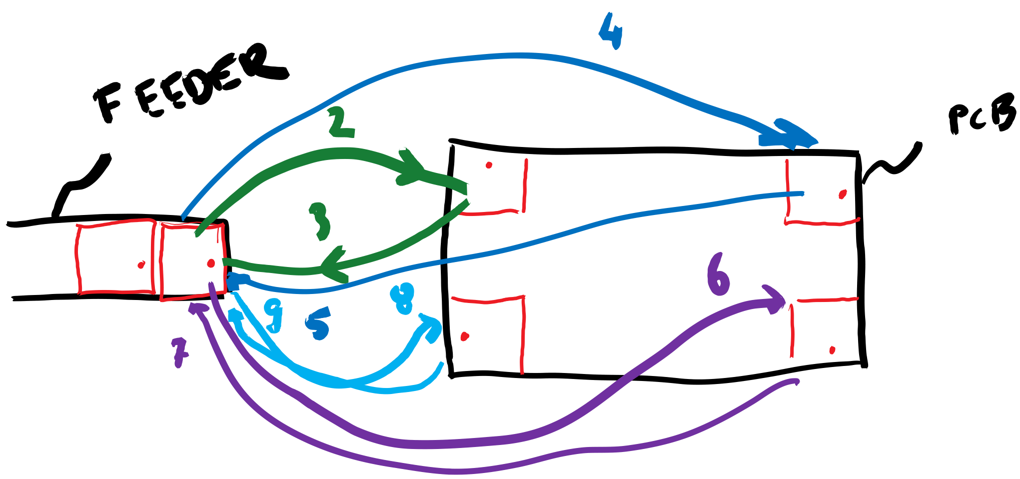
Open Geometrical Design Parameters

- Location of the feeder with respect to the world coordinate system {S}
- Location of the PCB with respect to the world coordinate system {S}

Initial and Final Arm Configurations – The arm is position such that the elbow is at 90 deg and the Z axis of the end effector is at the end of its range of motion fully retracted into the arm.

Trajectories – The arm has to complete the following trajectories (note the location of the dot at the feeder and the location of the dot in each one of the corners)

- Trajectory 1 - From the reference configuration of the arm to the feeder
- Trajectory 2 - From the feeder to the first corner
- Trajectory 3 - From the first corner to the feeder
- Trajectory 4 - From the feeder to the second corner
- Trajectory 5 - From the second corner to the feeder
- ~~Trajectory 6 - From the feeder to the third corner~~
- ~~Trajectory 7 - From the third corner to the feeder~~
- ~~Trajectory 8 - From the feeder to the forth corner~~
- ~~Trajectory 9 - From the forth corner to the reference configuration~~



System configuration – You as the designer of the system has the freedom to position the two elements of the system i.e. the feeder the PSB at any location that you wish in order to minimize the length of the trajectories and the completion time of the task under the following assumptions

- **Collisions** - Eliminate any collision between the arm and its griper and the objects in the environment i.e. the feeder ot the PCB.
- **Operational Point of the axis Z** - The preferred operational point of the arm is such that Z axis is at the middle of the its displacement d as identified by the spec.
- **Operational Point Elbow** – The preferred configuration of the arm is when the elbow is at about 90 deg.

Arm Definition – SCARA Mitsubishi Arm - Model RH-3FRH5515

Gripper – Yamaha YRG-4220W

Part 1 (for Both Ugrad and Grad)

1.1 Define the DH parameters of the system including their numerical values based on the spec of the robotic arm and the gripper

1.2 Derive the forward and inverse kinematics. Pay attention to the multiple solutions of the inverse kinematics (i.e. elbow up and elbow down)

1.3 Determined the initial positions of the feeder (i.e. the picking location) and the four target locations of the PCB with respect to the stationary frame {S}. These definitions should be expressed (numerically) as five homogeneous transformation matrixes.

1.4 Define via points for the various trajectory and expressed them numerically as homogenous transformation matrixes in order to avoid any potential collision

1.5 Develop using the Matlab Robotic Toolbox a model of the robotic arm

Part 2 (Only for Ugrad)

2.1 Joint Space Approach - Use the joint space approach to develop the trajectories of the robotic arm to complete the task. You may choose any of the methods described in class. It is recommended to use the linear interpolation with parabolic blends since this method is the most common one in industry

Part 3 (Only for Grad)

3.1 Joint Space & Task Space - Use both the joint space approach and the task space approach to develop the trajectories of the robotic arm to complete the task using the linear interpolation with parabolic blends since this method is the most common one in industry

3.2 Optimization – Based on the results of 3.1 change the locations of the feeder, the PCB, as well as the via points as needed to shorten the trajectories.

