VERSION 4

Filament Versatile Gripper
CDR

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+

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Edition	Modifications	Date	Revisor
1	-	21.8.2022	Yicheng, Jiyang
2		15.8.2022	Zhiyuan LI
3		03.8.2022	JiYang Liu
4		28.7.2022	Yicheng, Jiyang,Zhiyuan

Introduction

1. Brief review of requirements

With the rise of flexible production lines and advanced service robots, multifunctional grippers are becoming a more popular choice among manufacturers than traditional grippers. Conventional industrial grippers with two sets of pin arrays cannot hold certain objects, which requires more versatile and adaptable end effectors capable of gripping objects of various geometries.

We needed a versatile gripper that could grab a wide variety of objects of different shapes, weights and materials. Considering the disadvantage that the use of soft materials will greatly shorten its service life, we will focus on designing rigid universal clamps.

2. Overview of the design

This concept features a strong gripping force through relative linear motion between the two bases. The first base is connected to a linear actuator, which facilitates smooth linear motion, while the second base is fixed in space and connected to the first base by two linear guides on each side. A major advantage of this design is that only a small displacement of the base can produce an effect comparable to that of a parallel clamp, which can be much larger in size. However, this design prefers a specific grasping orientation when the target object is slender. More specifically, the moving direction of the first base is preferably perpendicular to the side of the object with the longer characteristic length.

Component and mechanism design

1. ISO CAD views

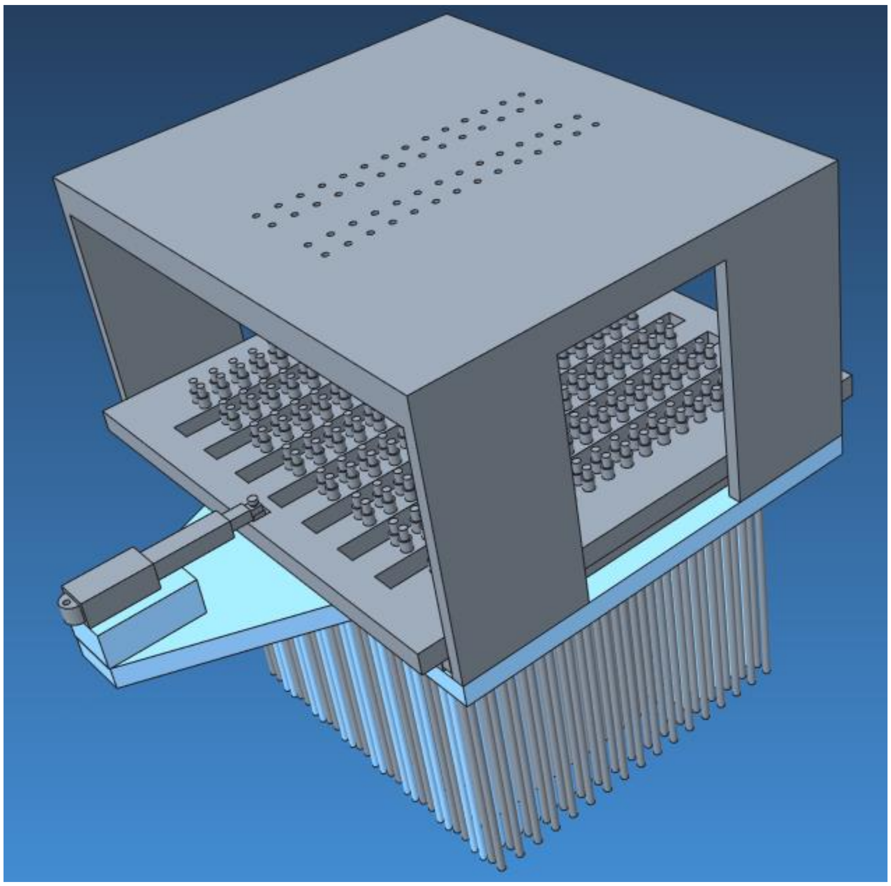


Fig. 1 Isometric view of the gripper

2. Bill of Material

Except the pin arrays, the remaining structure will be produced by PLA, a material compatible with 3D printer. By Creo built-in volume calculator, the volume of the gripper except the pin arrays is $2299910mm^3 = 2299.910cm^3$. We choose the filling as 35%, a level which provides a rigidity sufficient for most situations. PLA has a density of $1.25g/cm^3$, and the average PLA price per kilogram is 20.00$. Thus, the gross price of PLA is

$$Bill_1 = 2299.91 \cdot 0.00125 \cdot 0.35 \cdot 20 \approx 20.124\$$$

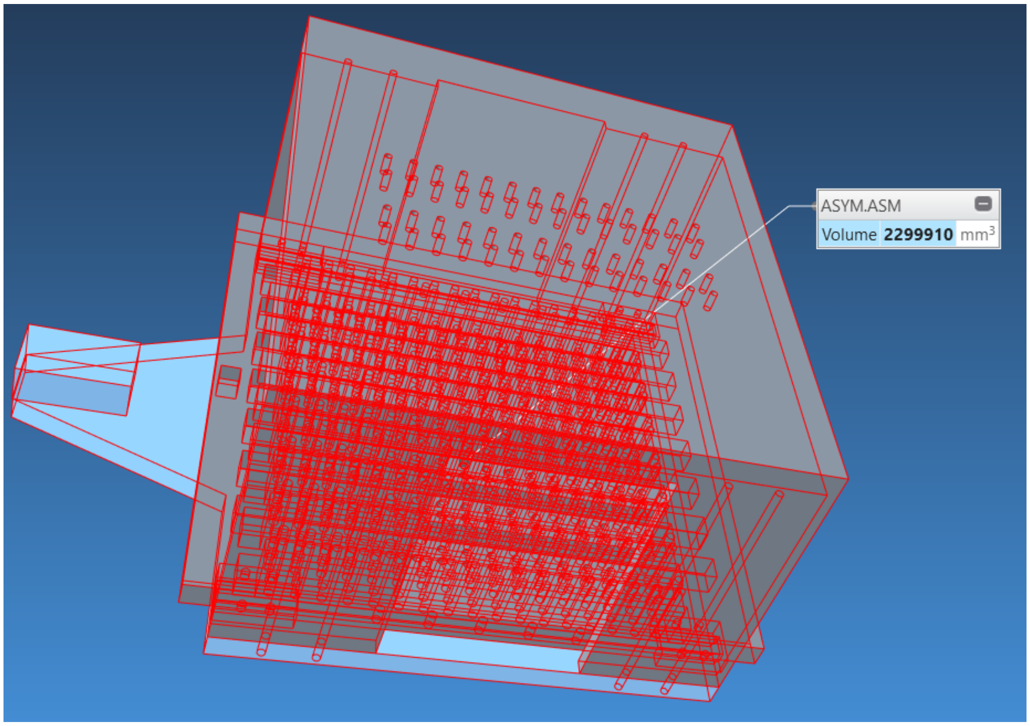


Fig. 2 volume computation by Creo

Regarding the pin arrays, though they will also be manufactured by PLA, we'll rise the filling to 100% to ensure high stiffness. We have 272 type 1 pin arrays, and from the formula for cylinder volume, we easily get the total volume is $229.917cm^3$. Similarly, the total volume of pin array 2 is $178.396cm^3$. Then, we get the expected price is

$$Bill_2 = (229.917 + 178.396) \cdot 0.00125 \cdot 1 \cdot 20 \approx 10.20\$$$

Therefore, the gross bill is approximately $30.3\$$

3. Table of components and properties

Part	Size	Numbers
Lower base	L=284mm ;W=237mm H = 10mm	1
Cap	L=237mm ;W=200mm H = 110mm	1
Upper base	L=225mm ;W=225mm H = 30mm	1
Pin array 1	D=2.5mm; L=172.2mm	272
Pin array 2	D=2.5mm ;L=152.7 mm	238
Linear actuator	10mm stroke	1
Force Sensing Resistor	D=3.8mm (active area)	1
Linear rail	L=20mm	1

Table. 1 components and properties

4. Independent section for each mechanism

<u>Cap</u>

The screw holes distribution is designed to match with that of the gripper end from a real robotics arm in Technion. Besides serving as an important connection, the cap also leaves enough room for the contraction of the pin arrays.

