

MAE 163B / 263B – Dynamics of Robotic System

Project No. 3

Jacobian Matrix

In this HW use the same SCARA robot/gripper defined in HW 2 (SCARA Mitsubishi Arm - Model RH-3FRH5515 - Yamaha YRG-4220W)

1. **Jacobian Derivation** - Derive the Jacobian in a parametric fashion (i.e. do not use numerical values for the DH parameters) using the following methods and express all the results in the base frame (i.e. frame {0}) and verify that all the expressions are identical
 - Velocity Propagation
 - Force Propagation
 - Explicit Method

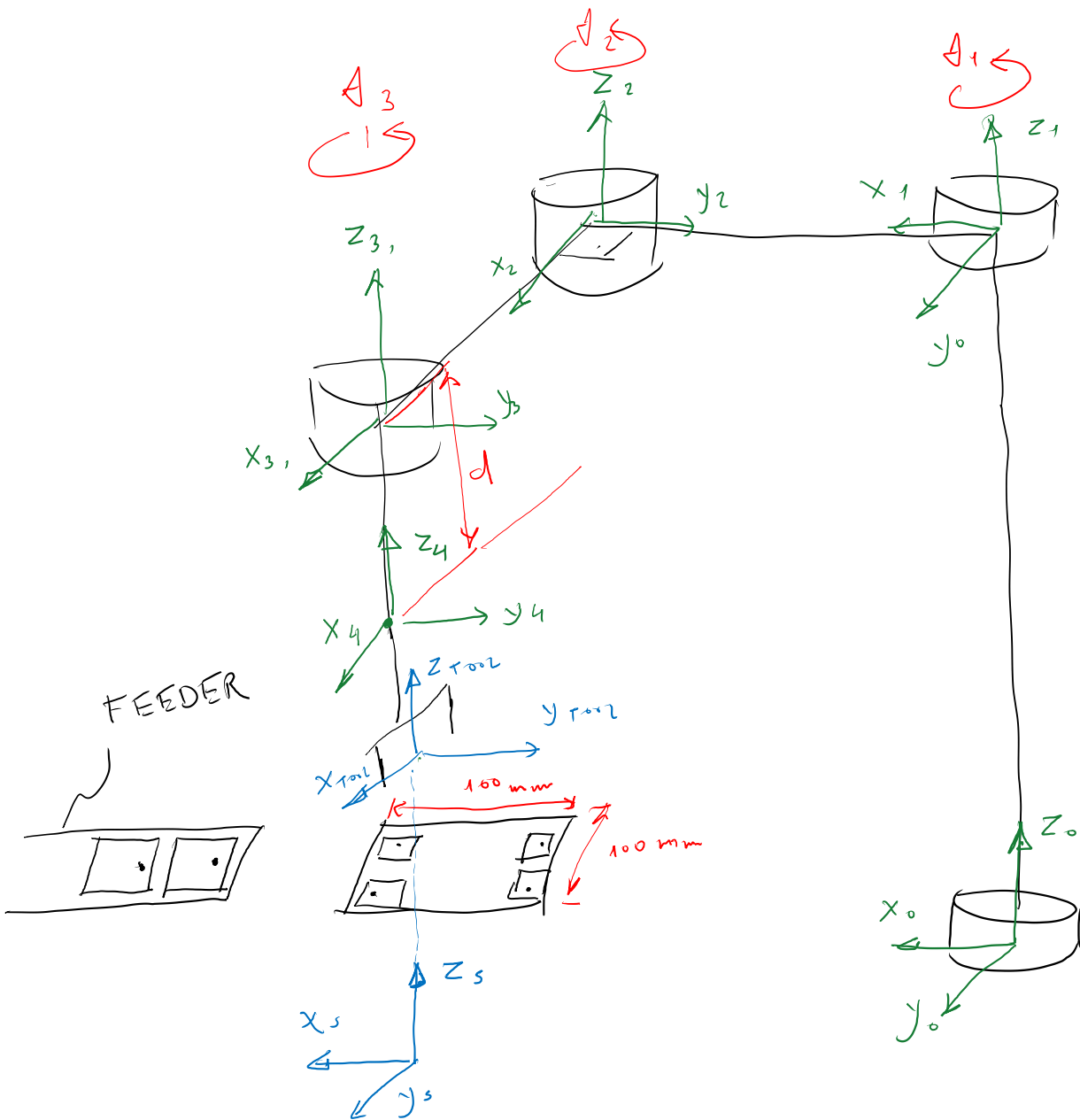
2. **Singularities**
 - a. **Pose Definition** - Define all the configurations in which the manipulator will reach singularity utilizing the Jacobean matrix. For the purpose of defining these theoretical configurations ignore the joints' range of motion of the SCARA Mitsubishi Arm.
 - b. **Implications** - Demonstrate analytically and explain in writing the implications of singularities

