VERSION 4

Filament micro- Gripper PDR

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Edition	Modifications	Date	Revisor
1	-	28.5.2022	Yicheng, Jiyang,Zhiyuan
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IV) Summary - Advantages and Disadvantages of Each Design

I) Versatile Gripper Based on Concentric Rotation Pin Array

a) Concept

This gripper design is consisted of several main parts (patterns): retractable pin arrays, concentric bases, mechanical transmission, and an actuator mechanism. Each two adjacent concentric base parts can rotate in opposite directions. After the robotic arm to which the gripper is connected moves above the target object, the gripping process will begin. There are basically three steps:

1. The shape-memorizing process. The robotic arm controls the gripper to drop, during which the retractable pin arrays that touching the target object are pushed into the base part and form the shape of the target object.
2. By rotating the concentric base parts for a certain small angle, the normal forces are provided by the pin arrays by the side of the object to the target object. The friction force is thus formed.
3. The actuator stops and hold the torque. Then the target is ready to be raised up and moved by the robotic arm.
4. By rotating the concentric base parts for a certain angle each in opposite direction compared to item 2, the normal force is gone and the object is released.

b) CAD 3D model and drawing view

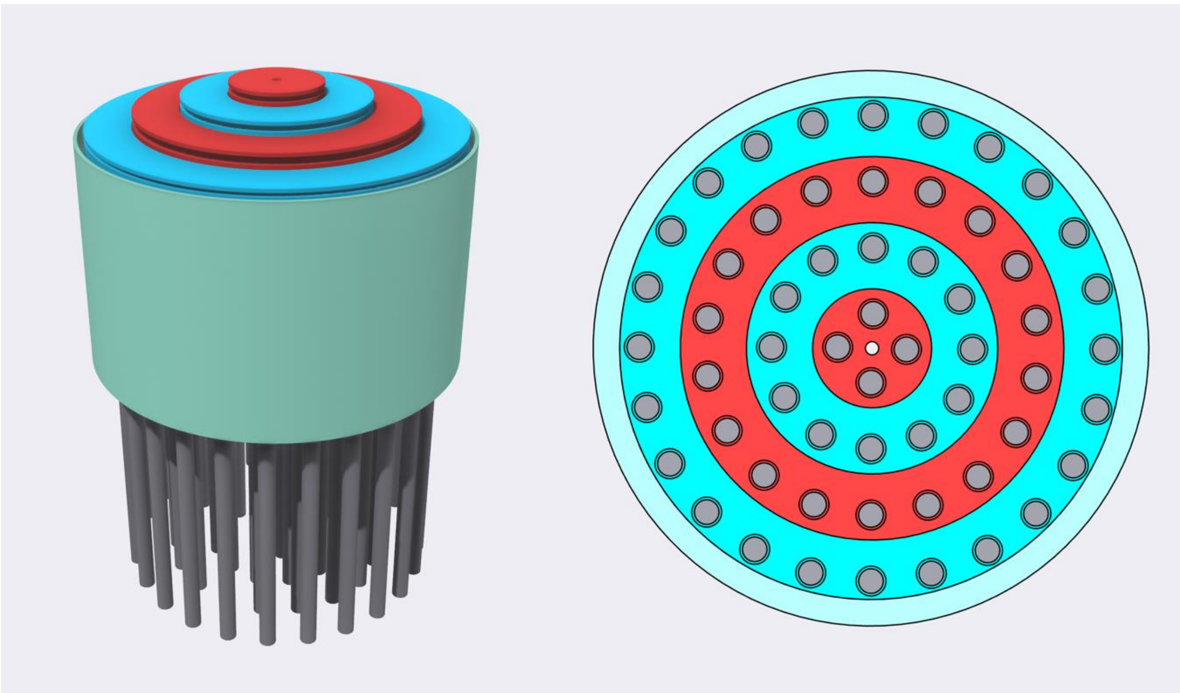


Figure 1 Concentric rotation gripper in general view and bottom view

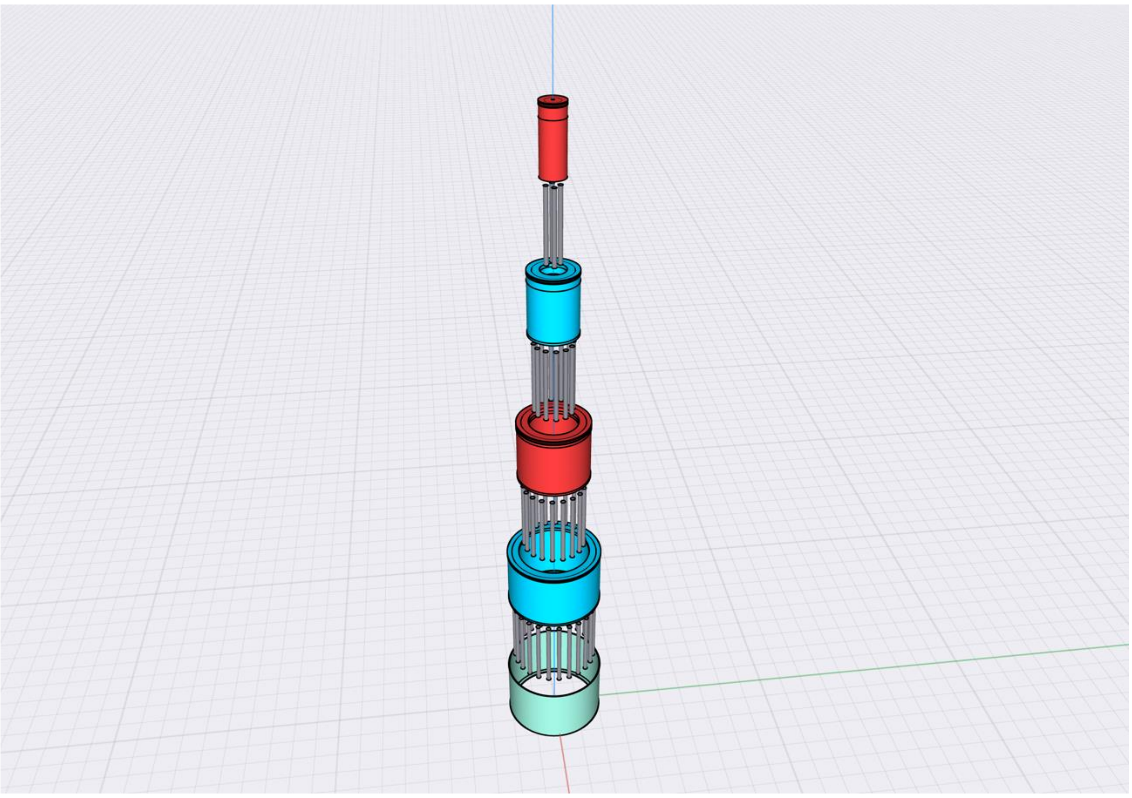


Figure 2 Concentric rotation gripper in exploded view

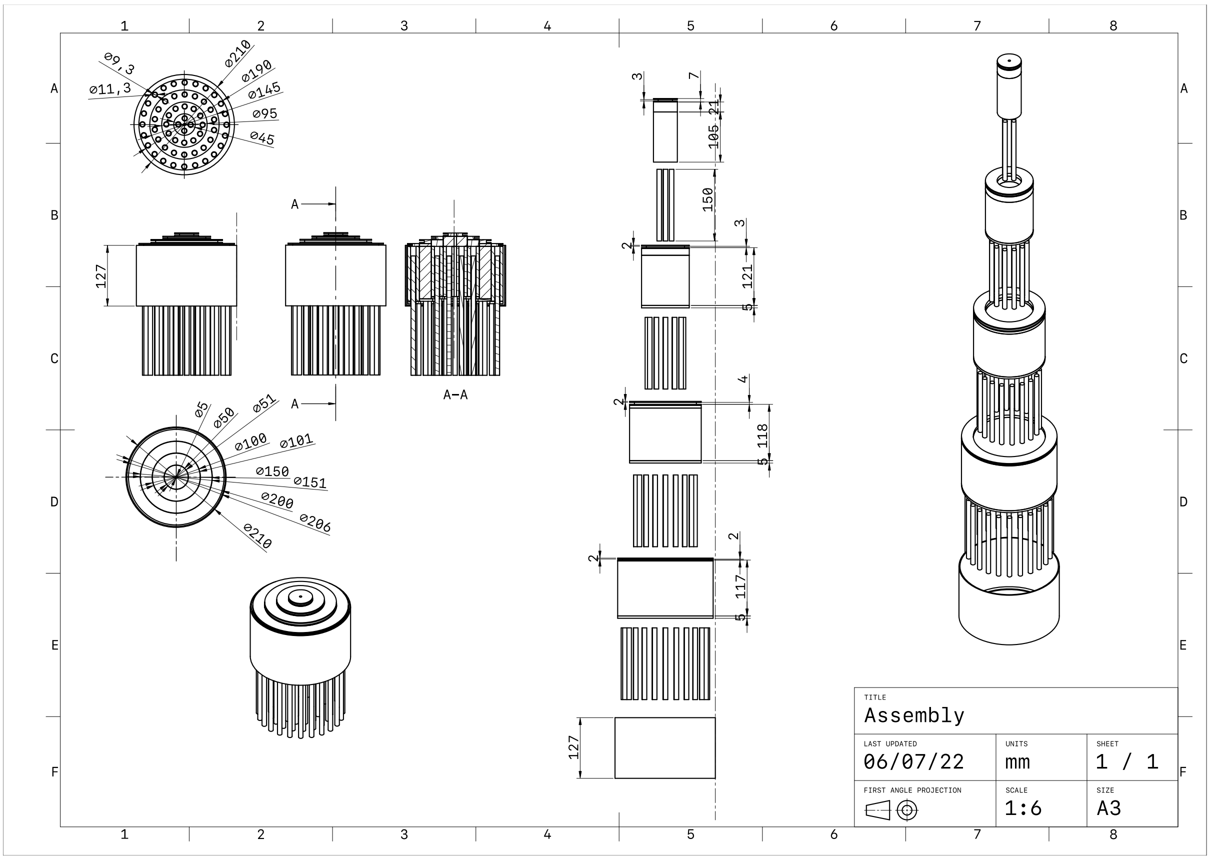
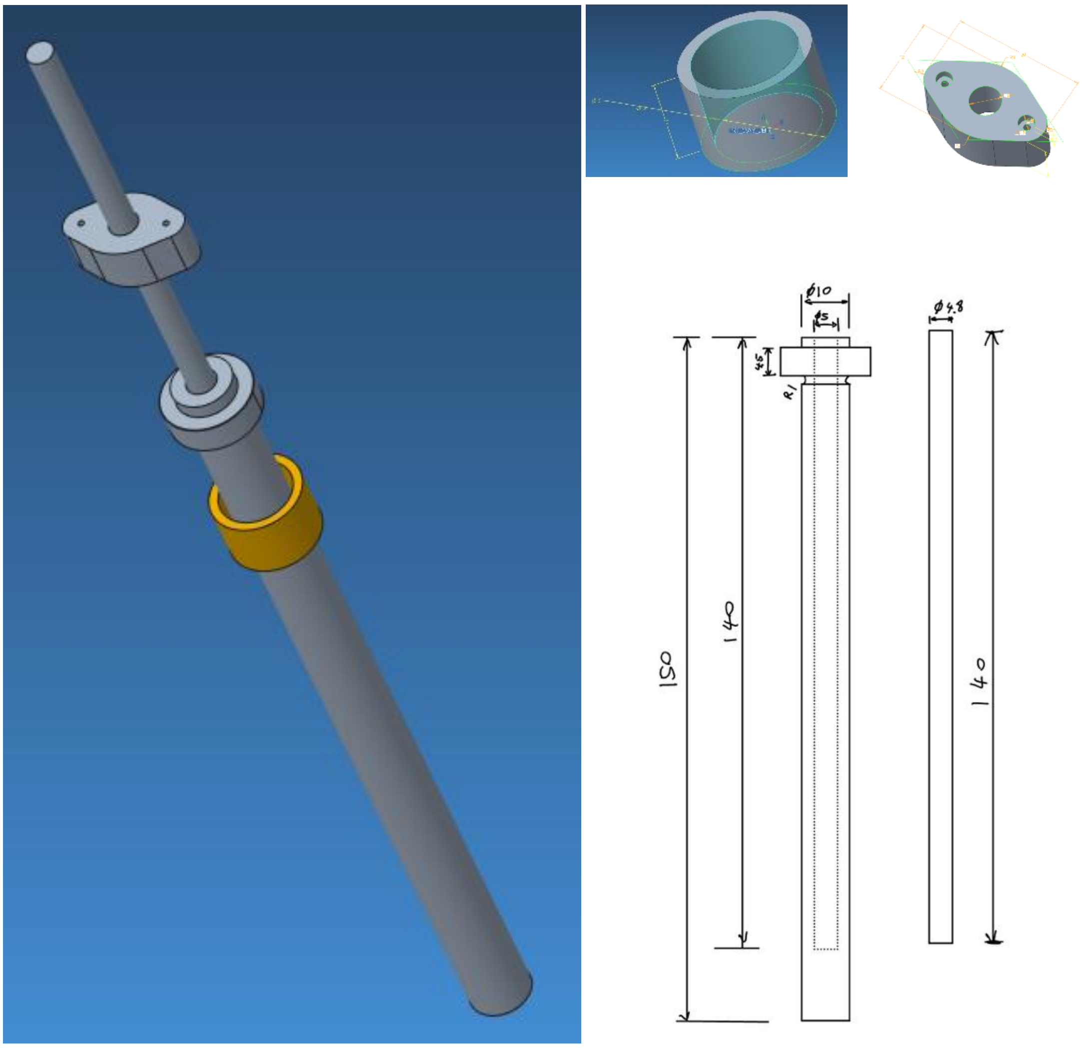


Figure 3 Drawing of the concentric rotation gripper

The mechanism of the retractable pin arrays is presented in item 2)

c) Design of the retractable pin arrays

An important feature in this design is the application of retractable pin arrays. Each pin array assembly is composed of five parts: PIN_BODY, GUIDE_PIN, PIN_SUPPORT, UPPER_FIX and a long spring along the guide pin. The pin array assembly is assembled to the base parts by screws. The adoption of springs is to guarantee that the pin body will not drop back into the base part shell when the gripper is pointing upwards.



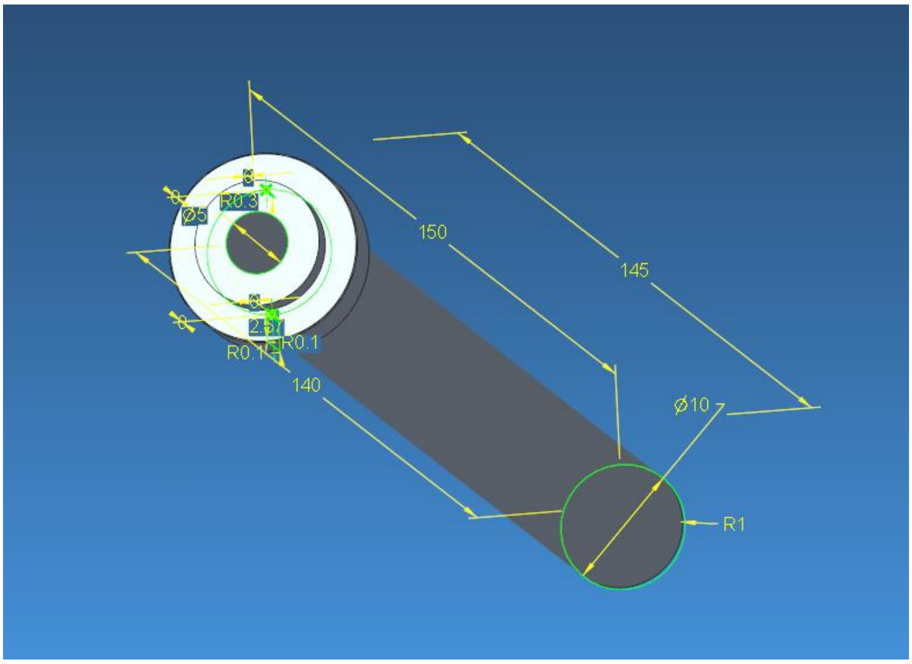


Figure 4 Pin array assembly and its parts

d) List of mechanisms

Part	Numbers
Pin assemblies	4 on (i) +12 on (ii)+18 on (iii) +24 on (iv)=58
Base parts	1*first inner base (i) 1*second inner base (ii) 1*second outer base (iii) 1*first outer base(iv)
Base shell	1
Actuator	1
Tendons	4
Bearings	1+1+1+1=4