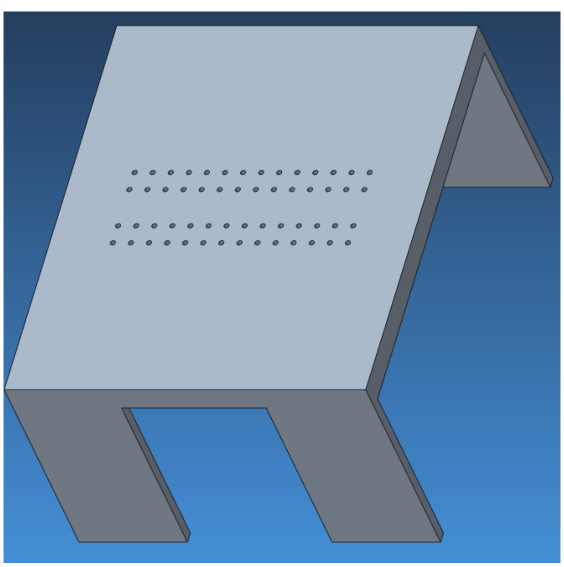


Fig.3 Isometric view of the cap

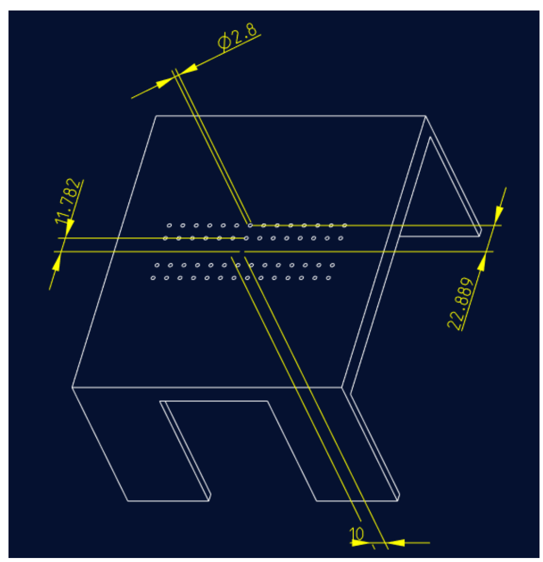


Fig.4 drawing of the cap in isometric view

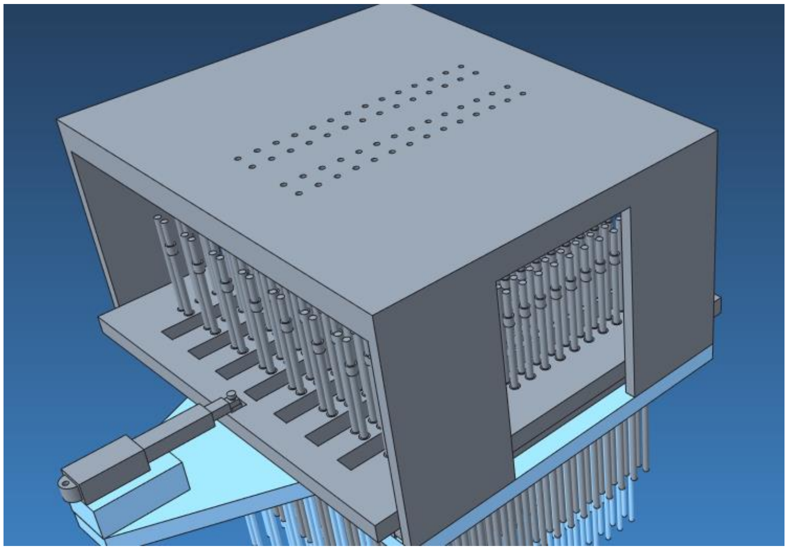


Fig.5 Isometric view when part of the pin rises due to external forces

Base

The structure of the upper and lower are closely resembled. Both is assembled with an appropriate number of pin array which will be pushed back when it is in direct contact with the target object.

The main difference is that the upper base is connected to a linear actuator, and it will slide on the linear rail installed to the lower base (blue line) when the actuator is initiated, while for the other base, it’s stationary relative to the target object, and external components such as linear rail and linear actuator are mounted on it.

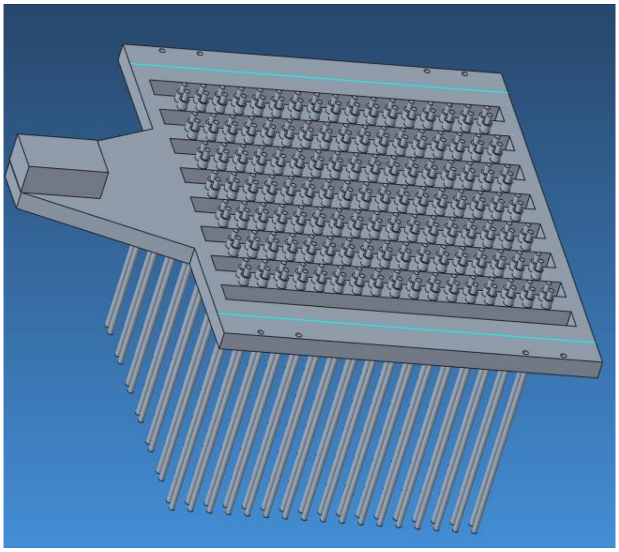


Fig. 6 Isometric view of the lower base

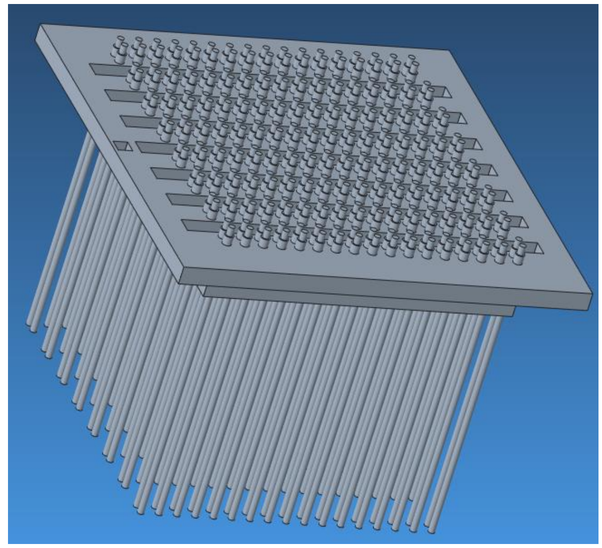


Fig. 7 Isometric view of the upper base

Pin array

The structure of a single pin is a slender cylinder with a head at the position near its tip to prevent the pin from falling due to gravity. Its upward motion is also constrained by the cap introduced before. There're two types of pins, and the only discrepancy is their length.

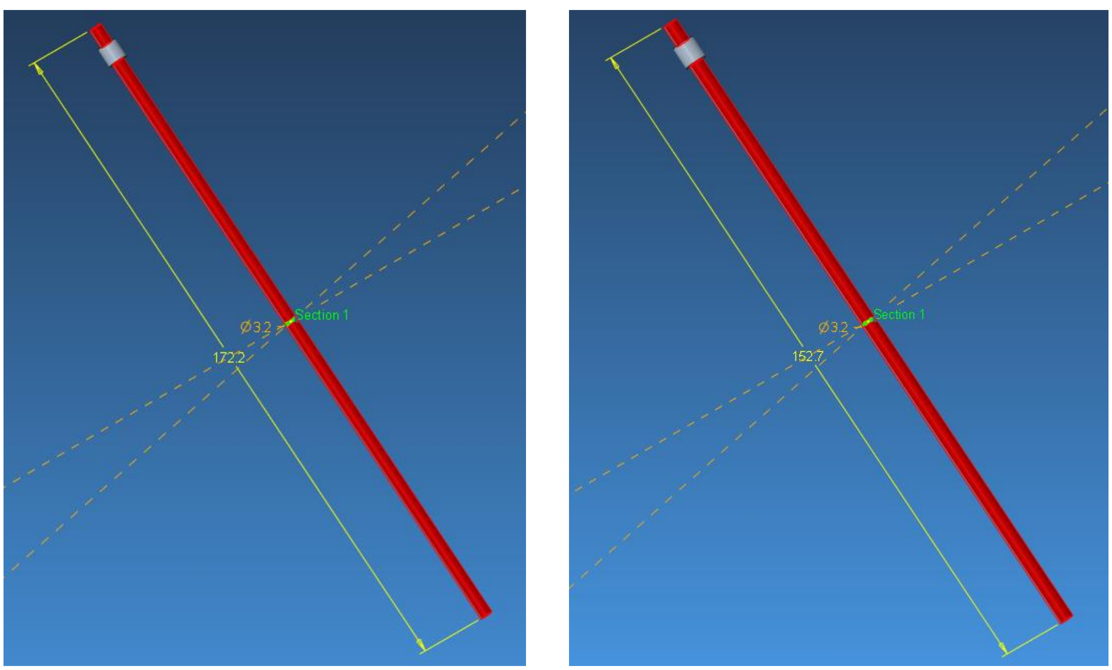


Fig. 8 Isometric view of the pin 1 and 2

FSR and linear actuator: Mechanism to obtain the appropriate final position of the gripper

A force sensor resistor (FSR) is attached in a designed groove as illustrated below. The groove is slightly wider than the actuator end so that the FCR can be properly placed. When the actuator end moves forwards and becomes in contact with the FSR, the sensor will feel the pressure and changes its internal resistance accordingly.

A reference code for FSR and actuator can be found in Appendix part, it ensures that the movement of the upper base will be terminated when the detected force on the FSR is beyond the predetermined threshold, and after holding the object for a specific time, the linear actuator will return to its initial state. It's written to be compatible with Arduino.

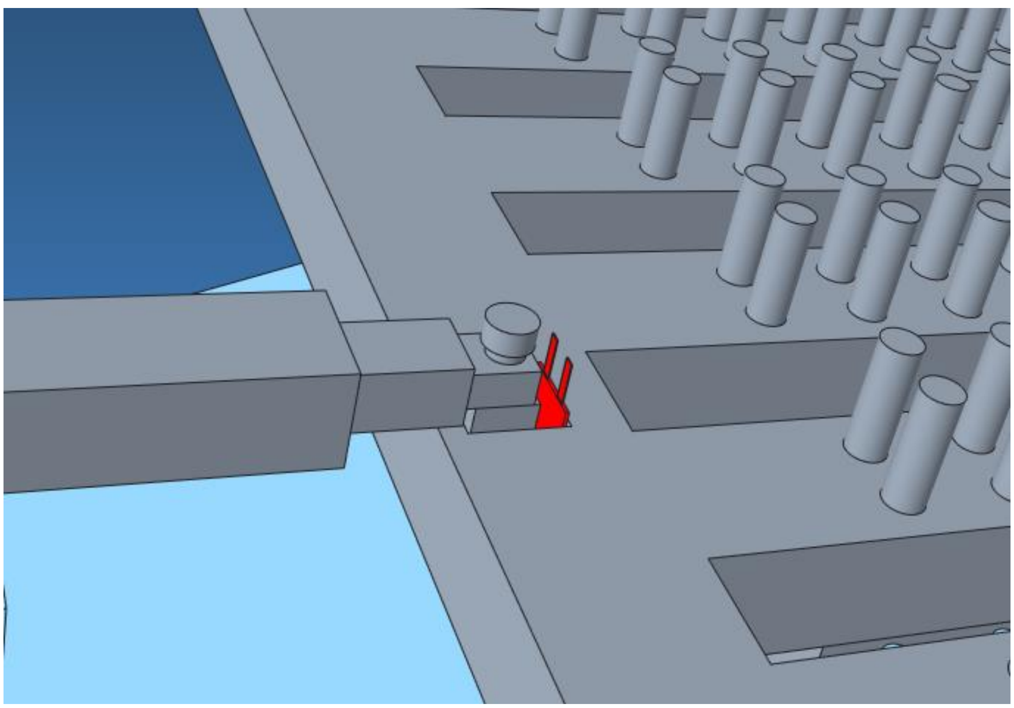


Fig. 9 detailed view of the gripper around the FSR

5. FBDs, calculations and analysis

Analysis for various parts

a) Nut

For a nut-shaped object, one possible gripping mode is demonstrated below. Twelve pins will have a direct contact with the outer surface of the object after it is clamped. Six of them provide force pointing to the left, while the other six provide force in the opposite direction. Under such circumstance, we assume each pin on the same side will exert an equal normal force, and thus equivalent friction across the surface.