3. **Jacobian Ellipsoid** – Note that for the purpose of drawing the ellipsoid the SCARA manipulator can be reduced to a 2R manipulator with two link lengths of 325mm and 225mm (total length 550mm).
 - a. Draw the ellipsoid in the range of 0mm to 550mm with increments of 55mm
 - b. Calculate the two eigen values
 - c. Suggest the configuration of the elbow such that the performance will be maximized.

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

Gripper – Yamaha YRG-4220W

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

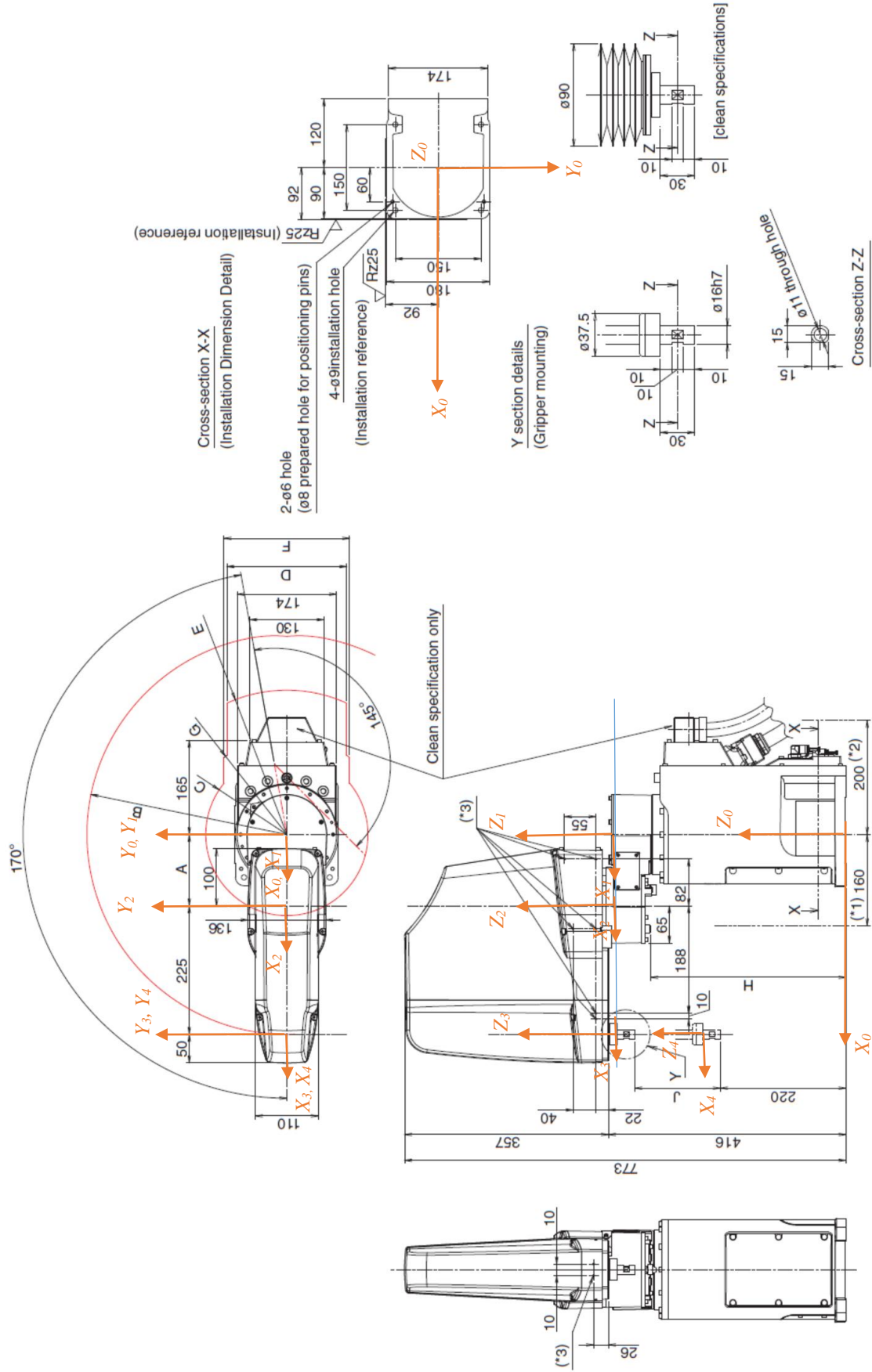
Ideal for compact cell construction, such as assembling or transporting small workpieces.