e) Grasp analysis

i. Contact model

As is shown in figure, an object is within the grasp area. When the concentric bass parts rotate for some angle, the pins will become in contact with the object, and thus provide normal forces. Although the exact position of the object is hard to predict, there will always be more than three pins that provide normal gripping forces. After a short-period manipulation of objects, the contacts will balance themselves.

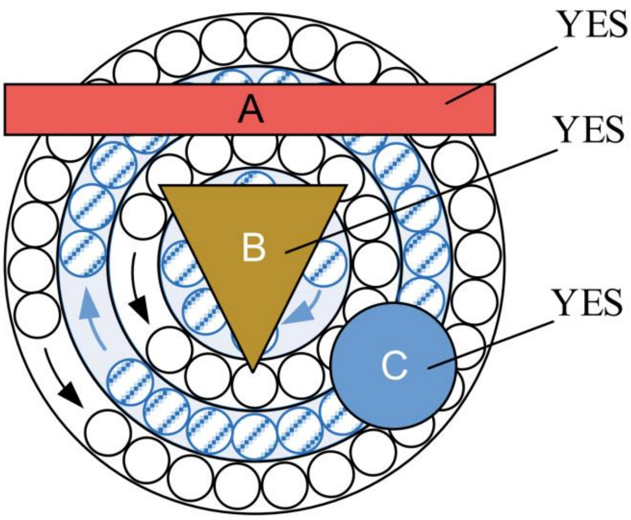


Figure 5 Grasp configuration

ii. Belt drive transmission mechanism

The transmission mechanism is the application of tendons that connects each concentric gripper base and the actuator pulley. The gripper concentric rings and actuator are connected to a frame (which is not shown in the drawing). For the inner rings, open and cross configurations of belt drive are alternate. Slippery between tendon and pulley/rings allows for shape adaption. When a ring is blocked, the other rings are able to continue rotating until their pins in contact with object.

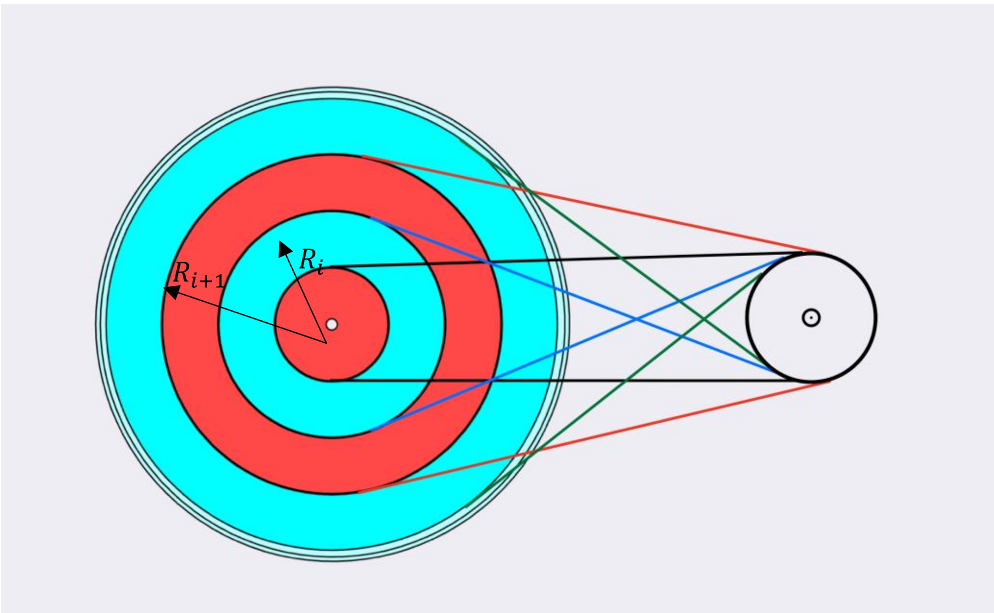


Figure 6 Top view with transmission tendons connecting the gripper bases and the actuator

Definition of parameters.

n	Number of rings
r	Radius of pulley (mm)
R_i	Radius of i^{th} ring (mm) for i = 1,…,n
a	Center distance between pulley and ring (mm)
α_{R_i}	Wrap angle of i^{th} ring (rad), for i = 1,…,n
α_{r_i}	Wrap angle of pulley with i^{th} ring
L_{oi}	Length of open tendon (mm)
L_{ci}	Length of crossed tendon (mm), i = 1,..,n
μ_t	Friction coefficient between tendon and pulley
μ_p	Friction coefficient between pins and objects
F_0	Pre-tension in tendon when tendon and pulley are at rest (N)
F_i	Contact force at each ring (N), for i = 1,…,n
F_{emax}	Total grasp force (N)

According to belt drive theory, the maximum tension is obtained:

$$F_{emax_i} = 2F_0 \frac{e^{\mu_i \alpha_i} - 1}{e^{\mu_i \alpha_i} + 1} \tag{1}$$

$$\alpha_i = \min\{\alpha_{Ri}, \alpha_{ri}\} \tag{2}$$

For open tendon:

$$\alpha_{Ri} = \pi + 2\beta_i, \qquad \alpha_{r_i} = \pi - 2\beta_i \tag{3}$$

$$\beta_i = \arcsin\left(\frac{R_i - r_i}{a}\right) \tag{4}$$

$$L_{oi} \approx 2a + \pi(R_i + r_i) + \frac{(R_i - r_i)^2}{a} \tag{5}$$

For closed tendon:

$$\alpha_{Ri} = \alpha_{r_i} = \pi + 2\beta_i \tag{6}$$

$$\beta_i = \arcsin\left(\frac{R_i + r_i}{a}\right) \tag{7}$$

$$L_{oi} \approx 2a + \pi(R_i + r_i) + \frac{(R_i + r_i)^2}{a} \tag{8}$$

Based on this model, grasp force can be analyzed for this design.

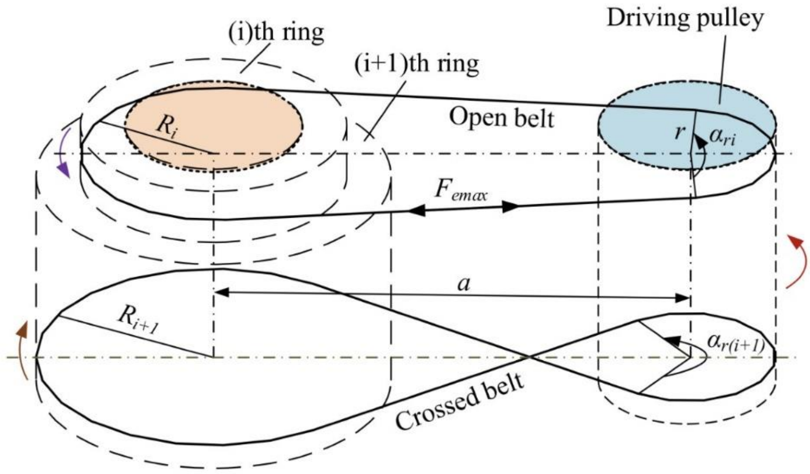


Figure 7 Force transmission of different rings from driving pulley

iii. Grasp force analysis

There are several ways to increase grasp force. Material of the pin rod is preferred with higher friction coefficient with the target object. Therefore, rubber rod is a good choice. Nevertheless, various geometry though this versatile gripper is capable to grasp, in order to continue later calculation, we will define a 3D printed target object as shown below. The material is PLA. The mass is 0.5kg. The target object is initially placed on a horizontal table.