Assume the object is made of plastic with a density of $1.25\frac{g}{cm^3}$, and its volume is $444.106cm^3$, thus its mass is 5.44 N approximately. We also assume the friction coefficient between rubber and plastic is roughly 0.7. Therefore, required normal force to lift the object is $7.77N$, and the force distributed on each pin is 0.657 N.

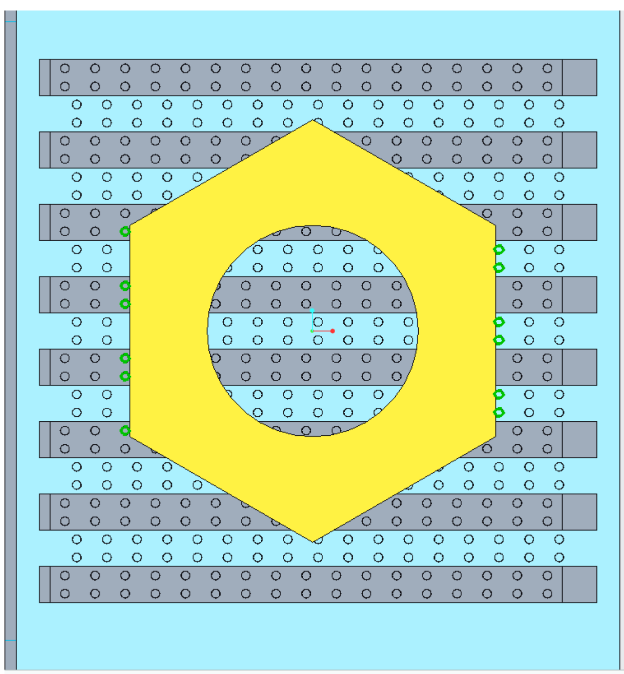


Fig.10 button view of the gripper when grasping a nut (possible gripping state1)

Another possible gripping state is illustrated below. Ten pins in total will have a direct contact with the r surface of the object after it is clamped. Among them, six of them provide force pointing to the left (denoted as F_1), two provide force in the opposite direction in outer surface (denoted as F_2), and the remaining two exert forces in the inner surface. (denoted as F_1)

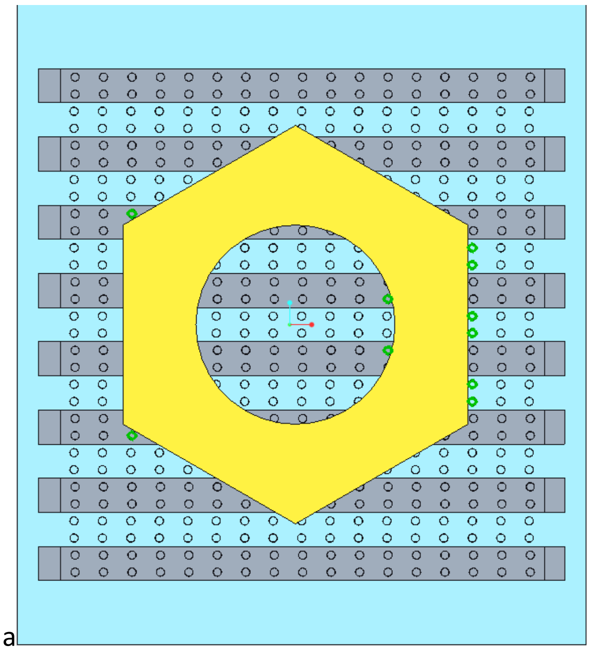


Fig.11 button view of the gripper when grasping a nut (possible gripping state2)

From moment and force balance, we get the following equation

$$\begin{cases} -3F_1 + F_2\cos(60) + F_3\cos(10) = 0 \\ (6F_1 + 2F_2 + 2F_3)\cdot 0.7 = 5.44 \\ -(3+21+27)\cdot 39\cos(60)F_2 + 3cos(10)F_3 = 0 \end{cases}$$

Simplifying the equation system

$$\begin{cases} -3F_1 + F_2\cos(60) + F_3\cos(10) = 0 \\ (6F_1 + 2F_2 + 2F_3) = 7.7714 \\ -51F_1 + 39\cos(60)F_2 + 3cos(10)F_3 = 0 \end{cases}$$

This system gives the following solution

$$\begin{cases} F_1 = 0.54 \\ F_2 = 1.26 \\ F_3 = 1 \end{cases}$$

Thus, the pin array on the left side of the structure withstand the maximum force, which is around $1.8N/pin$.

b) Cylinder

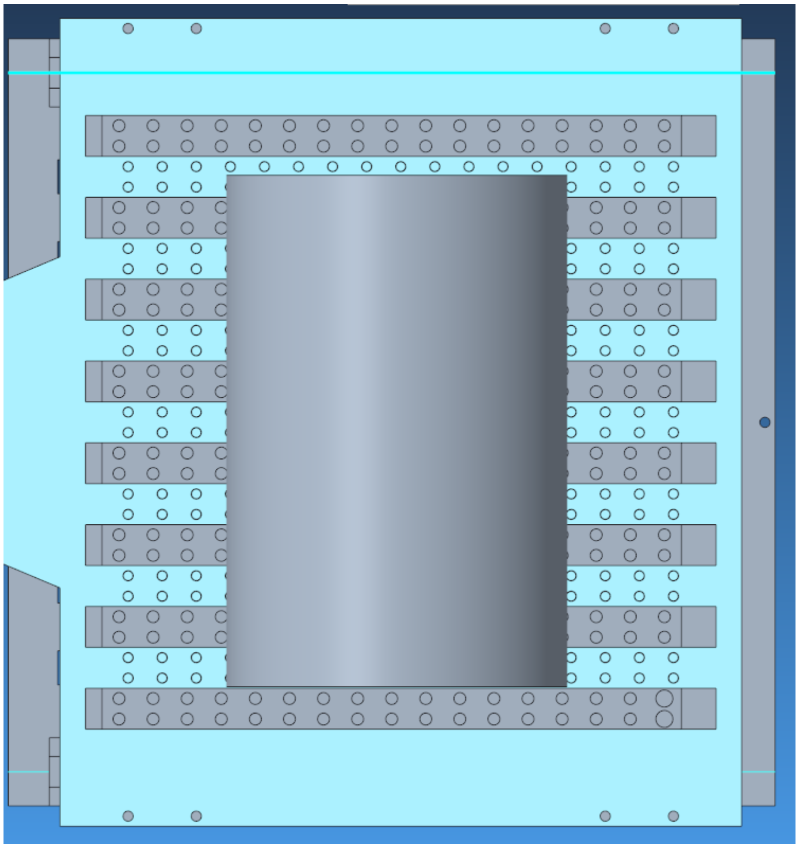


Fig. 12 button view of the gripper when grasping a cylinder

We make the same assumptions as before. The cylinder is made of plastic with a density of 1.25 g/cm^3. The diameter of the cylinder is 10cm, and the height of the cylinder is 15cm. Therefore, the volume of the cube is V=1767.1cm^3, and the mass is 21.7N approximately. We also assume the friction coefficient between rubber and plastic is 0.7. Therefore, the required normal force to lift the object is 30.9N. In this case there are 25 rods in contact with the cylinder, then the force distributed on each pin is 1.29N.

We are going to find the rod withstand the maximum force. There are 2 critical points in this case, one is the uppermost point on the right and one is the lowermost point on the left. We are going to compare these 2 points.

From moment and force balance in the middle, we get the following equations:

$\Sigma F = 0$: F_L+6.45 - F_R- 7.74 = 0

$\Sigma M = 0$: F_L*5*12 - $1.29 * 5 * 12$ + F_R*6*12 – 1.29*6*12 = 0

Solve the equations and we get

$F_L = 12.43$ N

F_R = 11.14 N

Where the force is combined by 2 rod, therefore the maximum force is 12.43/2 = 6.215N on the left lowermost rod.

c) Cube

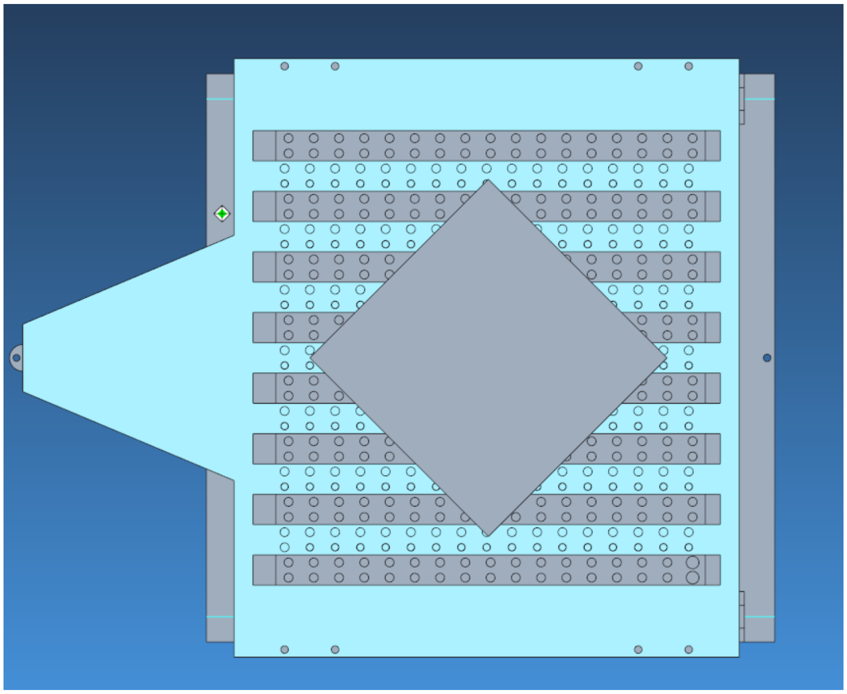


Fig. 13 button view of the gripper when grasping a cube

For a cube, one possible grab is a grab at a 45-degree angle as shown. The length of the cube is 100mm. The cube is made of plastic with a density of 1.25 g/cm^3. Therefore, the volume of the cube is V=1000cm^3, and the mass is 12.26N approximately. The friction coefficient between rubber and plastic is 0.7. Therefore, the required normal force to lift the object is 8.58N. In this case there are 16 rods in contact with the cylinder, then the force distributed on each pin is 0.54N.