Report Outline – Submitted a written report

Part 1

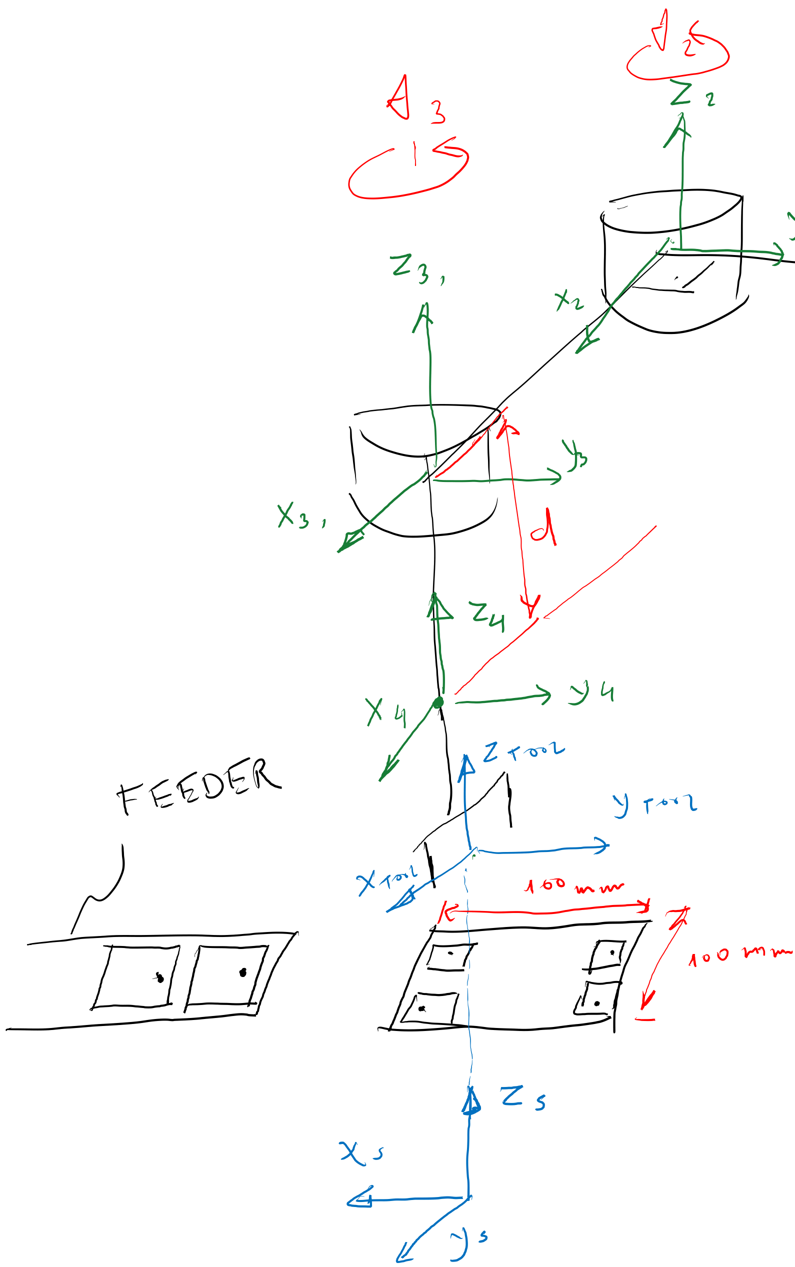
- DH parameters
- Forward Kinematics
- Inverse Kinematics
- Locations of the feeder and PCB
- Locations of the via points
- Matlab Code of the arm (M-file)

Part 2

- Extended Matlab code for the entire project (M-file). The code should be in a shape that allow one to run it without any additional knowledge of the code and verify the results.

- Animation of the robotic arm moving through the trajectories (can be broken up to individual segments)
- Joint angles, velocity, acceleration of all the trajectories including joint limits (angles, velocities, accelerations)
- End effector position and orientation plotted in 3D
- Verifications that all the conditions are met in designing the trajectories i.e.
    - kinematic limitation – joint angle velocity and accelerations
    - Collision avoidance
- Discussion of the outcomes

System Configuration



Appendix Technical Information

SCARA Mitsubishi Arm - Model RH-3FRH5515

https://us.mitsubishielectric.com/fa/en/support/technical-support/knowledge-base/getdocument/?docid=3E26SJWH3ZZR-38-2664

MELFA RH-3FRH35 RH-3FRH45 RH-3FRH55

Horizontal 3kg type

Ideal for compact cell construction, such as assembling or transporting small workpieces.

