THE DESIGN OF LASER ALIGNMENT SYSTEM

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Course Number: ME175C

Team Number: AS-1

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Project: Alignment System

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Executive Summary

In some specific situations, such as distant communications or UAV precise positioning. Antenna or other related devices itself should be positioned precisely to reduce the final total error of the product. So, our goal is to design and construct a device which will allow a laser to be precisely adjusted to an UAV in the process of assemble and, once it is in the final position, will hold the laser in place. We design a device which can rotate the adjusting bolts to control the threaded rod to achieve our requirements. We first determine the system's some of the most basic requirements, through several iterations, we get the current model, then verified the device's adjustment accuracy and range by modeling and analysis by Solidworks and MATLAB. Up to now, we have completed all the design process. Under the assumption that the minimum adjustment angle of hand is 4 degree, we get the result that the accuracy is between 0.2-0.4 degree, which meets the requirement we set.

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1. Introduction

Alignment systems are widely used, from Mars probes to drones. Because of the highly directional nature of these high-performance systems, even small misalignments in the system can prevent the receiver from seeing the signal. Our goal is to design and construct a device which will allow a laser to be precisely adjusted to an UAV in the process of assemble and, once it is in the final position, will hold the laser in place. We set the adjustment range is 10°, adjustment accuracy is 0.3°, two axis control and total mass less than 500g. In this article, we introduce the detailed device information, demonstration process, model building and validation and detailed component and assembly drawings.

2. Problem Statement

Alignment systems are widely used, from Mars probes to drones. It is especially important to precisely align the interface and related fixtures. Our group mainly considers the alignment system to fix a laser pen on the joint surface and point it in any predetermined direction.

2.1 System Requirements

In order to increase generality, we set our system's size about 200mm, and because of our project is a high precision device, we consider the adjustment range and accuracy are the main requirements of our design, thus we set the adjustment range is 20°, adjustment accuracy is about 0.2°---0.4°. In order to reduce the impact on the performance of the drone and increase reliability, we decide the fixing system total mass is less than 500g. Our main task is to control its pointing direction; thus, the effect of laser pen rotate around the long axis can be ignored.

Adjustment range	±10°
Adjustment accuracy	0.2°~0.4°
System mass	<500g
System size	≈200mm
Working temperature	0℃-40℃
Control dimensions	2-axis (roll pitch)

Table.1 System requirements

3. Design Solution

The mechanical structure we finally designed consists of two parts, adjusting mechanism and fixing mechanism (Fig. 1).

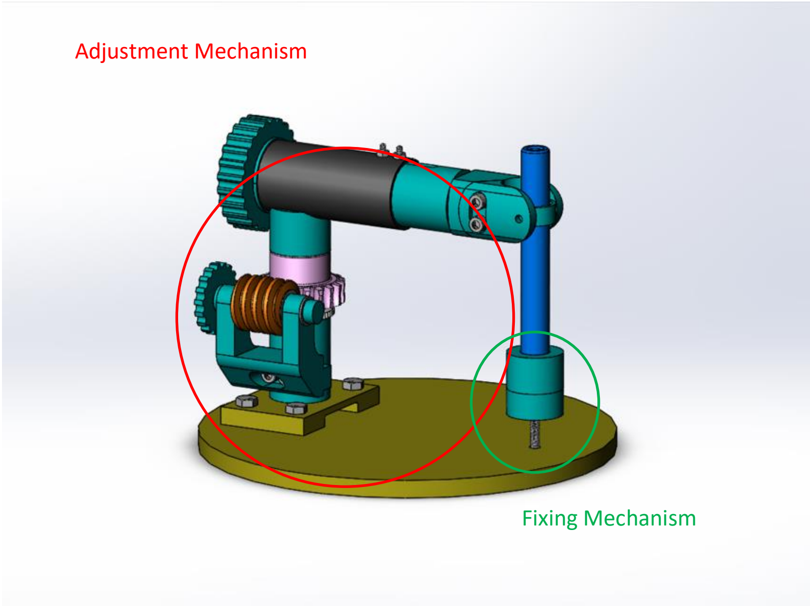

Fig. 1 Adjustment mechanism and Fixing mechanism

3.1 Adjustment Mechanism

The Fig. 2 shows the name of key components, an adjusting bolt and threaded nut are to control the vertical extension and shortening of the robot arm. Another adjusting bolt and worm also have gear to control the rotation of the robot arm in the horizontal direction. The sleeve could move along the laser pen and rotate to satisfy any angle, so that these two bolts could control the laser pen move in a fan-shaped plane, and point to any point in this area.