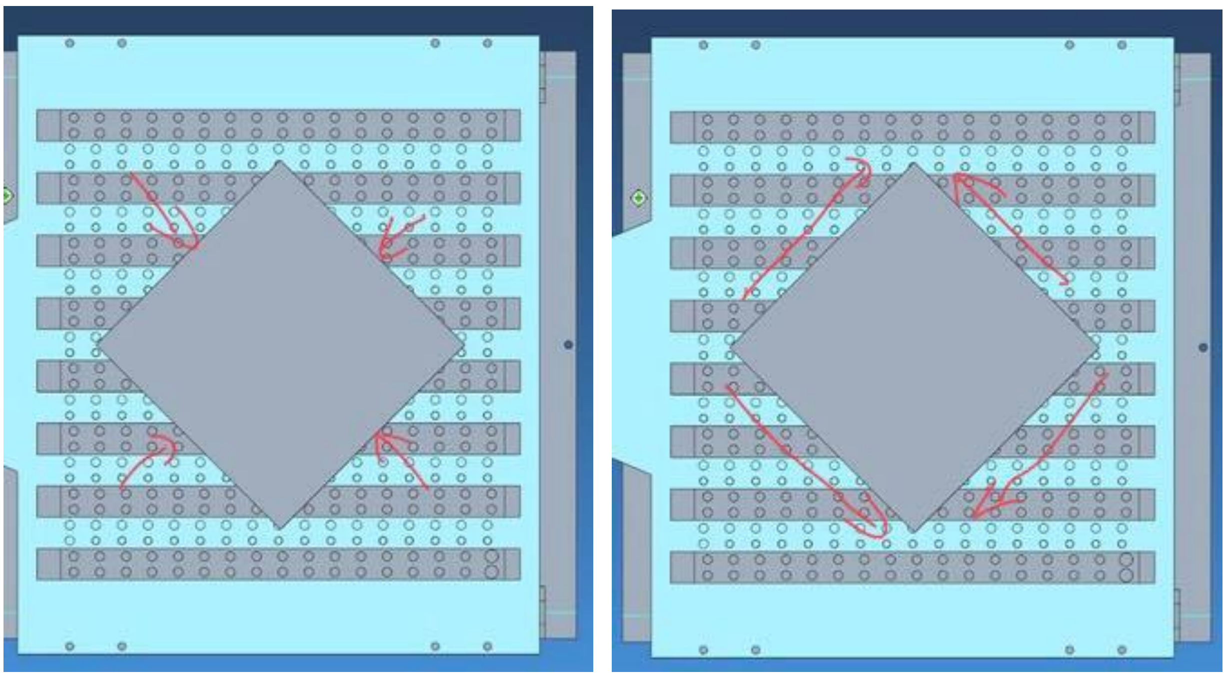


Fig. 14 exerted force when grasping a cube

We can decompose the whole force into normal and shear force. From the picture we can see that the corner of the square will stand the biggest force. The rod on the corner will provide 0.54/$\frac{\sqrt{2}}{2}$ = 0.76N force.

Bending analysis

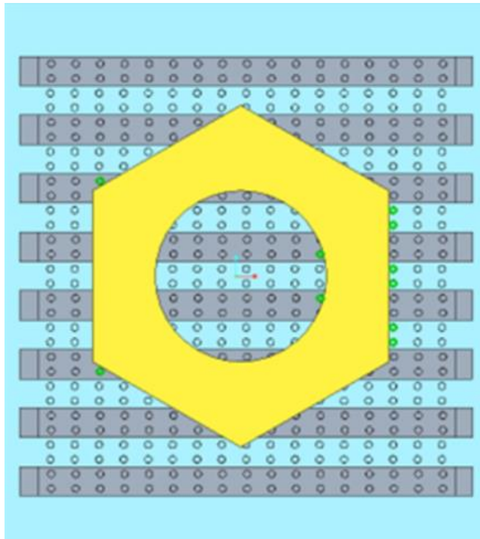


Fig. 15 button view of the gripper when grasping a nut-shaped geometry

In this section we are going to analysis the bending filament.

From PDR our grasping object is a nut. It is the thick part of the bottom of the filament that is in contact with the object in the horizontal direction, and the height is 10mm. Therefore, the force on filament is at x=5mm. The total length of filament is L=152.7mm.

Also, we calculated the maximum force on filament is F=1.8N. Therefore, the FBD showed as below:

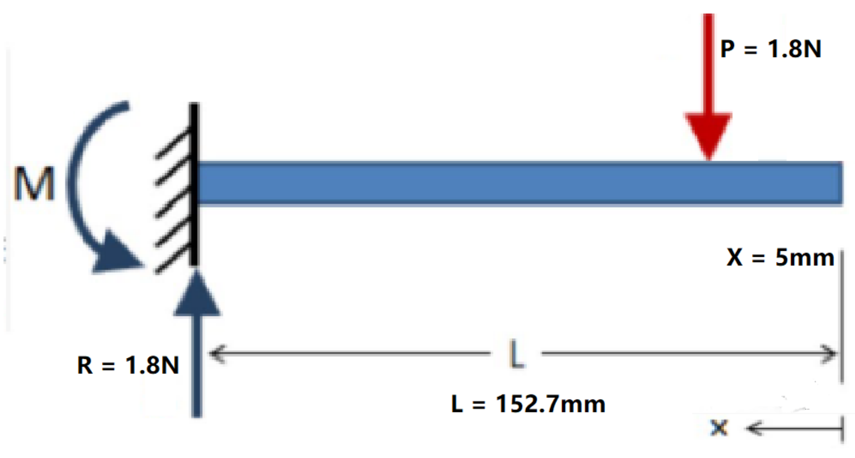


Fig. 16 schematic illustration of the bending moment

First, we calculate the moment of inertia for one filament.

For circular section,

$$I=\begin{bmatrix} \frac{\Pi R^2}{4} & 0 \\ 0 & \frac{\Pi R^2}{4} \end{bmatrix} = \begin{bmatrix} \frac{\Pi R^2}{4} & 0 \\ 0 & \frac{\Pi R^2}{4} \end{bmatrix} = \begin{bmatrix} 1.23 & 0 \\ 0 & 1.23 \end{bmatrix}.$$

The young modulus is E=4.107Gpa.

$$EI = 5.052*10^6$$

Then we do the beam break analysis:

For x∈(0,5) there is no force and moment on beam. Then the beam keeps rigid.

For x∈(5,152.7):

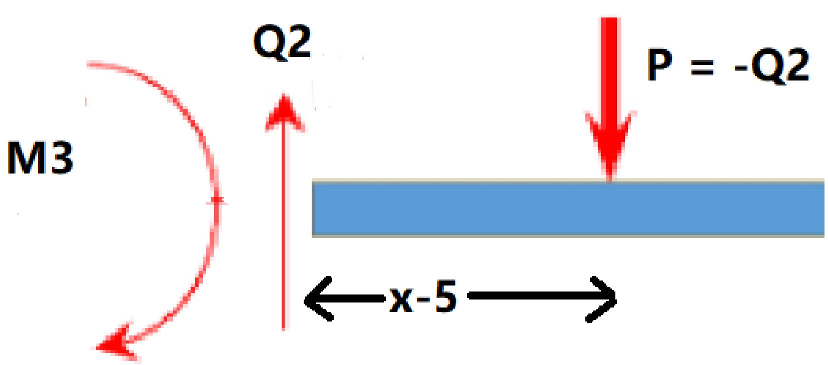


Fig. 17 schematic illustration of the bending moment

$$\Sigma Me3 = -M3+P*(x-5) = 0$$

$$M3 = P*(x-5) = M(x)$$

Elastic energy of beam:

$$U(x) = \frac{1}{2}\int_5^x \frac{M(x)^2}{EI}dx$$

The displacement of bending:

$$q(x) = \frac{dU}{dP} = \int_5^x \frac{M(x)}{EI} * \frac{dM(x)}{dP}dx$$

where

$$\frac{dM(x)}{dP} = x - 5$$

Then

$$q(x) = \frac{1}{EI}\int_5^x P(x-5)^2 dx = \frac{P}{3EI}(x-5)^3$$

Plug P=1.8 ; EI = $5.052*10^6$

$$q(x) = 1.2*10^{-7}*(x-5)^3$$

At x = L = 152.7 mm, q=0.39 mm

Now we can plot the displacement diagram as below

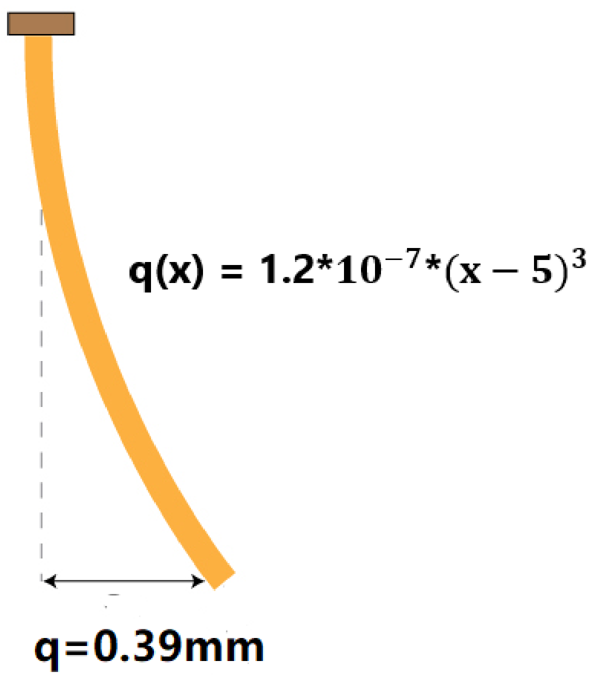


Fig. 18 schematic illustration of the bending effect

References

1. Reference both sources and imported parts such as motors/gears etc.

Linear actuator: we'll choose a 10mm stroke linear actuator, with a fully close length(L1) equal to 64.4mm, and a fully open length(L2) equal to 74.5mm. Shown below is the schematic drawing of the actuator.