■Among the fastest moving robots in its class
[XY composite: 8,300 mm/s]
[J4 (θ axis): 3,000 deg/s]

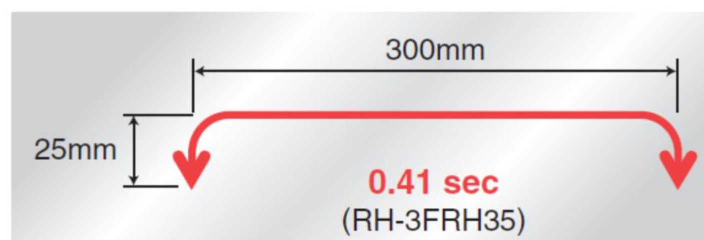
■Standard cycle time
[0.41 s (RH-3FRH35)]

■Pivotal operating range: ±170°

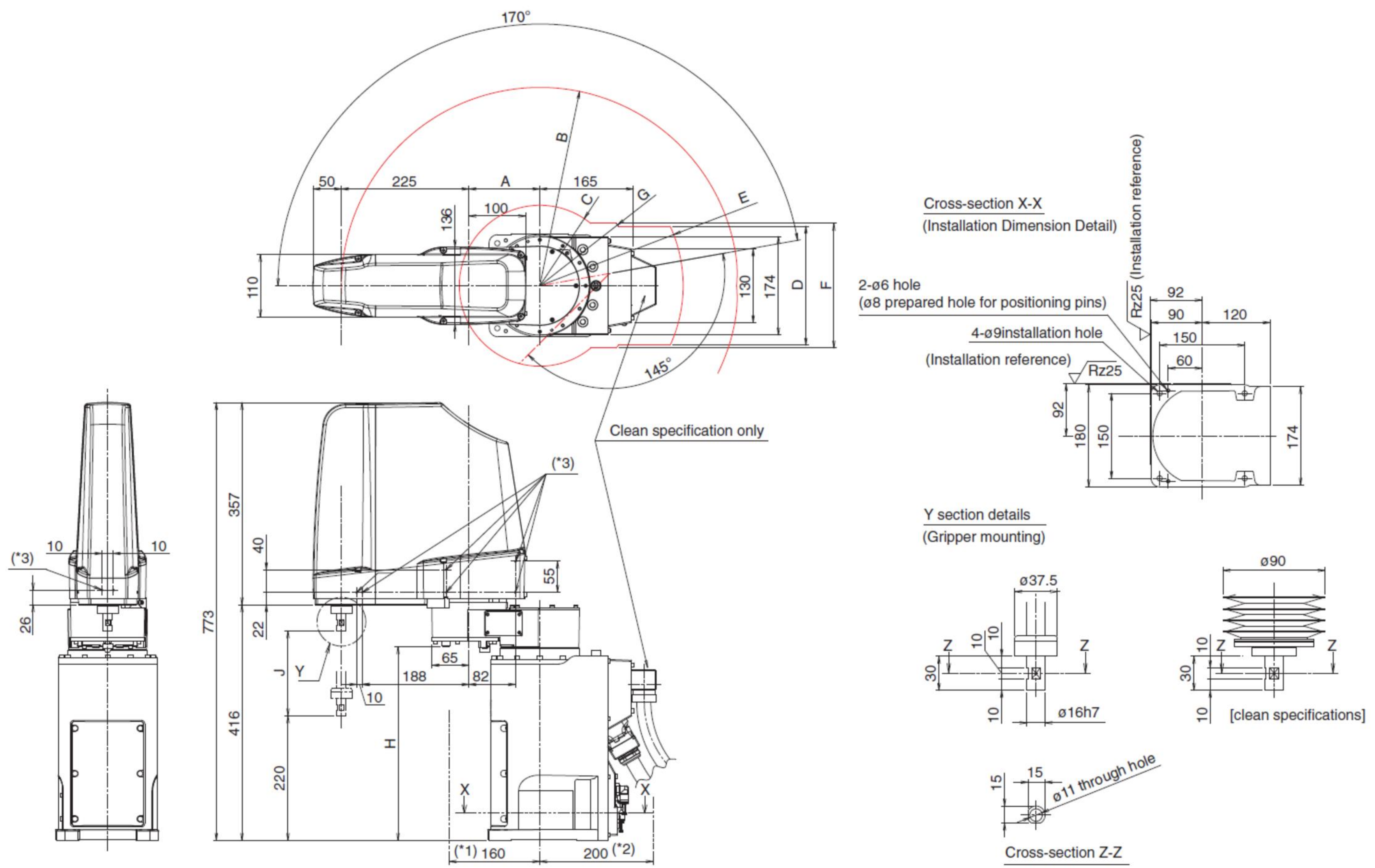
■Environmental specifications
[standard: IP20; cleanroom: ISO class 3]