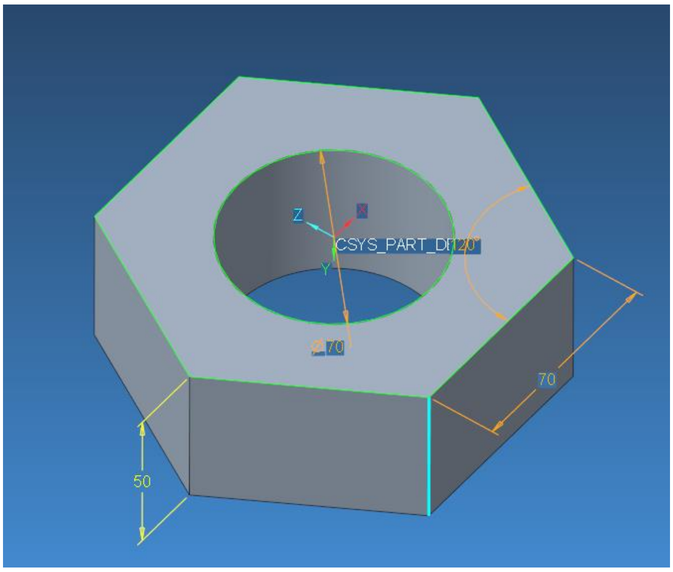


Figure 8 Target object – nut

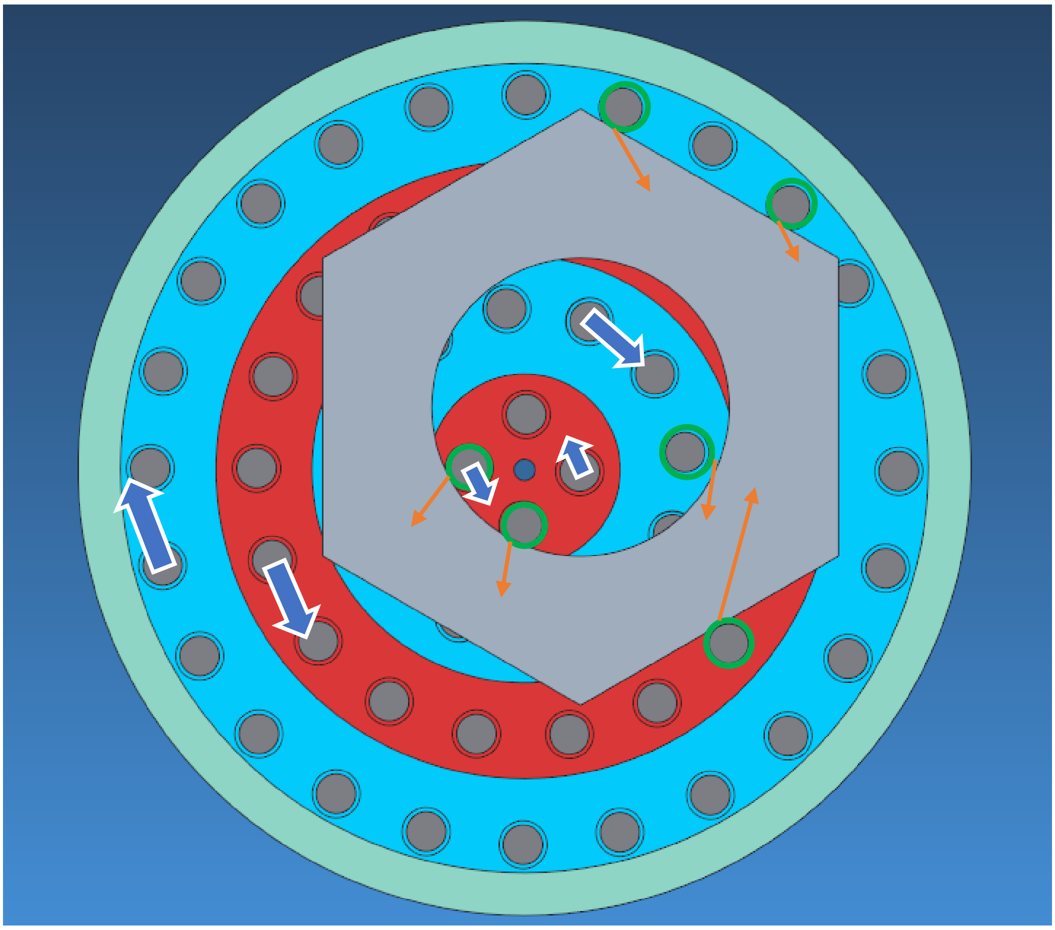


Figure 9 Bottom view pin configuration and free body diagram after the shape-memorizing step

After a short-period manipulation of objects, the contacts will balance themselves. As is shown in the free body diagram, in this case, there are 6 pins that are in side-contact with the object and provide gripping forces. Each horizontal force is composed of normal forces and friction force. Considering that the object has a depth of 50mm, the horizontal forces cannot be simplified as acting on the same horizontal plane. In other word, there are two moment balances around two horizontal axes.

Let's say, we neglect the friction in bearings. There are two force balances in horizontal directions: 1. vector sum of all the horizontal forces will equal zero; 2. the tangent component of vector sum of all horizontal forces on the i^{th} ring equals the total grasp force that the belt drive mechanism provides to on this ring, i.e. F_{emax_i}, which can be calculated with Eq. 1.

Moreover, there are one moment balance of all horizontal forces acting on the object.

The sum of all vertical friction forces equals the gravity of the object. Each vertical friction force can be approximately calculated by the friction coefficient μ $(\mu = 0.7,$ $see\ the\ friction\ coefficient\ table\ in\ SRR\ document)$ multiplied by the corresponding normal force. After a short-period manipulation of objects, the contacts will balance themselves.

Basically, software simulation is suggested for grasp force analysis. However, to verify feasibility, assume each pin fails at a bending moment of at least 10N acting at the end tip. Then, in the case of 6 pins in side-contact with the object, the maximal friction force provided by 5 is estimated to be $6 \times 0.7 \times 10N = 42N$. Given that the target testing object is only $0.5kg \times 9.8\frac{N}{kg} = 4.9N$, which is only about $1/9$ of the estimation limit. Then we consider the test is passed.