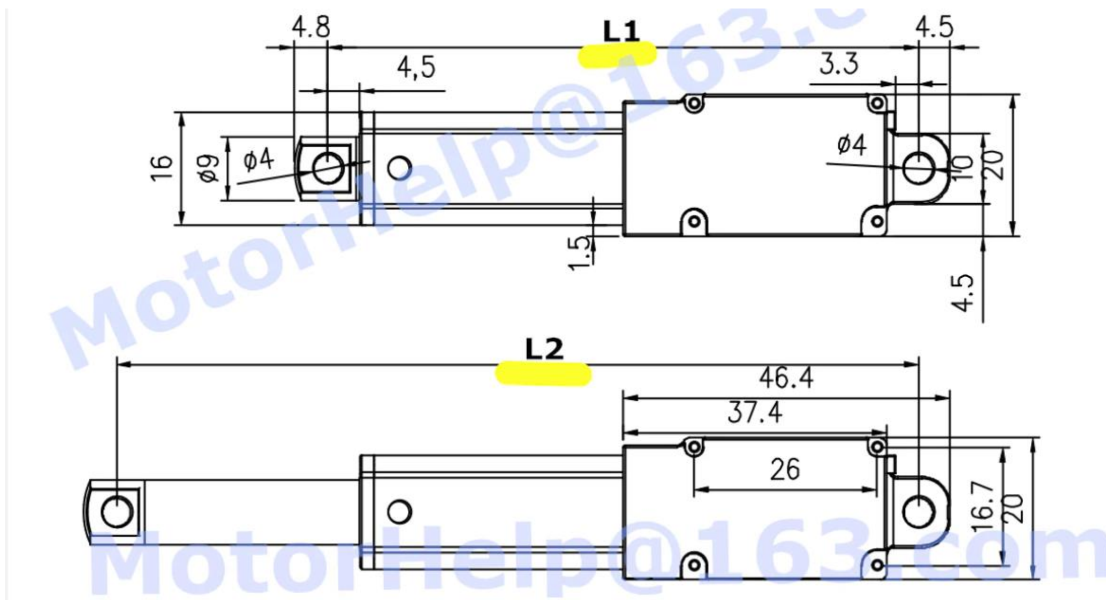


Fig. 19 schematic illustration of the linear actuator

The link to the website where such an actuator is provided is as follows

https://www.aliexpress.com/item/1005001427208855.html?spm=a2g0o.productlist.0.0.49b21ec0usVdrX&algo_pvid=d737ee82-11e8-4ada-a656-c4dabeca4daa&aem_p4p_detail=20220726030842123015353224877400664320 51&algo_exp_id=d737ee82-11e8-4ada-a656-c4dabeca4daa-0&pdp_ext_f=%7B%22sku_id%22%3A%2212000016079927411%22%7D&pdp_npi=2%40dis%21ILS%21%2175.76%21%21%21%21%21%402100bddf16588301226804257e823f%2112000016079927411%21sea

Force sensor resistor: we'll select model 400 short tail FSR, shown below is the dimensional description of this type

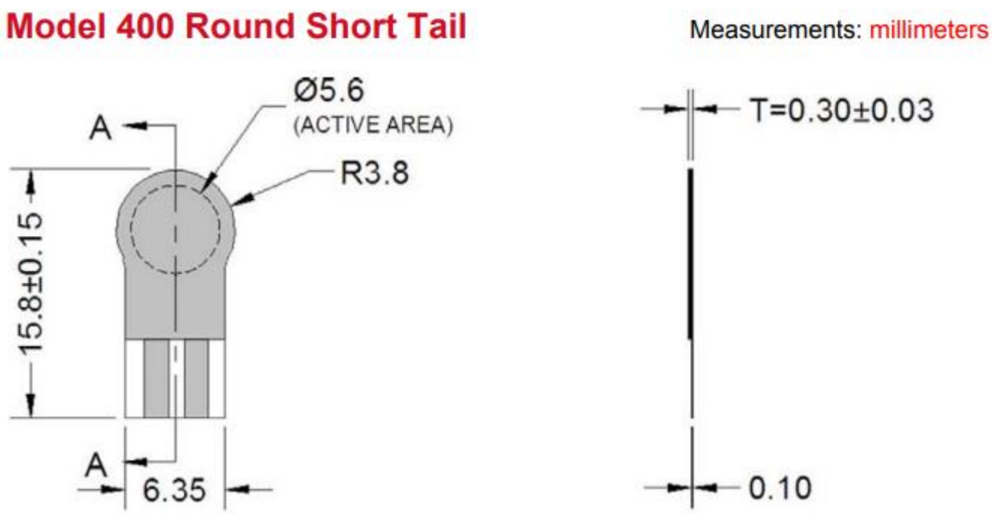


Fig. 20 side and front view of the FSR

Illustrated below is the graph of resistance vs. force in FSR, it can shown that in specific region the resistance in the FSR shows a linear relationship between the force, meaning we're able to approximate the force in the FSR by simply finding the current resistance in FSR.

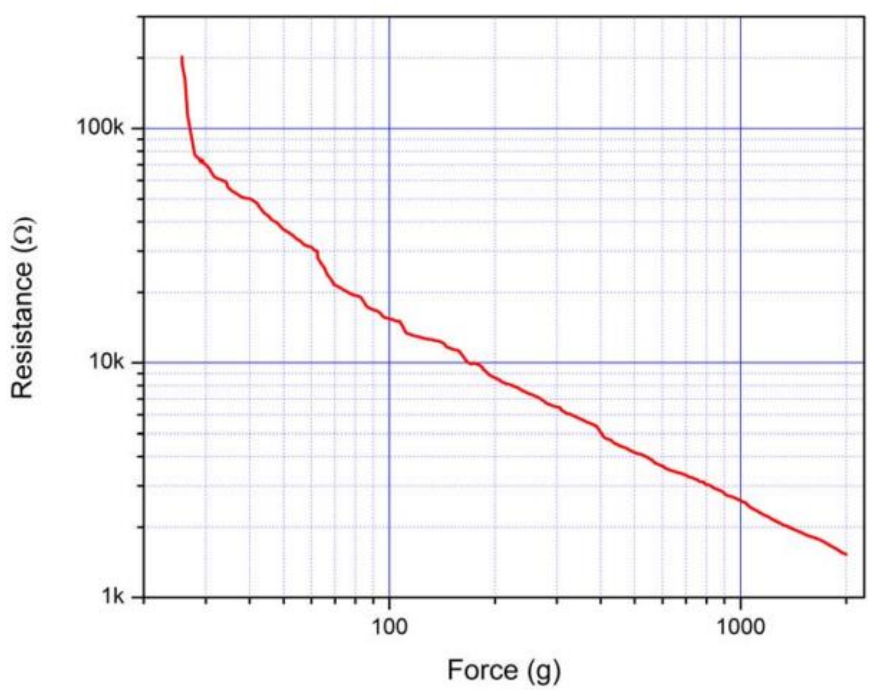


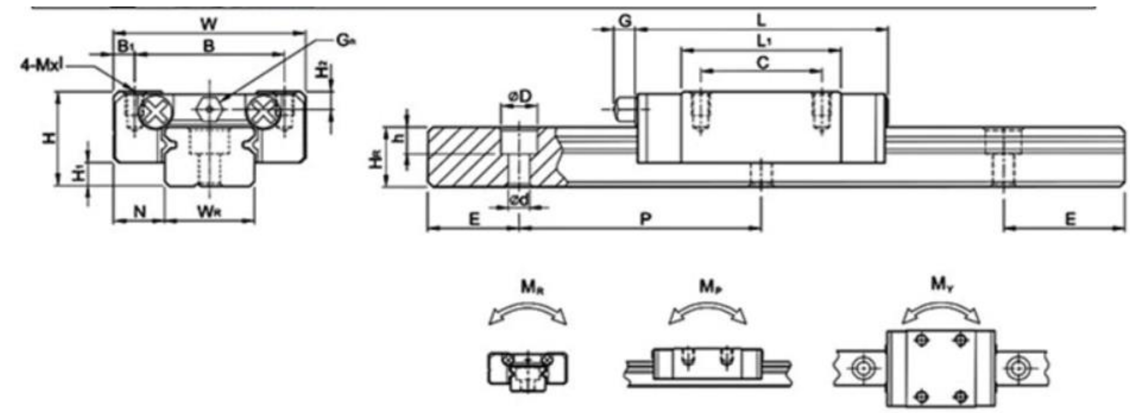
Fig. 21 resistance and force relationship in FSR

Full specification of the sensor is available from the link below

https://www.pololu.com/file/0J749/FSR400-Series-Integration-Guide-13.pdf

Linear Rail

We reckon MGN9C model as the suitable model since it's neither too large to occupy the area for pin arrays, nor too small to support the motion of the upper base. The rail length is chosen as 200mm to cover the whole range of the base.