■Standards compliance
Compliant with European Machinery Directives (CE) as standard.
Compliance with other standards is available in specialized machines.
Contact Mitsubishi Electric for details.

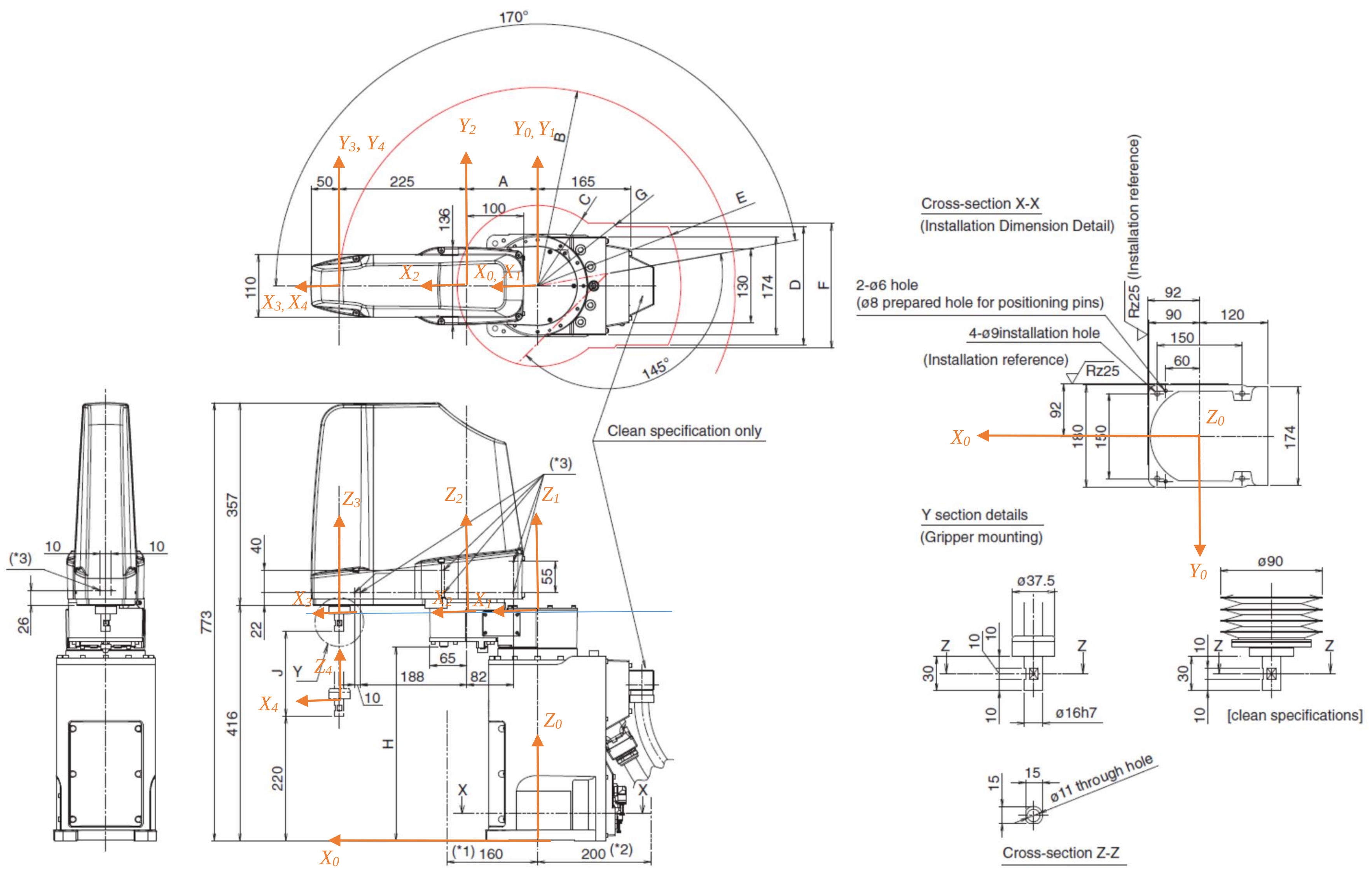
RH-3FRH35
RH-3FRH45
RH-3FRH55



Type		Unit	RH-3FRH3515/12C	RH-3FRH4515/12C	RH-3FRH5515/12C
Environmental specifications			Standard/ Cleanroom		
Protection degree *1			IP20/ ISO class3 *6		
Installation			Floor type		
Structure			Horizontal multiple-joint type		
Degrees of freedom			4		
Drive system			AC servo motor		
Position detection method			Absolute encoder		
Maximum load capacity		kg	Maximum 3 (Rated 1)		
Arm length	NO1 arm	mm	125	225	325
	NO2 arm		225		
Maximum reach radius		mm	350	450	550
Operating range	J1	deg	340 (±170)		
	J2		290 (±145)		
	J3 (Z)	mm	150 (Clean specification: 120) *1		
	J4 (θ)	deg	720 (±360)		
Maximum speed	J1	deg/sec	420		
	J2		720		
	J3 (Z)	mm/sec	1100		
	J4 (θ)	deg/sec	3000		
Maximum composite speed *2		mm/sec	6800	7500	8300
Cycle time *3		sec	0.41	0.46	0.51
Position repeatability	Y-X composite	mm	±0.010	±0.010	±0.012
	J3 (Z)		±0.01		
	J4 (θ)	deg	±0.004		
Ambient temperature		°C	0 to 40		
Mass		kg	29	29	32
Tolerable amount of inertia	Rating	kgm^2	0.005		
	Maximum		0.06		
Tool wiring			Gripper: 8 input points/8 output points (20 pins total) Signal cable for the multi-function gripper (2-pin + 2-pin power line) LAN × 1 <100 BASE-TX> (8-pin) *4		
Tool pneumatic pipes			Primary: ø6 × 2 Secondary: ø4 × 8		
Machine cable			5m (connector on both ends)		
Connected controller *5			CR800-D, CR800-R, CR800-Q		



*1: Space required for the battery replacement
*2: Space required for the interconnection cable
*3: Screw holes (M4, 6 mm long) for affixing user wiring and piping. (6 locations on both sides and 2 locations on the front of the No. 2 arm.)