II) Versatile Gripper Based on Meshed Pin Array

a) Introduction

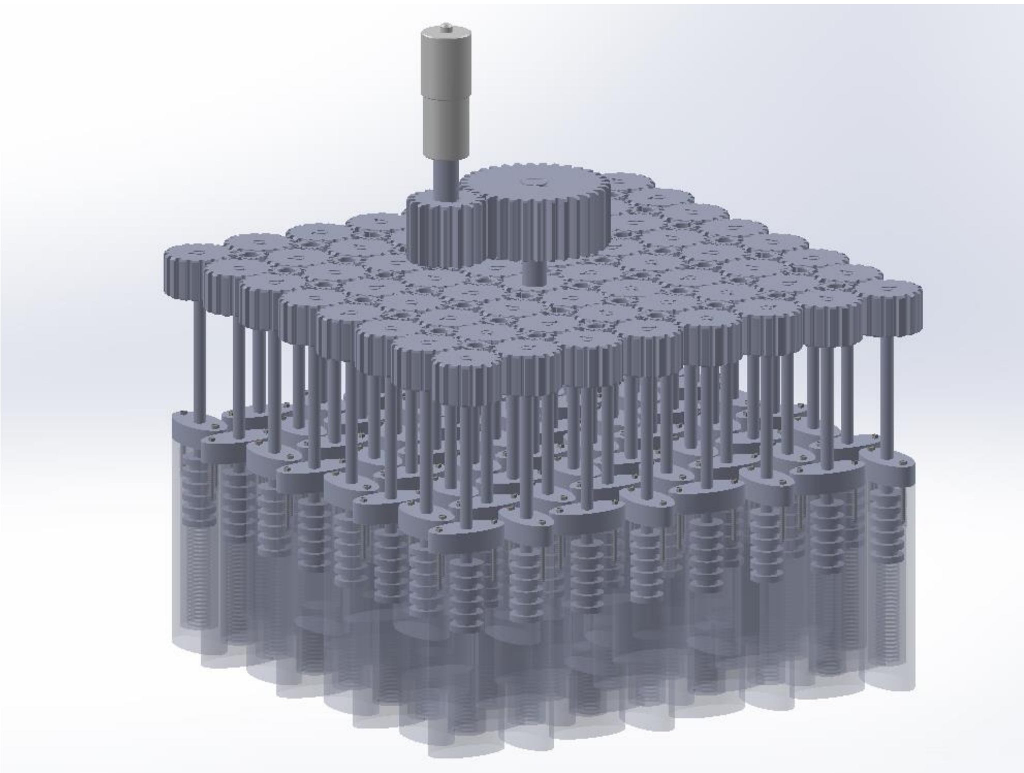
The gripper features provide greater gripping force by maximizing each pin's conformation to the surface of the object. Each pin can complete two motions: the first is to stretch up and down through spring and piston, in order to maximize the contact between the bottom surface of the pin and the e1e2 plane of the object. The second is to rotate through the gears above, in order to maximize the contact between the sides of the pin and the e1e3 and e2e3 planes of the object. Finally, the object is picked up by the friction between the pin and the surface of the object.

The driving force of the gripper is provided by the motor above. The motor drives a small gear and then a large gear through one, and then drives the rotation of all the gears below.