Model number	Slide size (mm)													Guide size mm)							Guide's Fixed Bolt size	Weight	
	H	H1	N	W	B	B1	C	L1	L	G	Gn	Mxl	H2	WR	HR	D	h	d	P	E	(mm)	slide kg	guide kg/m
MGN7C	8	1.5	5	17	12	2.5	8	13.5	22.5	-	ø1.2	M2*2.5	1.5	7	4.8	4.2	2.3	2.4	15	5	M2*6	0.010	0.22
MGN7H							13	21.8	30.8													0.015	
MGN9C	10	2	5.5	20	15	2.5	10	18.9	28.9	-	ø1.4	M3*3	1.8	9	6.5	6	3.5	3.5	20	7.5	M3*8	0.016	0.38
MGN9H							16	29.9	39.9													0.026	
MGN12C	13	3	7.5	27	20	3.5	15	21.7	34.7	-	ø2	M3*3.5	2.5	12	8	6	4.5	3.5	25	10	M3*8	0.034	0.65
MGN12H							20	32.4	45.4													0.054	
MGN15C	16	4	8.5	32	25	3.5	20	26.7	42.1	4.5	M3	M3*4	3	15	10	6	4.5	3.5	40	15	M3*10	0.059	1.06
MGN15H							25	43.4	58.8													0.092	

Fig. 22 schematic illustration of the linear actuator and the model table

The link to the website where the rail is provided is as follows

https://www.aliexpress.com/item/4000706013922.html?spm=a2g0o.order_detail.0.0.1981f19cb0tYrZ

Production file

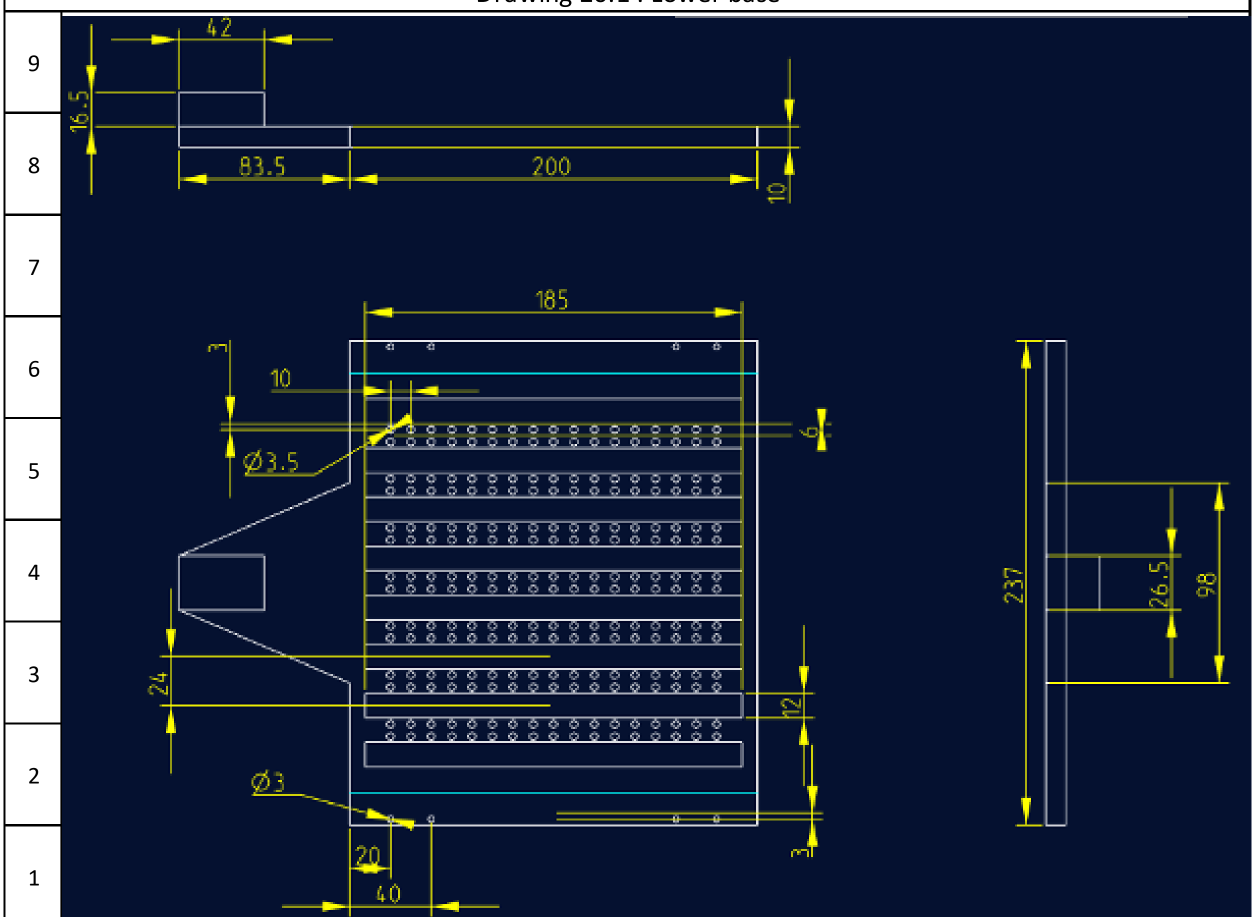
RC Part name: Lower Base			Edition: 1
NO.	Operation	Document	Remarks
10	3D printer testing		
20	3D printing	Drawing 20.1	
30	Inspection	Drawing 20.1 IS 30.1	
40	Packing & transfering to warehouse		Each part should be wrapped with bubble paper
Eng: Date:	Z.-Y. Li 01-Aug-22	PP&C: Y.-C. Wang Date: 05-Aug-22	QC: J.-Y. Liu Date: 18-Aug-22

RC Part name: Upper Base			Edition: 1
NO.	Operation	Document	Remarks
10	3D printer testing		
20	3D printing	Drawing 20.2	
30	Inspection	Drawing 20.2 IS 30.2	
40	Packing & transfering to warehouse		Each part should be wrapped with bubble paper
Eng: Date:	Z.-Y. Li 01-Aug-22	PP&C: Y.-C. Wang Date: 05-Aug-22	QC: J.-Y. Liu Date: 18-Aug-22

RC Part name: Rod			Edition: 1
NO.	Operation	Document	Remarks
10	3D printer testing		
20	3D printing	Drawing 20.3	
30	Inspection	Drawing 20.3 IS 30.3	
40	Packing & transfering to warehouse		Each part should be wrapped with bubble paper
Eng: Date:	Z.-Y. Li 01-Aug-22	PP&C: Y.-C. Wang Date: 05-Aug-22	QC: J.-Y. Liu Date: 18-Aug-22

RC Gripper Assembly			Edition: 1
NO.	Operation	Document	Remarks
10	Collect parts	Part list	
20	Assembling	Drawing 20	
30	Inspection	Drawing 20 IS 30	
40	Packing & transfering to warehouse	PS 40	
Eng: Z.-Y. Li Date: 01-Aug-22		PP&C: Y.-C. Wang Date: 05-Aug-22	QC: J.-Y. Liu Date: 18-Aug-22

Drawing 20.1 : Lower base

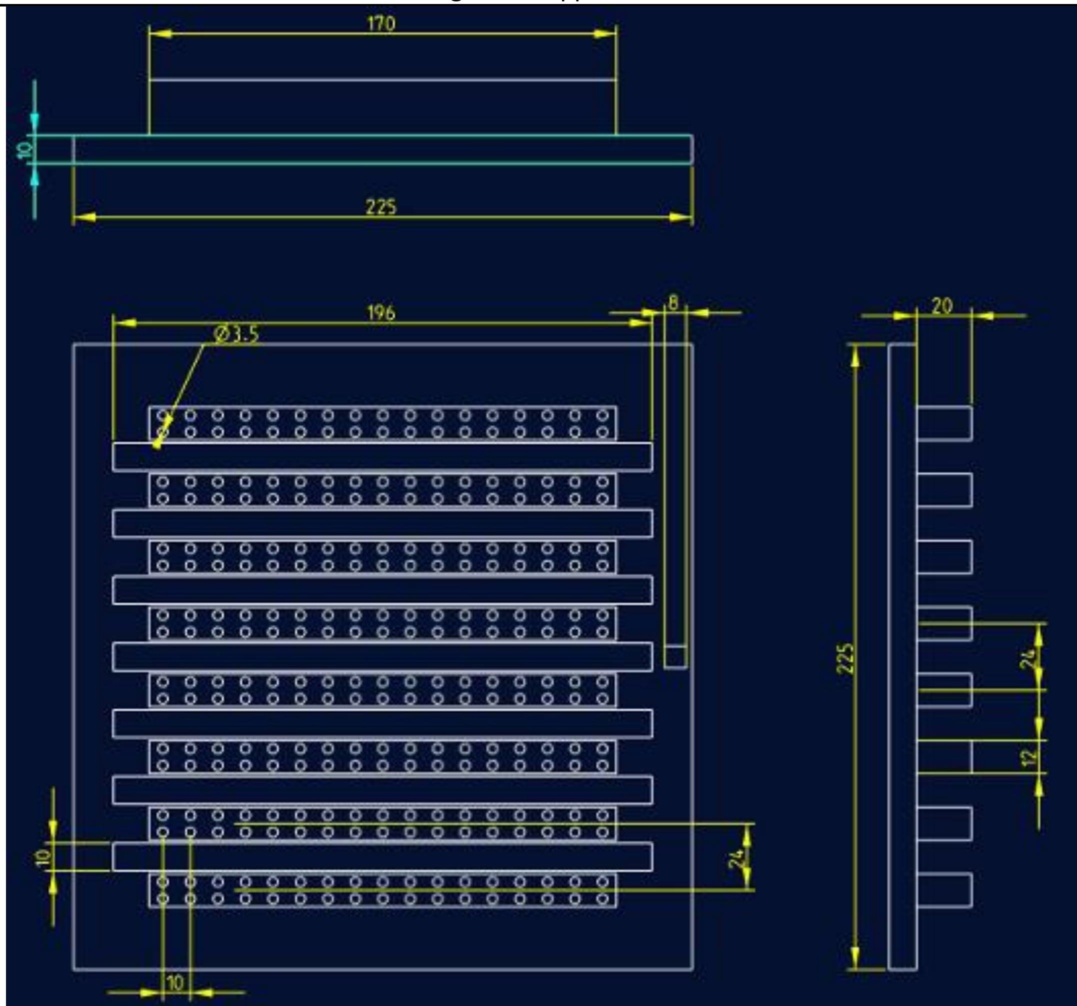


	A	B	C	D	E	F	G	H	I
	Drawn by: Z.-Y. Li Date: 01/08/2022			Checked by: Y.-C. Wang Date: 01/08/2022			Approved by: Date:		

IS 30.1 : Lower base				Edition: 1	
Required	Measured	Location		Remarks	
$16.5^{\pm 0.2}$		A8			
$42^{\pm 0.2}$		B9			
$83.5^{\pm 0.2}$		B8			
$200^{\pm 0.2}$		D8			
$10^{\pm 0.2}$		F8			
$185^{\pm 1}$		D7			
$3^{\pm 0.2}$		B6			
$10^{\pm 0.2}$		B6			
$\phi 3.5^{+0.2}_{\ 0}$		B5			
$24^{\pm 0.2}$		A3			
$\phi 3^{\ 0}_{-0.2}$		B2			
$20^{\pm 0.2}$		C1			
$40^{\pm 0.2}$		C1			
$6^{\pm 0.2}$		F5			
$12^{\pm 0.2}$		F3			
$3^{\pm 0.2}$		F1			
$237^{\pm 1}$		H4			
$26.5^{\pm 0.2}$		I4			
$98^{\pm 0.2}$		I4			
Eng:	Z.-Y. Li	PP&C:	Y.-C. Wang	QC:	J.-Y. Liu
Date:	01-Aug-22	Date:	05-Aug-22	Date:	18-Aug-22