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Variable dimensions

Robot series	A	B	C	D	E	F	G	H	J
RH-3FRH3515	125	R350	R142	210	R253	220	R174	342	150
RH-3FRH3512C	125	R350	R142	224	R253	268	R196	342	120
RH-3FRH4515	225	R450	R135	210	R253	220	R174	337	150
RH-3FRH4512C	225	R450	R135	224	R253	268	R197	337	120
RH-3FRH5515	325	R550	R191	160	R244	172	R197	337	150
RH-3FRH5512C	325	R550	R191	160	R253	259	R222	337	120

RH – 3 FRH 55 15 □ – D

Robot structure
RH: Horizontal, multiple-joint type

Maximum load capacity
3: 3kg

Series
FRH: FR series

Arm length
35: 350mm
45: 450mm
55: 550mm

Controller type
D: CR800-D
R: CR800-R
Q: CR800-Q

Environment specification
Blank: Standard specifications
C: Cleanroom specifications

Vertical stroke
12: 120mm
15: 150mm

*1: The range for vertical movement listed in the environmental resistance specifications (C: Clean specifications) for the RH-3FRH is narrower than for the standard model. Keep this in mind when working with the RH-3FRH. The environment-resistant specifications are factory-set custom specifications.
*2: The value assumes composition of J1, J2, and J4.
*3: Value for a maximum load capacity of 2 kg. The cycle time may increase if specific requirements apply such as high work positioning accuracy, or depending on the operating position. (The cycle time is based on back-and-forth movement over a vertical distance of 25 mm and horizontal distance of 300 mm.)
*4: Can also be used as a spare line (0.2 sq. mm, 4-pair cable) for conventional models.
*5: Select either controller according to your application. CR800-D: Standalone type, CR800-R: MELSEC iQ-R compatible type, CR800-Q: MELSEC Q Series compatible type.
*6: Preservation of cleanliness levels depends on conditions of a downstream flow of 0.3 m/s in the cleanroom and internal robot suctioning. A ø8-mm coupler for suctioning is provided at the back of the base.