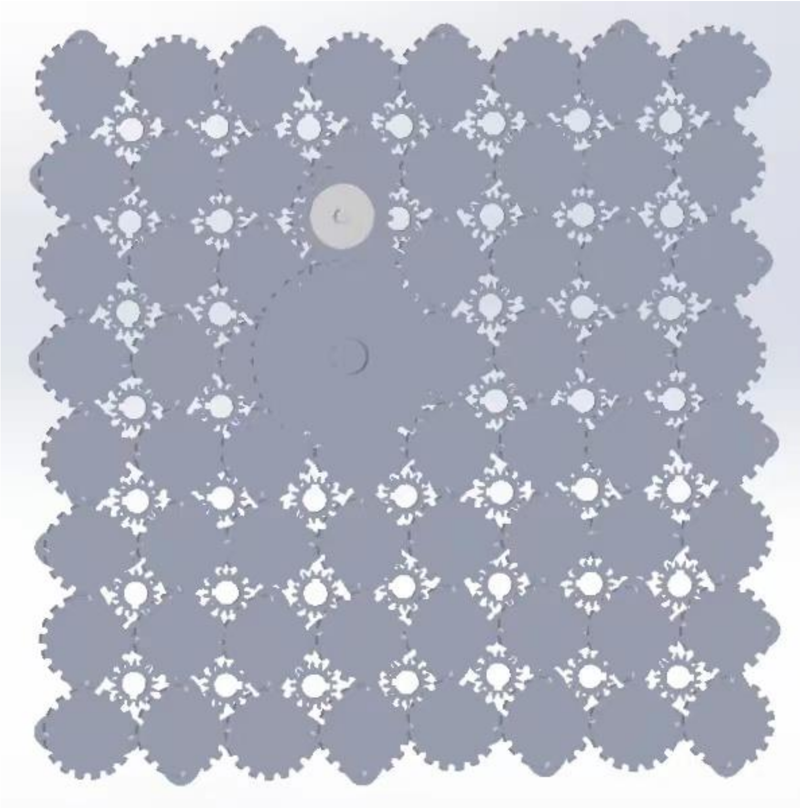
b) CAD 3D model and drawing views

i. Assembly view

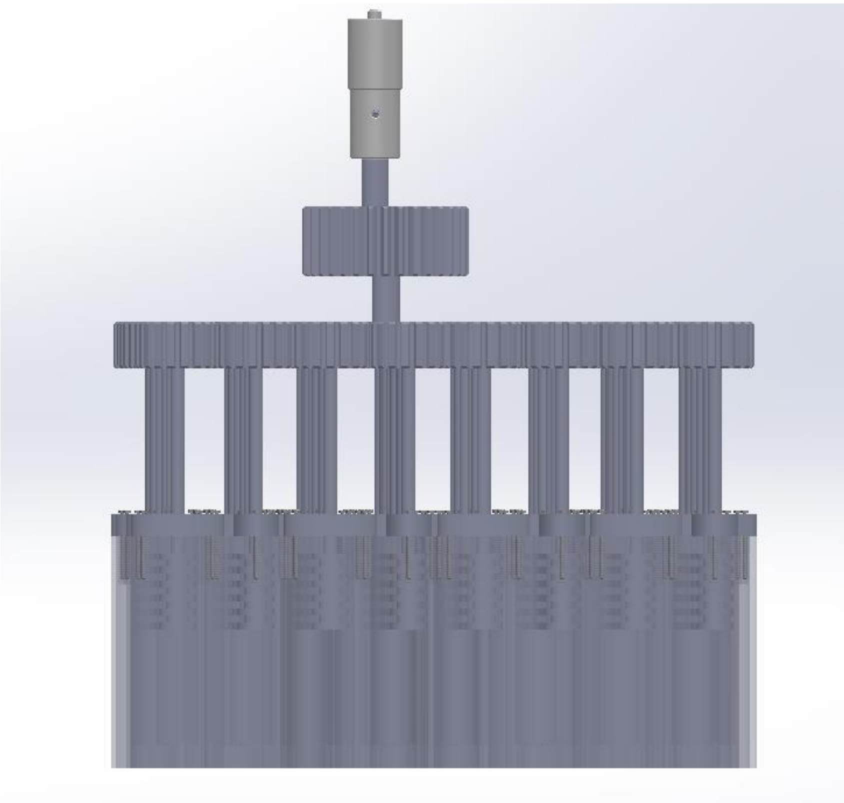
Overview



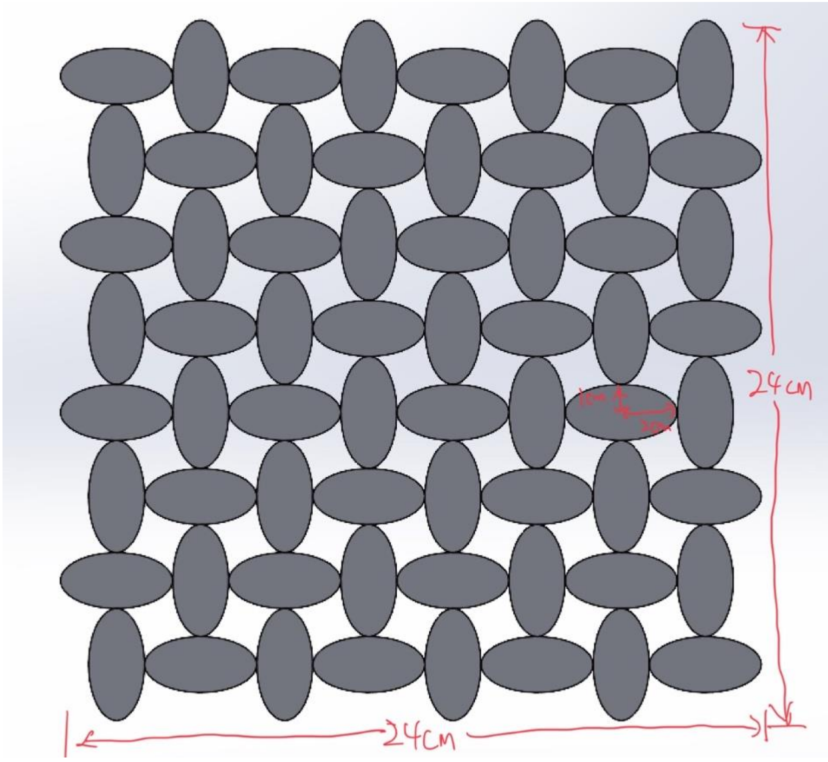
Top view



Front view

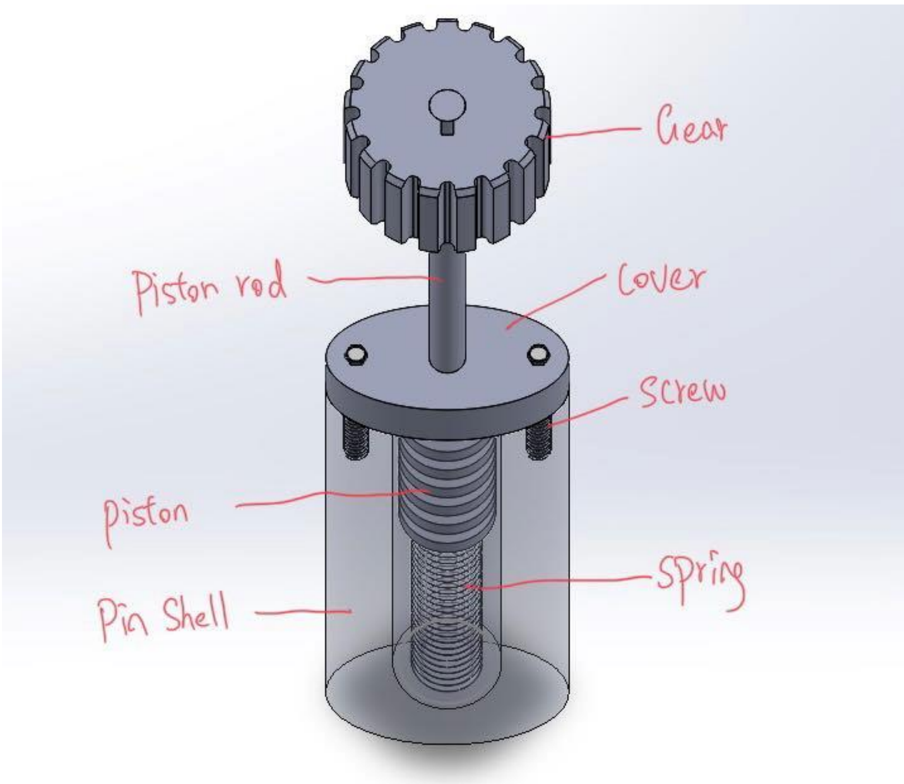


Bottom view

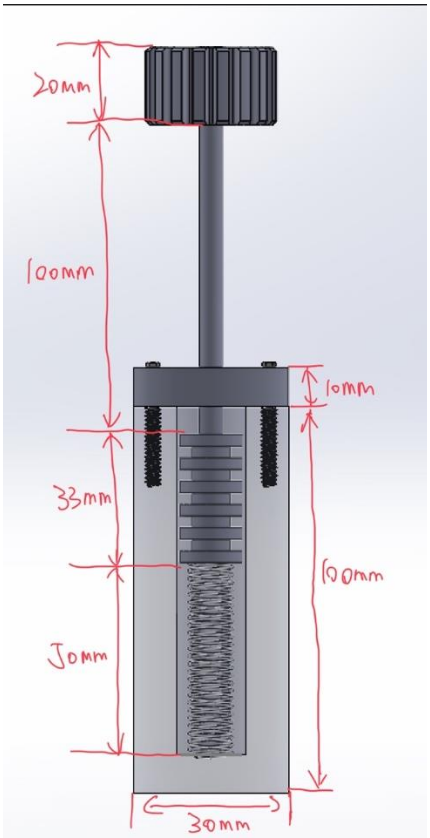


ii. One pin view

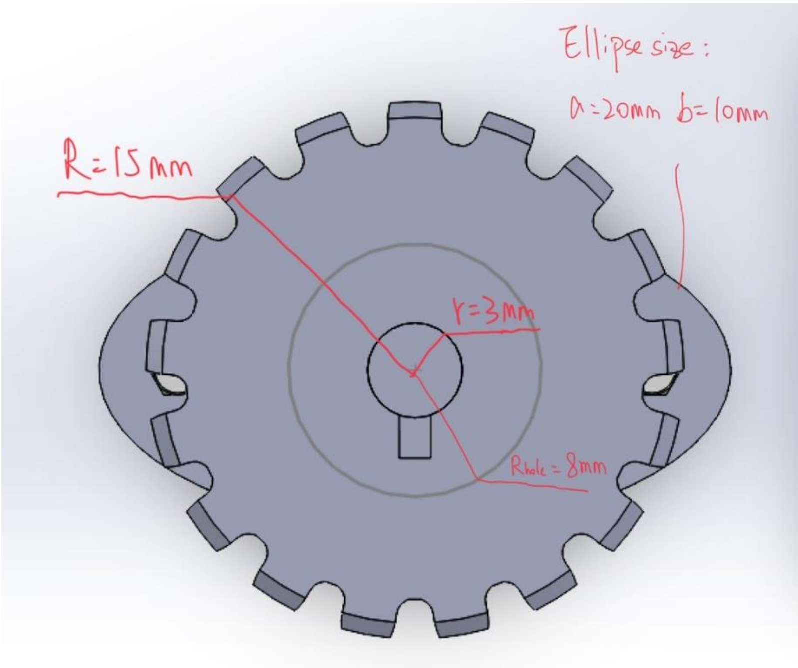
Overview



Front view



Top view



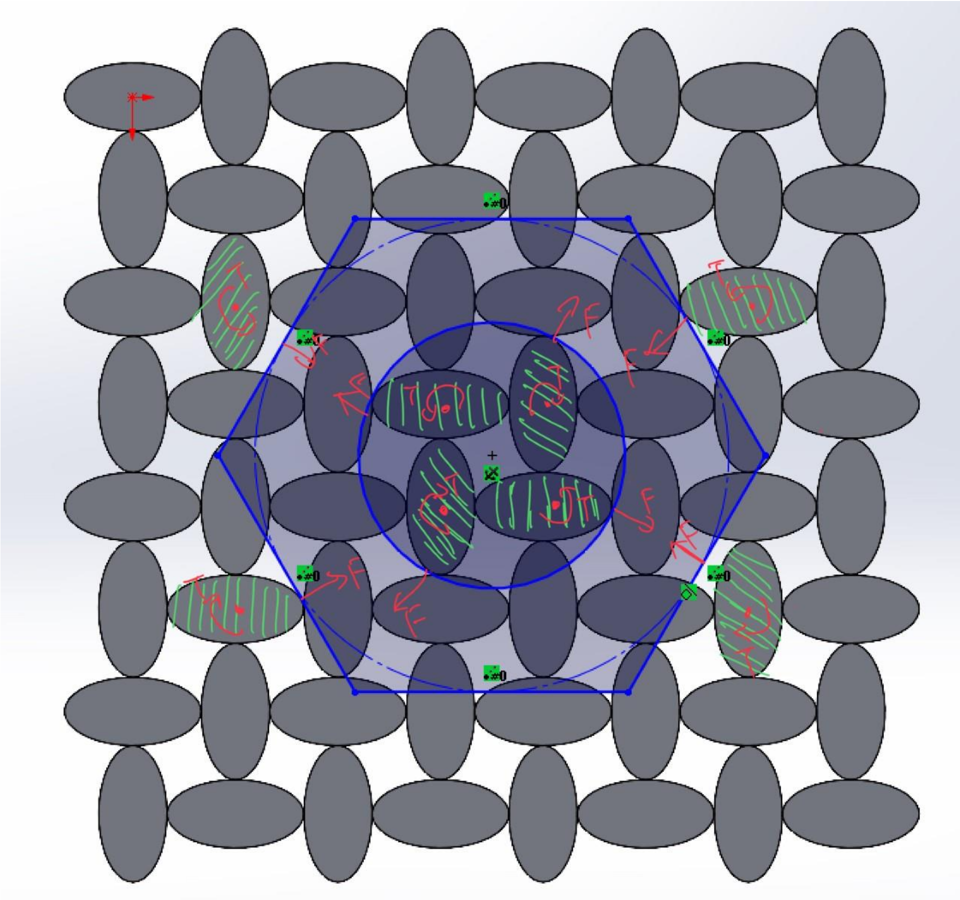
c) List of mechanisms

Part	Size	Numbers

Ellipse Pin shell	a=20mm;b=10mm h=100mm ; R(hole)=8mm	1*64
Spring	Pitch = 2mm ; Number of turns = 25	1*64
Piston	R=7mm ; H = 33mm	1*64
Cover	a=20mm;b=10mm h=10mm	1*64
Screw (M6*25)	Diameter=6mm ; Length=25mm	2*64
Piston rod	r=3mm ; L=100mm	1*64
Gear big	R=15mm ; r=3mm ; H=20mm	1*64
Gear small	R=12.46mm ; H=20mm	1*49
Driving rod	R=6mm ; L=50mm	1
Driving gear big	R=30mm ; r=6mm H=30mm	1
Driving gear big	R=17mm ; r=6mm H=30mm	1
Connecting rod	R=6mm;L=50mm ; r=3mm	1
Motor	N=60rpm ; P=4.8W ; T= 367.7 N*mm	1

d) Free body diagram and Related calculations

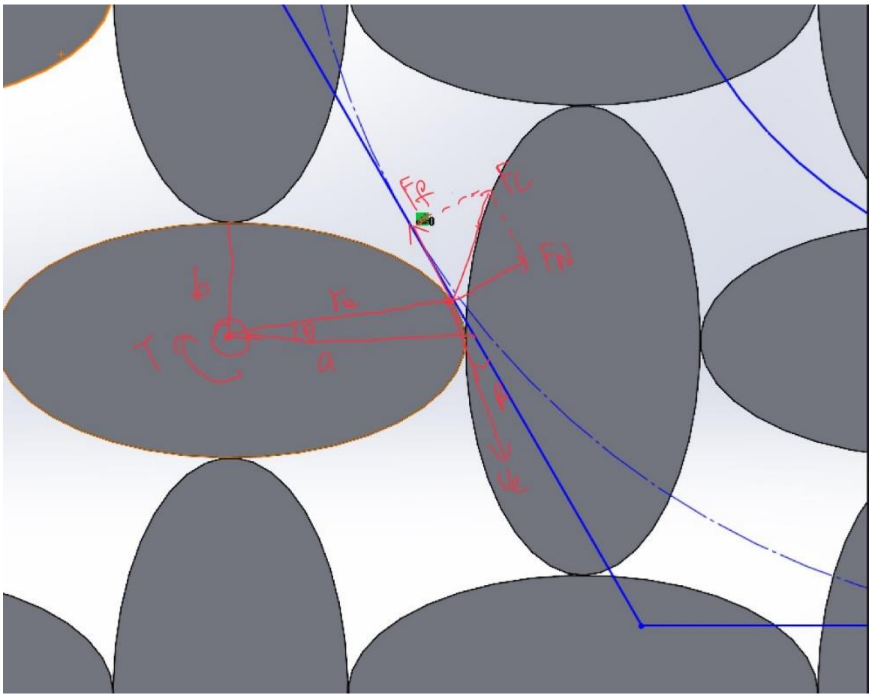
To investigate the general grasping capability of the proposed gripper, it is important to analyze how the lateral contact is constructed, which ultimately leads to the normal and frictional forces on the object for grasping.



L=75mm ; r=40mm

Investigate the contacts of a single pin

Driven by a torque T, the pin rotates clockwise and contacts an object. The distance between the contact point and the center of the pin is re, and the angle of rotation to the main axis is Θ. The linear velocity of the pin profile at the point of contact is Ve, perpendicular to re. The vertical dashed line is tangent to the pin and the surface of the object, where ϭ is the angle difference from Ve. The resultant force acting on the object is Fc, where r is its arm to the center of the pin. It can be decomposed into normal force FN and friction force Ff.