Drawing 20.2 : Upper base

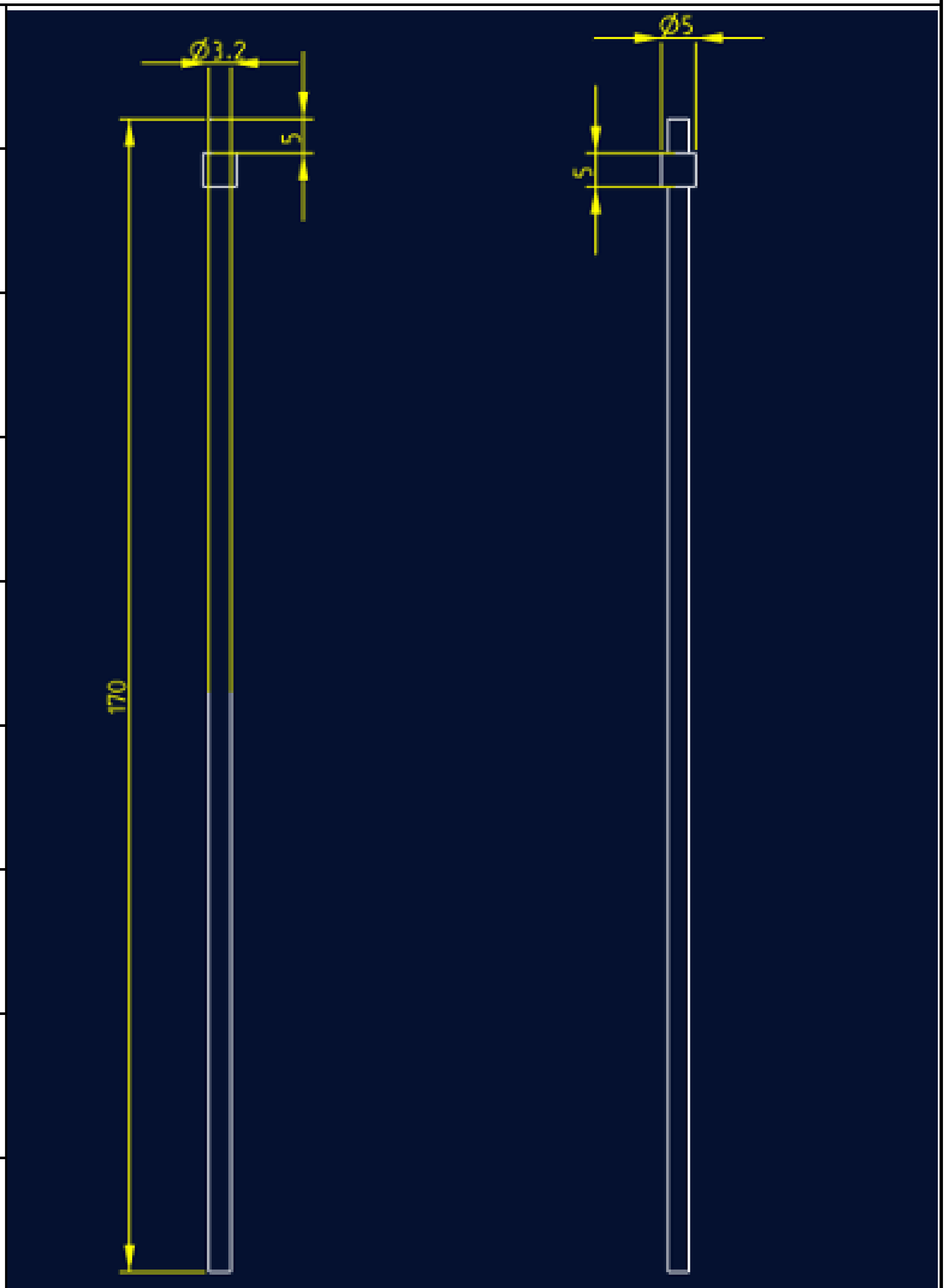
9									
8									
7									
6									
5									
4									
3									
2									
1									
	A	B	C	D	E	F	G	H	I



Drawn by: Z.-Y. Li	Checked by: Y.-C. Wang	Approved by:
Date: 01/08/2022	Date: 01/08/2022	Date:

IS 30.2 : Upper base				Edition: 1	
Required	Measured	Location		Remarks	
$10^{\pm 0.2}$		A8			
$170^{\pm 1}$		D9			
$225^{\pm 1.5}$		D8			
$196^{\pm 1}$		D7			
$\phi 3.5^{+0.2}_{\ 0}$		B7			
$10^{\pm 0.2}$		A2			
$10^{\pm 0.2}$		B1			
$8^{\pm 0.2}$		F7			
$24^{\pm 0.2}$		F2			
$225^{\pm 1.5}$		G4			
$20^{\pm 0.2}$		H7			
$24^{\pm 0.2}$		I4			
$12^{\pm 0.2}$		I3			
Eng:	Z.-Y. Li	PP&C:	Y.-C. Wang	QC:	J.-Y. Liu
Date:	01-Aug-22	Date:	05-Aug-22	Date:	18-Aug-22

Drawing 20.3 : Rod



	A	B	C	D	E	F
	Drawn by: Z.-Y. Li		Checked by: Y.-C. Wang		Approved by:	
	Date: 01/08/2022		Date: 01/08/2022		Date:	

IS 30.3 : Rod				Edition: 1	
Required	Measured	Location		Remarks	
$170^{\pm1}$		A5			
$\phi3.2^{\pm0.2}$		B9			
$5^{\pm0.2}$		B8			
$\phi5^{\pm0.2}$		E9			
$5^{\pm0.2}$		D8			
Eng:	Z.-Y. Li	PP&C:	Y.-C. Wang	QC:	J.-Y. Liu
Date:	01-Aug-22	Date:	05-Aug-22	Date:	18-Aug-22

Drawing 20.4 : Cap

9
8
7
6
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4
3
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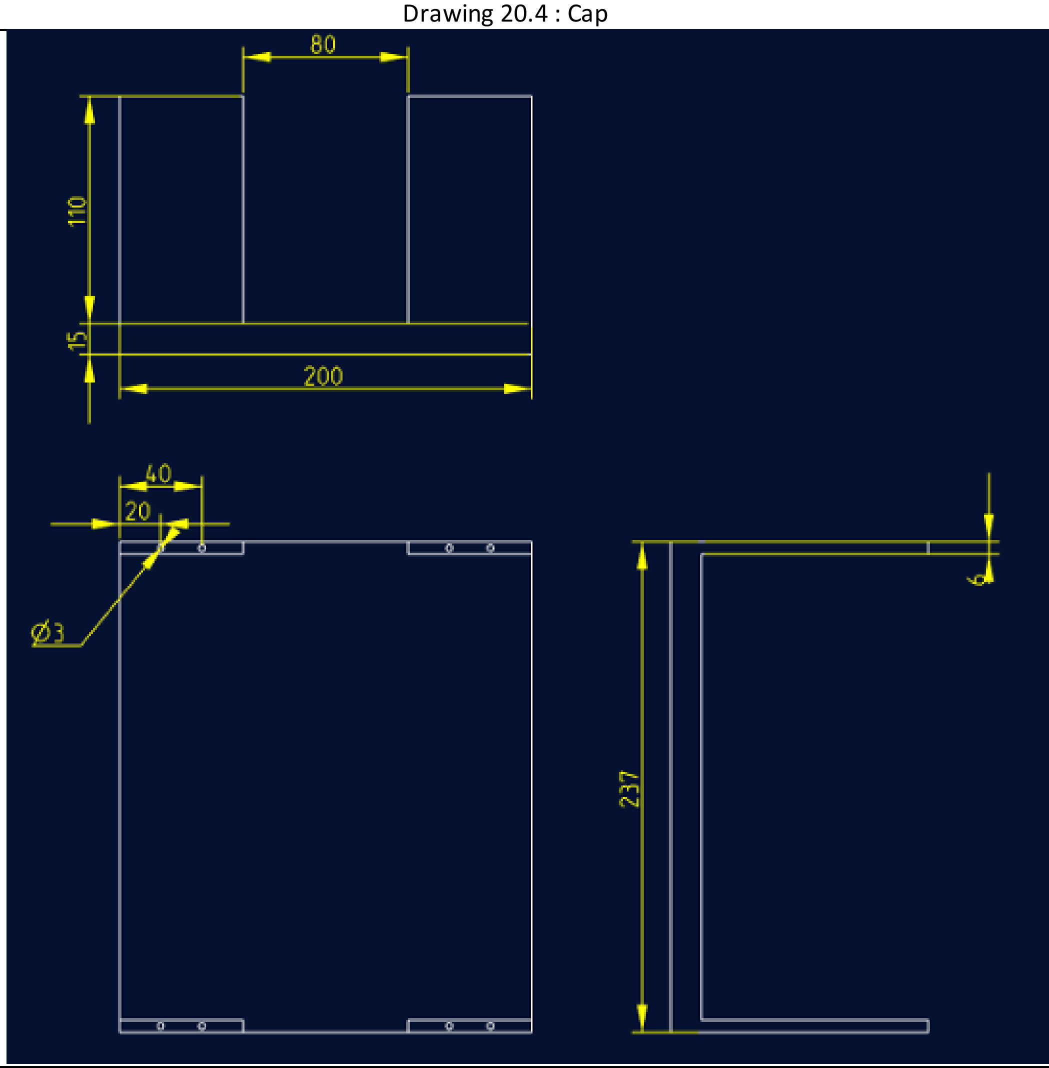
1



	A	B	C	D	E	F	G	H	I

Drawn by: Z.-Y. Li	Checked by: Y.-C. Wang	Approved by:
Date: 01/08/2022	Date: 01/08/2022	Date:

IS 30.4 : Cap				Edition: 1	
Required	Measured	Location		Remarks	
$110^{\pm 1}$		A8			
$15^{\pm 0.2}$		A7			
$80^{\pm 0.5}$		C9			
$200^{\pm 0.2}$		C6			
$40^{\pm 0.4}$		B6			
$20^{\pm 0.2}$		B5			
$\phi 3^{\pm 0.2}$		A4			
$237^{\pm 1.5}$		F3			
$6^{\pm 0.2}$		I5			
Eng:	Z.-Y. Li	PP&C:	Y.-C. Wang	QC:	J.-Y. Liu
Date:	01-Aug-22	Date:	05-Aug-22	Date:	18-Aug-22

Parts list : gripper assembly		Edition: 1
Part		Quantity
First base cover		1
First base column		7
Second base		1
Pin array 1		272
Pin array 2		238
Linear actuator		1
Force Sensing Resistor		1
Linear rail		1
Eng: Z.-Y. Li	PP&C: Y.-C. Wang	QC: J.-Y. Liu
Date: 01-Aug-22	Date: 05-Aug-22	Date:18-Aug-22

Drawing 20 : Gripper assembly

9
8
7
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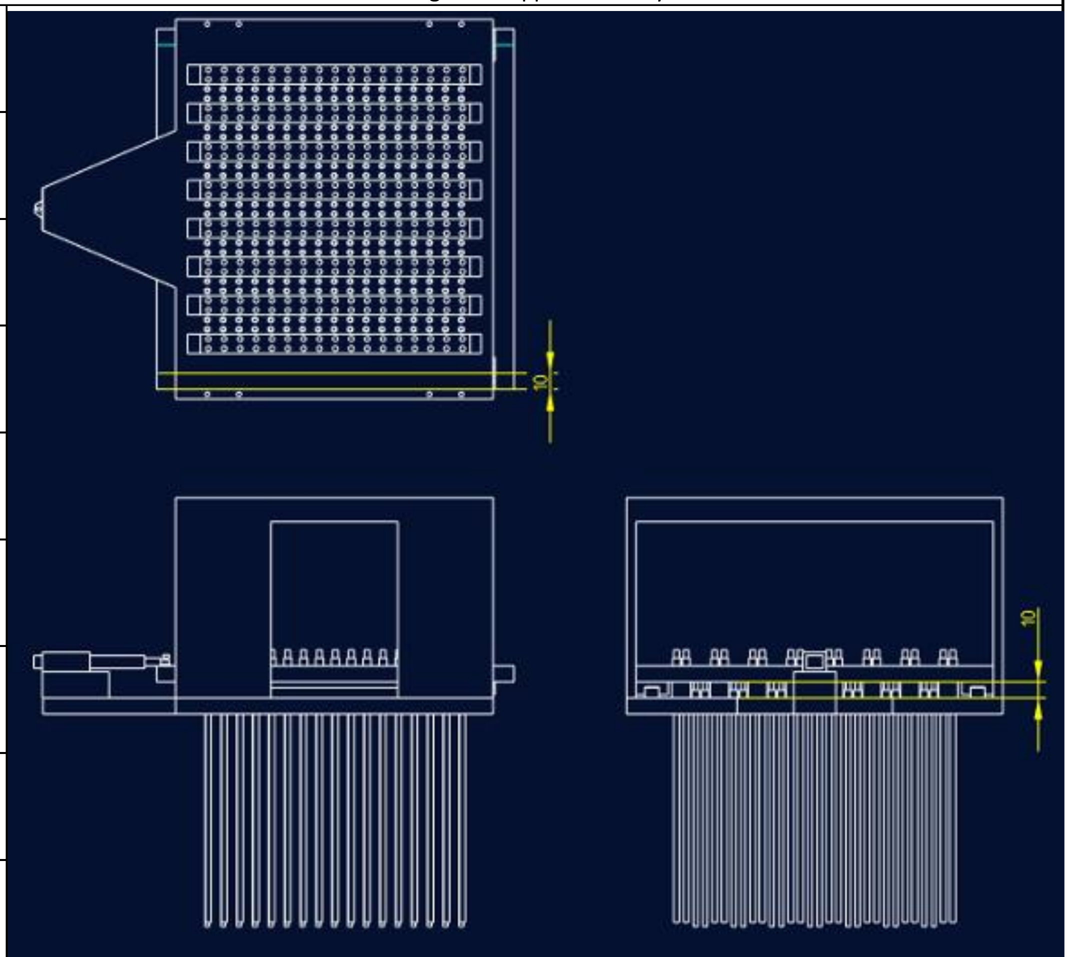

A	B	C	D	E	F	G	H	I

Drawn by: Z.-Y. Li	Checked by: Y.-C. Wang	Approved by:
Date: 01/08/2022	Date: 01/08/2022	Date:

IS 30 : Gripper assembly				Edition: 1	
Required	Measured	Location		Remarks	
$10^{\pm 0.2}$		E6			
$10^{\pm 0.2}$		I3			
Eng:	Z.-Y. Li	PP&C:	Y.-C. Wang	QC:	J.-Y. Liu
Date:	01-Aug-22	Date:	05-Aug-22	Date:	18-Aug-22

Packing Specifications 40					Edition: 1
Each part should be wrapped separately with bubble paper. Each 272 rods should be packed in a carton. Each assembly should be packed in a box and kept under dry environment.					
Eng:	Z.-Y. Li	PP&C:	Y.-C. Wang	QC:	J.-Y. Liu
Date:	01-Aug-22	Date:	05-Aug-22	Date:	18-Aug-22

Appendix

<u>Code for linear actuator and force senor resistor</u>

```
const int stepPin = 3;
const int dirPin = 4;
const int slpPin = 7;
const int fsrVoltagePin = 13;
int fsrPin = 0;     // the FSR and 10K pulldown are connected to a0
int fsrReading;     // the analog reading from the FSR resistor divider
int fsrVoltage;     // the analog reading converted to voltage
int FSR=1;           // not using force sensor resistor if FSR is set to zero
int keepRotating;
int frequency=100;    // frequecny which applied force is measured
int count=0;
int sleep=0;
unsigned long fsrResistance;  // The voltage converted to resistance
unsigned long fsrConductance;
double fsrForce;       // Finally, the resistance converted to force
double NewtonThreshold=3; // threshold in Newton to stop the DC motor


void setup(void) {
  pinMode(stepPin,OUTPUT);
  pinMode(dirPin,OUTPUT);
  pinMode(slpPin,OUTPUT);
  pinMode(fsrVoltagePin, OUTPUT);
  Serial.begin(9600);  // We'll send debugging information via the Serial monitor
}

void loop(void) {
  //write initial state
  digitalWrite(dirPin,HIGH);
  if (sleep==0){
    digitalWrite(slpPin,HIGH);
    }else {digitalWrite(slpPin,LOW);}

  // input desired rotation numeber mannually
  if (FSR==0){
    //rotate the motor based on input revolution number
    //(open)
    digitalWrite(dirPin,HIGH);
    for(int x = 0; x < 204*0;x++) {
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(1000);
      digitalWrite(stepPin,LOW);
      delayMicroseconds(1000);
    }
    delay(1000);

    // reverse the rotation direction
    digitalWrite(dirPin,LOW);
    //(close)
```

```
    //put the block to initial condition
    for(int x = 0; x < 204*0; x++) {
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(1000);
      digitalWrite(stepPin,LOW);
      delayMicroseconds(1000);
    }
    delay(1000);
    exit(0);
  } else{ ///////////apply FSR to detecting force//////
    digitalWrite(fsrVoltagePin, HIGH);
    fsrReading = analogRead(fsrPin);

    // analog voltage reading ranges from about 0 to 1023 which maps to 0V to 5V (=
5000mV)
    fsrVoltage = map(fsrReading, 0, 1023, 0, 5000);

    if (fsrVoltage == 0) {
      keepRotating = 1;
    } else {
      // The voltage = Vcc * R / (R + FSR) where R = 10K and Vcc = 5V
      // so FSR = ((Vcc - V) * R) / V        yay math!
      fsrResistance = 5000 - fsrVoltage;     // fsrVoltage is in millivolts so 5V =
5000mV
      fsrResistance *= 220000;                // 10K resistor
      fsrResistance /= fsrVoltage;
      fsrConductance = 1000000;           // we measure in micromhos so
      fsrConductance /= fsrResistance;

      // Use the two FSR guide graphs to approximate the force
      if (fsrConductance <= 1000) {
        fsrForce = 1000*fsrConductance / 80;
      } else {
        fsrForce = fsrConductance - 1000;
        fsrForce /= 1000*30;
      }
    }
    keepRotating=(fsrForce<NewtonThreshold*1000);
    if (keepRotating==1){
      digitalWrite(dirPin,LOW);// close the gripper
      for(int x = 0; x < 204*0;x++) {
        digitalWrite(stepPin, HIGH);
        delayMicroseconds(1000);
        digitalWrite(stepPin,LOW);
        delayMicroseconds(1000);
      }
    }else {
      Serial.print("Final Force in mili_Newtons: ");
      Serial.println(fsrForce);
      delay(10000);//hold the object for 10s
      digitalWrite(dirPin,HIGH);// reverse direction,open the gripper
      for(int x = 0; x < 204*0;x++) {//back to initial statee
        digitalWrite(stepPin, HIGH);
        delayMicroseconds(1000);
        digitalWrite(stepPin,LOW);
```

```
        delayMicroseconds(1000);
        }
      exit(0);}

    ///update all parameters
    if (count%frequency==0){
      if (fsrVoltage == 0){
        Serial.println("No pressure");
      }else {
        Serial.print("Analog reading = ");
        Serial.println(fsrReading);
        Serial.print("Voltage reading in mV = ");
        Serial.println(fsrVoltage);
        Serial.print("FSR resistance in ohms = ");
        Serial.println(fsrResistance);
        Serial.print("Conductance in microMhos: ");
        Serial.println(fsrConductance);
        Serial.print("Force in mili_Newtons: ");
        Serial.println(fsrForce);
        Serial.println("--------------------");
      }
    }
    count++;
    delay(1000/frequency);
  }
}
```