Gripper – Yamaha YRG-4220W

https://global.yamaha-motor.com/business/robot/lineup/yrg/w/

https://global.yamaha-motor.com/business/robot/lineup/yrg/w/pdf/index/yrg_2005w_2810w_4220w.pdf

Double cam type

YRG-2005W/2810W/4220W

Basic specifications

Model name		YRG-2005W	YRG-2810W	YRG-4220W
Holding power	Max. continuous rating (N)	50	150	250
	Min. setting (% (N))	30 (15)	30 (45)	30 (75)
	Resolution (% (N))	1 (0.5)	1 (1.5)	1 (2.5)
Open/close stroke (mm)		5	10	19.3
Speed	Max. rating (mm/sec)	60	60	45
	Min. setting (% (mm/sec))	20 (12)	20 (12)	20 (9)
	Resolution (% (mm/sec))	1 (0.6)	1 (0.7)	1 (0.45)
	Holding speed (Max.) (%)	50		
Repetitive positioning accuracy (mm)		+/-0.03		
Guide mechanism		Linear guide		
Max. holding weight Note 1 (kg)		0.5	1.5	2.5
Weight (g)		200	350	800

• Hoding power control : 30 to 100% (1% steps) • Speed control : 20 to 100% (1% steps)
• Acceleration control : 1 to 100% (1% steps) • Multipoint position control : 10,000 max.

Note. Design the finger as short and lightweight as possible.

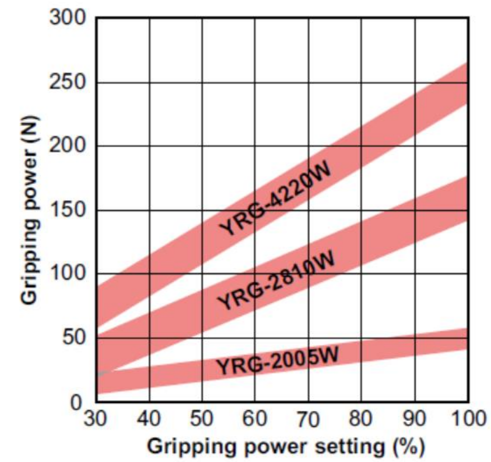
Note. Set the parameters and holding power (%) of the holding movement command so that any excessive shock is not applied to the finger during operation.

Note. When installing or uninstalling the finger, tighten the bolts while the finger is being held securely so that any excessive force or shock is not applied to the guide block.

Note. Workpiece weight that is able to be held may greatly vary depending on the material, shape, and/or holding surface conditions of the finger.

Note 1. Design the weight of a workpiece to be held so that it is approximately 1/10 to 1/20 of the holding power. (Consider further allowance when moving and swinging the gripper that keeps holding a workpiece.)

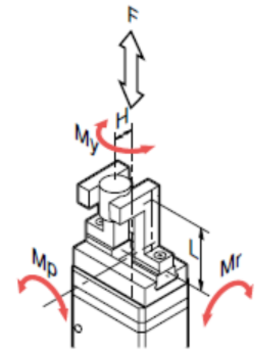
Gripping power vs. gripping power setting (%)



• Graph shows a general guide to gripping power versus gripping power setting (%). Variations will appear in the actual gripping power.