- 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: $\pm 170^\circ$
- 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				
Protection degree *1			Standard/ Cleanroom	
Installation			IP20/ ISO class3 *6	
Structure			Floor type	
Degrees of freedom			Horizontal multiple-joint type	
Drive system			4	
Position detection method			AC servo motor	
Maximum load capacity	kg		Absolute encoder	
NO1 arm		125	Maximum 3 (Rated 1)	325
NO2 arm	mm			
Maximum reach radius	mm	350		550
J1	deg		340 (±170)	
J2	deg		290 (±145)	
J3 (Z)	mm		150 (Clean specification: 120) *1	
J4 (θ)	deg		720 (±360)	
J1	deg/sec		420	
J2	deg/sec		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
Y-X composite		±0.010	±0.010	±0.012
J3 (Z)	mm		±0.01	
J4 (θ)	deg		±0.004	
Ambient temperature	°C		0 to 40	
Mass	kg	29	29	32
Tolerable amount of inertia	kgm ²		0.005	
			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 x 1 <100 BASE-TX> (8-pin) *4		
Tool pneumatic pipes		Primary: ø6 x 2 Secondary: ø4 x 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.)

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-3FRH5515-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



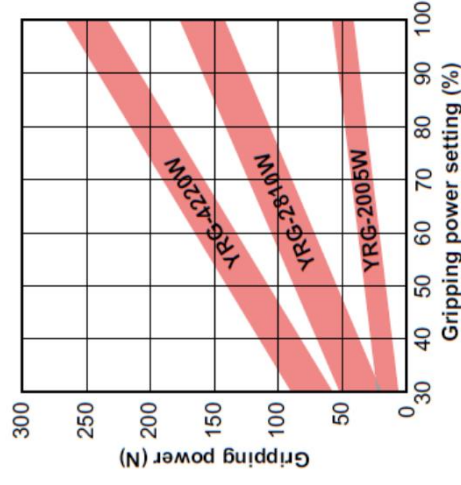
Basic specifications

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
	Max. rating (mm/sec)	60	60	45
Speed	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	

• Holding 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.)

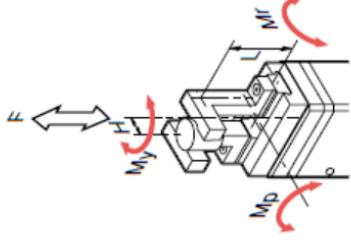
Gripping power vs. gripping power setting (%)