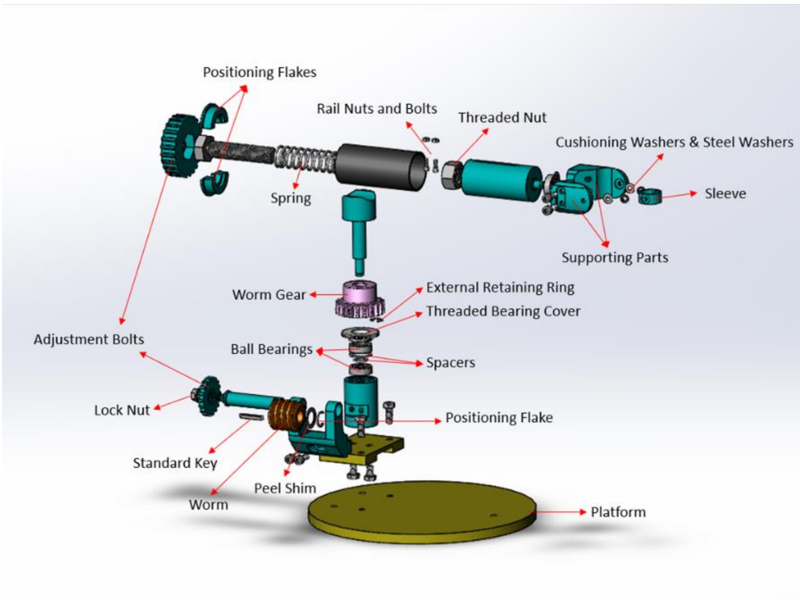

Fig. 2 Key components of adjustment mechanism

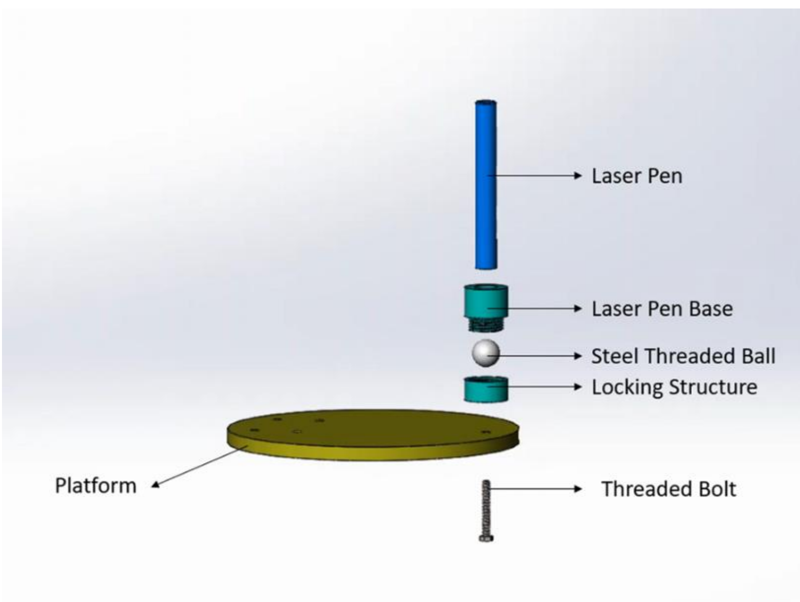

Fig. 3 Components of fixing mechanism

3.2 Fixing Mechanism

The fixing mechanism is mainly composed of steel ball, locking structure, threaded bolt, as shown in Fig. 3. And the threaded bolt is used to fix the ball joint on the platform, the structure is similar to the ball joint on tripod and phone holder on vehicle, a high friction will be produced by pressure, and stable fix the ball joint.