Let μs and μk be the coefficient of static friction and the coefficient of kinetic friction, respectively. i marks the torque exerted on the ith static friction pin, and j marks the torque exerted on the jth dynamic friction pin. The corresponding gripping forces F_{gs} and F_{gk} for static friction and kinetic friction are given by:

$$F_{gs} = \mu_s T_i r_e sin\beta$$

$$F_{gk} = \mu_k T_j r cos\alpha$$

Equations above show that the gripping force can be increased in three ways: using an appropriate material with a high coefficient of friction, increasing the input torque, and1 enlarging the pin size.

A single pin can't hold an object, while multiple contacts around the object can. It is assumed that there are both static frictional contact and dynamic frictional contact. Total grip force F_G given:

$$F_G = \sum_{i=1}^{m} Fgs(\theta i) + \sum_{j=1}^{n} Fgk(\theta j)$$

where the numbers of static and dynamic contacts are m and n, respectively. i and j mark each specific contact. For example, given the boundary conditions in our case:

Contacted pin torque: $T_i = T_j = 10$ Nmm

Semi axis: $a = 20$ mm, b=10mm

Coefficient of friction: $\mu_s = \mu_k = 0.5$

Number of contacted pins: $n = m = 4$

Rotation angle Θ: From 0° to 90°.

Bringing into the above formulas, the maximum grasping force in this model is 84.8N.

III) Pin Array Gripper Inspired by Traditional Parallel Gripper Designs

a) Introduction

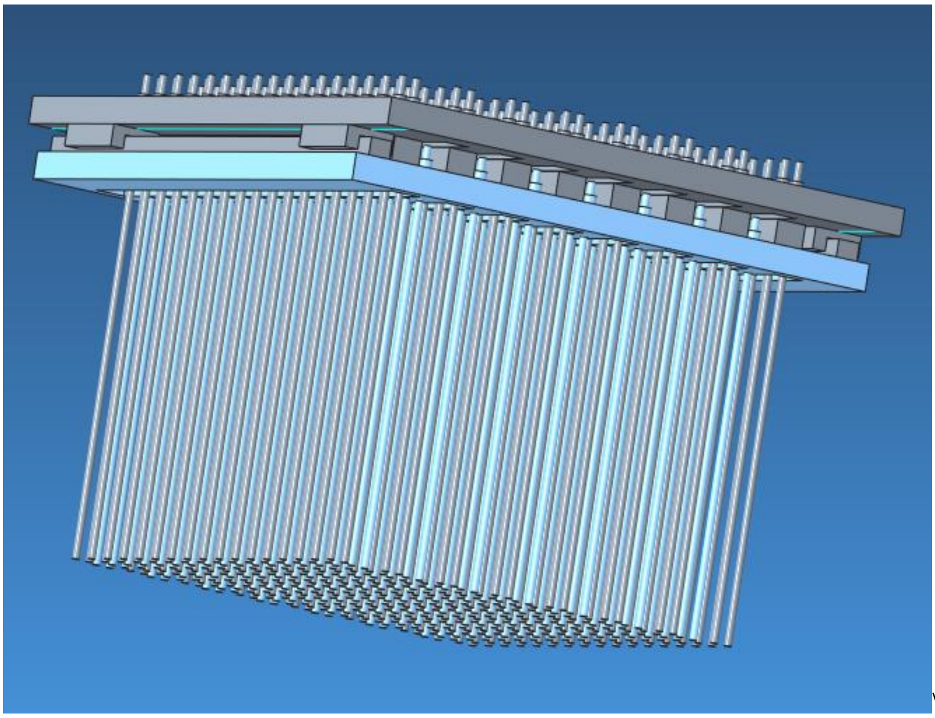
This concept is characterized by providing strong gripping force through the relative linear motion between two bases. The first base is connected to a linear actuator which facilitates a smooth linear motion, while the second base is stationary in the space and is joined to the first base with two linear rails on each side. A major advantage of the design lies in only a small displacement of the base could yield an equivalent effect from a parallel gripper, whose dimension can be much larger than the former.