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

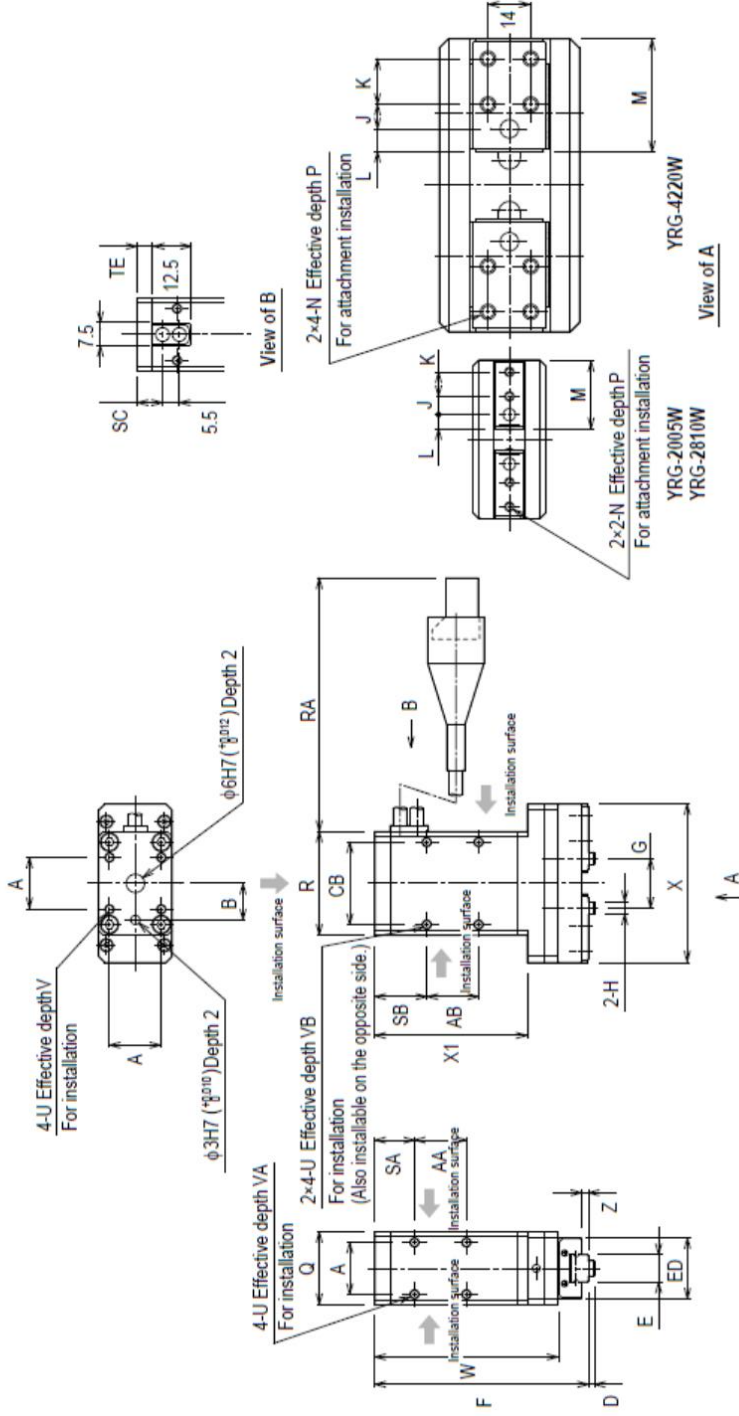
■ Allowable load and load moment

		YRG-2005W	YRG-2810W	YRG-4220W
Guide	Allowable load	F	N	
	Allowable pitching moment	Mp	N•m	
	Allowable yawing moment	My	N•m	
	Allowable rolling moment	Mr	N•m	
Finger	Max. weight (1 pair)		g	
	Max. holding position	L	mm	
	Max. overhang	H	mm	



- 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 YAMAHHA sales dealer for further information on combination of L and H.