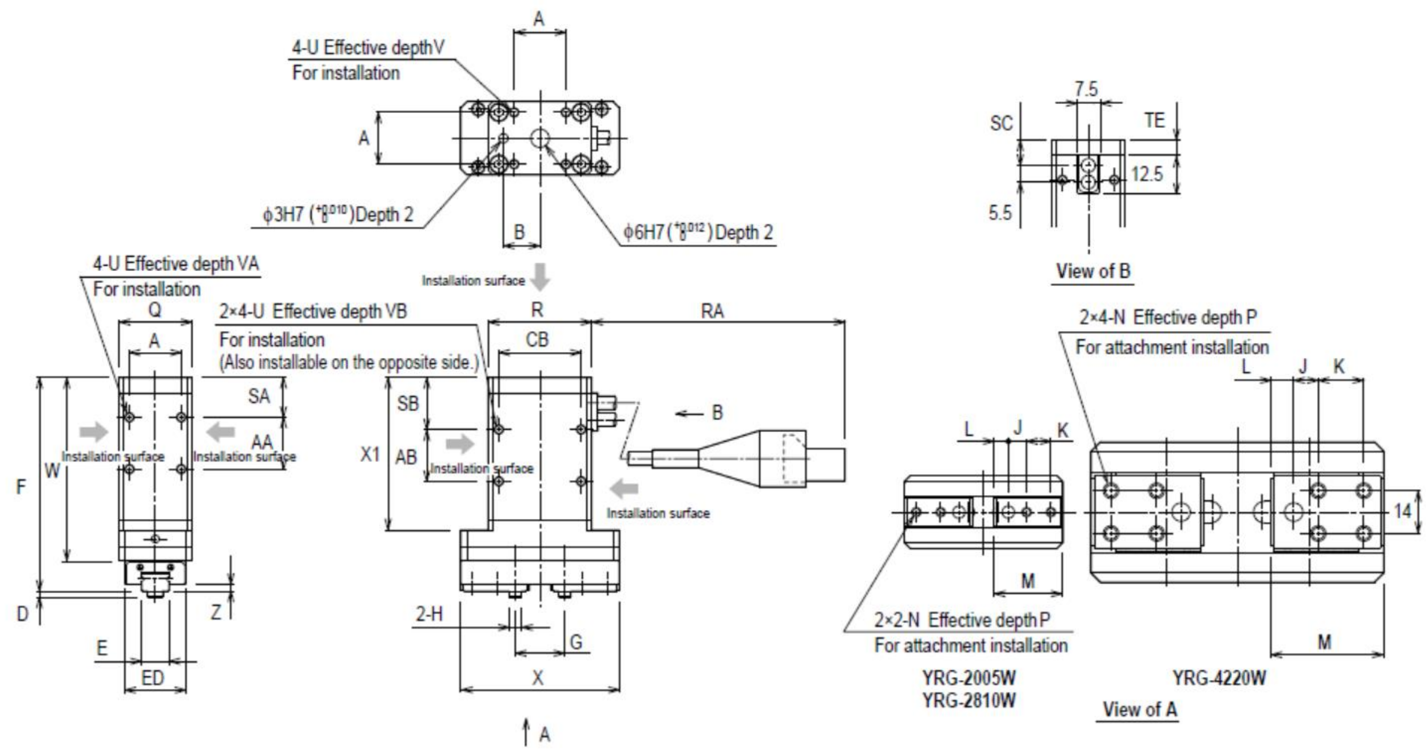
Allowable load and load moment

				YRG-2005W	YRG-2810W	YRG-4220W
Guide	Allowable load	F	N	1000	1000	2000
	Allowable pitching moment	Mp	N•m	6.7	8.1	20.1
	Allowable yawing moment	My	N•m	4	4.8	12
	Allowable rolling moment	Mr	N•m	5.1	7.8	25.9
Finger	Max. weight (1 pair)		g	40	80	200
	Max. holding position	L	mm	30	30	50
	Max. overhang	H	mm	20	20	30



• Mount the finger so that the allowable load and load moment of the guide do not exceed the values stated in the table above.
• Make the adjustment so that the finger weight, holding length (L) from the installation surface to the holding point, and overhang (H) do not exceed the values stated in the table above.
• Please contact your YAMAHA sales dealer for further information on combination of L and H.