This concept has the edge over other two in terms of mechanism and geometry complexity, and it's also easier to assemble and disassemble different components. However, such design prefers a specific gripping orientation when the target object is slender and thin. More pertinently, the moving direction of the first base is preferred to be perpendicular to the side of the object with a longer characteristic length.

b) CAD 3D model and drawing views

Assembly view

Overview



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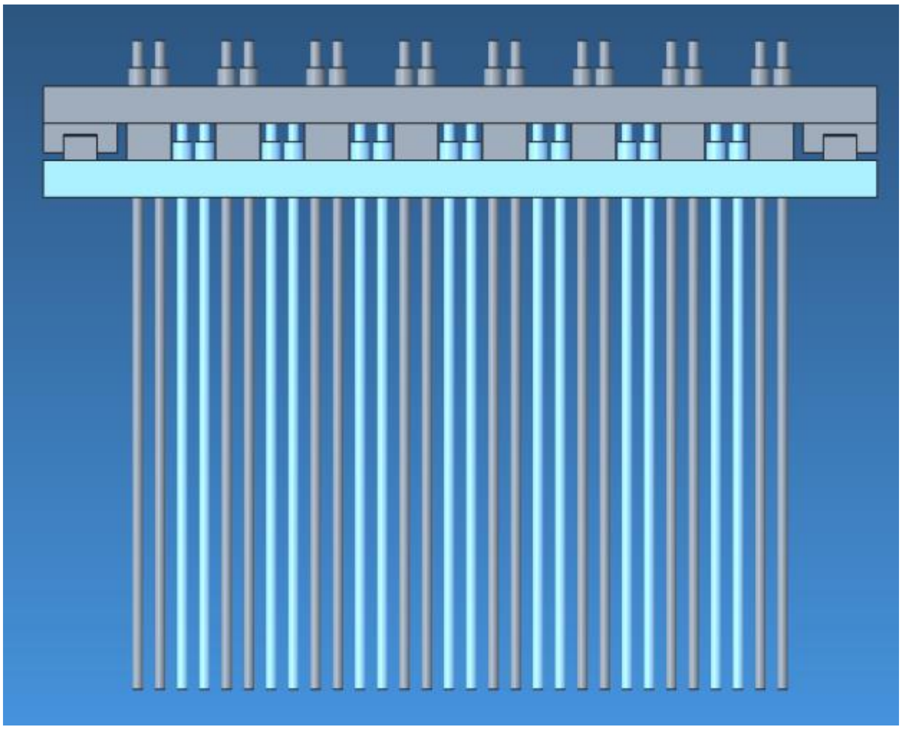
Front view

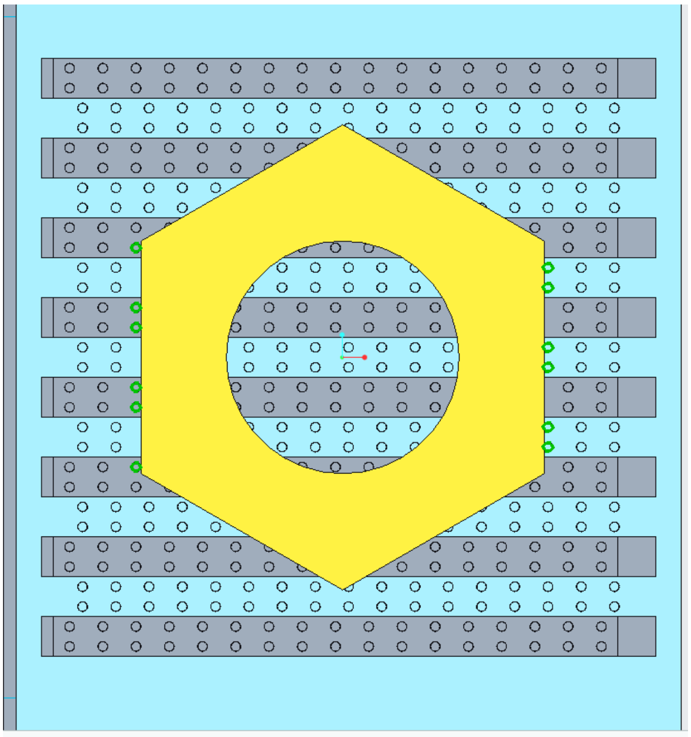


c) List of mechanisms

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

d) Free body diagram

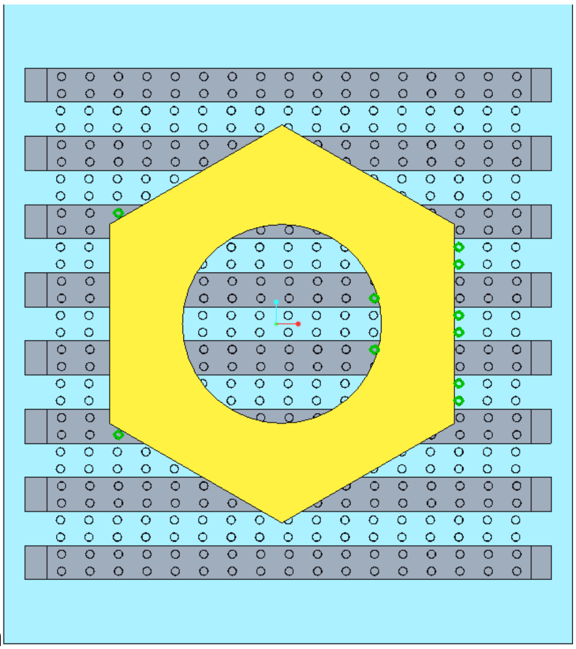
For a nut-shaped object, one possible gripping mode is demonstrated below. Twelve pins will have a direct contact with the outer surface of the object after it is clamped. Six of them provide force pointing to the left, while the other six provide force in the opposite direction. Under such circumstance,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



e) Related calculations

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.

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)



a

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 $1.8N/pin$.

IV) Summary - Advantages And Disadvantages of Each Design

1. **Versatile Gripper Based on Concentric Rotation Pin Array** can grip the vastest variety of objects with complex geometric shapes. The concentric ring design enables the implement of belt drive mechanism. Slippery between tendon and pulley/rings allows for shape adaption. When a ring is blocked, the other rings can continue rotating until their pins in contact with object. Therefore, more pins can contact and provide friction forces from the side. However, the design requires different mechanisms (e.g. bearings, tendons, springs), and the parts are relatively difficult to manufacture. This gripper is costly.

2. **Pin Array Gripper Inspired by Traditional Parallel Gripper Designs** is much more delicate compared to the other two. The thin pins allow the gripper to pick up small objects. Nevertheless, the simple parts make is easier to manufacture and assemble. However, one problem is that without the support of springs, the gripper accomplish the shape-memorizing process when the gripper is facing upwards, since the pin arrays will fall back into the base.

3. **Versatile Gripper Based on Meshed Pin Array** is capable of gripping objects with complex geometric shapes as well. It works especially well when it comes to circular shaped objects. However, the use of gear transmission introduces additional friction forces between gears, and chances are that the pin arrays will be stuck without proper installation.