YRG-2005W/2810W/4220W



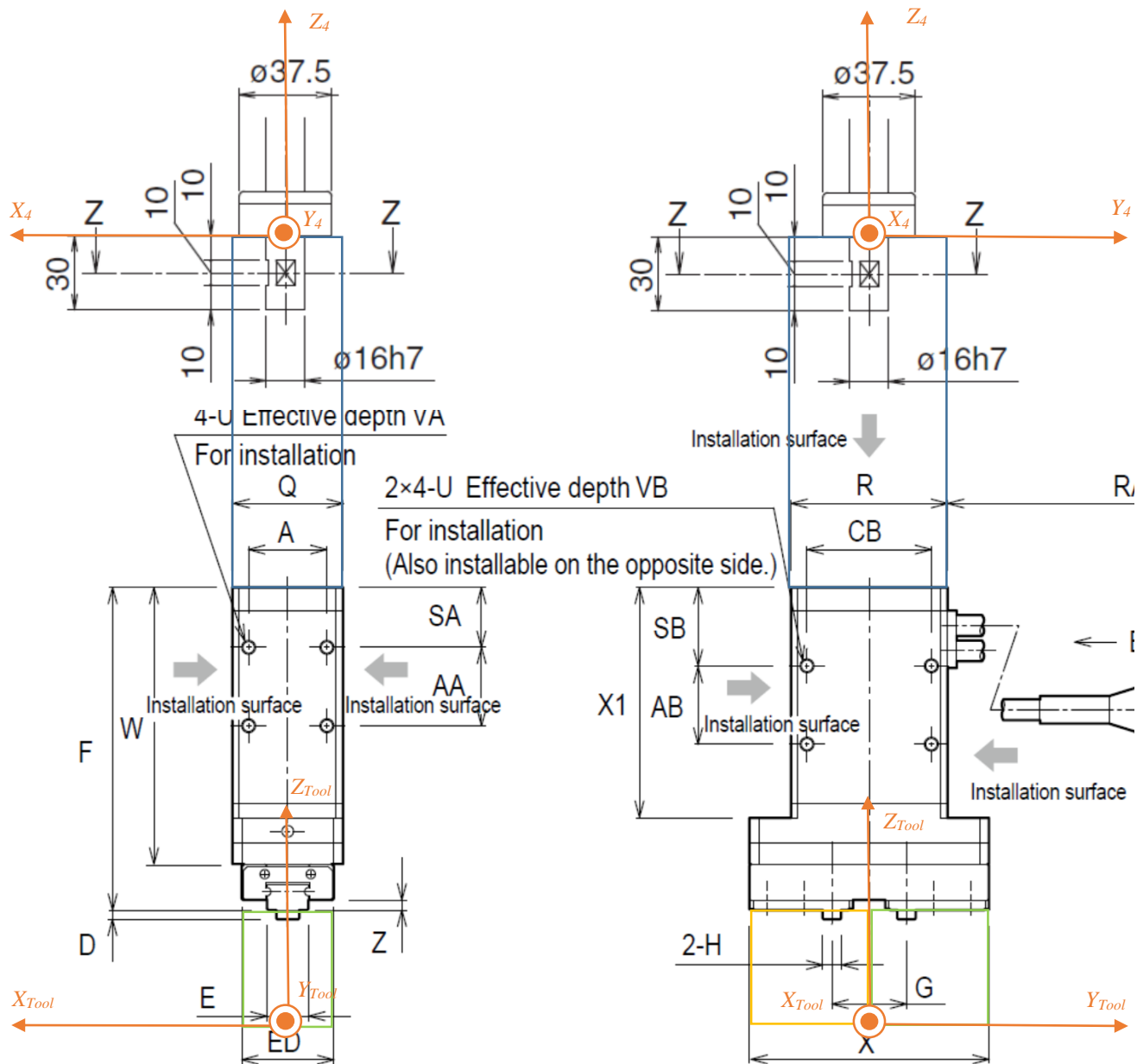
	A	AA	AB	B	CB	D	E	ED	F	G	H	J	K	L
YRG-2005W	17	17	17	12	27	2	9 ⁰ _{-0.05}	20	74	10.6 to 15.6	φ4 ⁰ _{-0.012}	6	8	4.6
YRG-2810W	24	24	14	15	38	2	14 ⁰ _{-0.05}	25	80	12.6 to 22.6	φ5 ⁰ _{-0.012}	7	10	5.65
YRG-4220W	36	25	13	20	50	3	24 ⁰ _{-0.05}	40	90	17.0 to 36.3	φ6 ⁰ _{-0.012}	8	15	7.5

	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 of 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