YRG-2005W/2810W/4220W



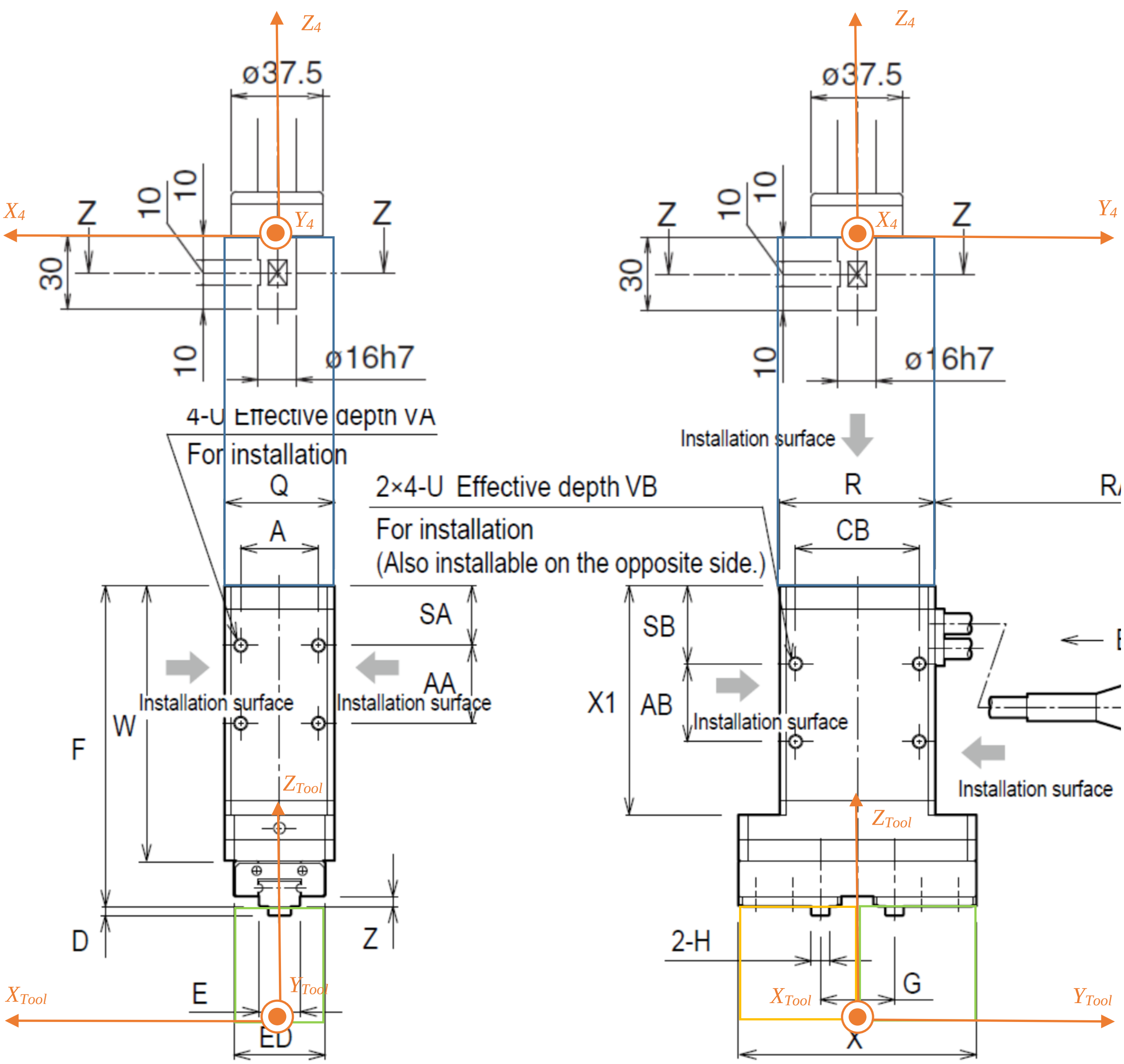
	A	AA	AB	B	CB	D	E	ED	F	G	H	J	K	L
YRG-2005W	17	17	17	12	27	2	$9^{0}_{-0.05}$	20	74	10.6 to 15.6	$\phi 4^{0}_{-0.012}$	6	8	4.6
YRG-2810W	24	24	14	15	38	2	$14^{0}_{-0.05}$	25	80	12.6 to 22.6	$\phi 5^{0}_{-0.012}$	7	10	5.65
YRG-4220W	36	25	13	20	50	3	$24^{0}_{-0.05}$	40	90	17.0 to 36.3	$\phi 6^{0}_{-0.012}$	8	15	7.5

	M	N	P	Q	R	RA	SA	SB	SC	TE	U	V	VA	VB	W	X	X1	Z
YRG-2005W	22.5	M3	5	24	34	165+/-10	13	17	8.3	5	M3	5	6	6	64	52	54	2.2
YRG-2810W	27.5	M4	5	32	46	140+/-10	16	21	9.3	6	M4	6	8	8	71	67	61	2
YRG-4220W	37	M5	8	46	60	235+/-10	18	24	10.8	7.5	M5	7.5	8	10	76	96	63	3

Connection Between the Tip of the Robot and the Gripper

Notes (Assembly drawing not to scale)

- Connective Block (marked by a blue cube) with a high of 60mm
- Left jaw if the gripper (marked by a yellow cube) and right jaw of the gripper (marked by a green cube) each with a height of 20mm



Note

- Assume that the bottom of the computer chip grasped by the jaws is fleshed with the face of the gripper as it is being placed on the PCB