The operator only needs to handle these two adjustment bolts to adjust the mechanical arm to extend or shorten in vertical direction and to rotate the mechanical arm in the horizontal direction. The movement of the laser is driven by the movement of the mechanical arm. When moving to the specified position, user can tighten the ball joint to fix it. Finally, we will dismantle the adjustment mechanism and keep aligned laser.

3.3 Function and Material of Components

Some of the parts that make up our mechanical device are standard parts purchased directly. What we introduce below are that we need to purchase materials and manufacture.

The parts in Figures 4 to 17 are made by Acetal Rod. They are manufactured by CNC milling machine and CNC lathe according to the parts drawing. The holes on the parts can be drilled directly by laser drilling technology or punching machine.

Adjustment knob is a handle part to fix the bolt into its hexagon hole; the base adjustment knob is also a handle part for worm and worm gear, it could be threaded into the rod and fixed by locking nut; the base adjustment rod could connect knob and worm, there are two way threads: left and right, which could ensure the locking nut will not fall off after adjustment.

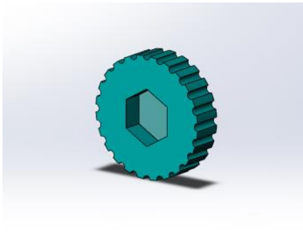

Fig. 4 Adjustment knob

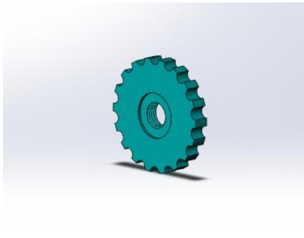

Fig. 5 Base adjustment knob

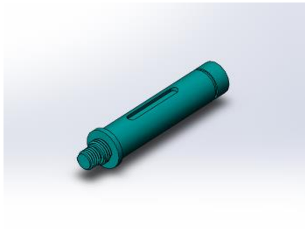

Fig. 6 Base adjustment rod

Base rod is a basic part, which could connect base, top parts and worm part, there are four threaded holes and a deep hole for two ball bearings; laser pen base could hold the laser pen and the threaded ball, it could work with the nut for threaded ball together to produce enough friction to fix the ball joint.

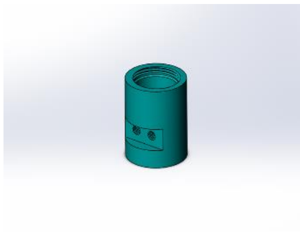

Fig. 7 Base rod

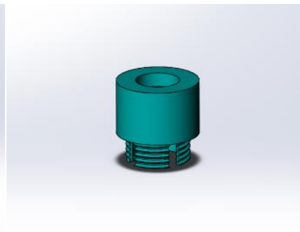

Fig. 8 Laser pen base

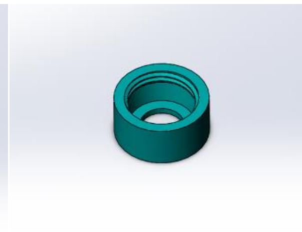

Fig. 9 Nut for threaded ball

Positioning flake is a supporting part for adjustment bolt, two flakes could limit the axial movement of bolt during the adjustment, and another step could support the spring; the rail rod is working as a mechanical arm, which could fix the adjustment nut into its hexagon hole, and the groove could limit the rotation during the adjustment, on the other side, the small rod could fix the ball bearing and support the sleeve part; the supporting rod for shell is a supporting part to connect base rod and shell.

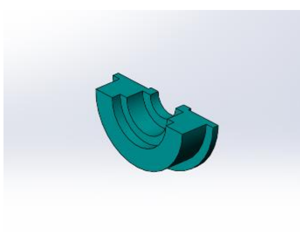

Fig. 10 Positioning flake

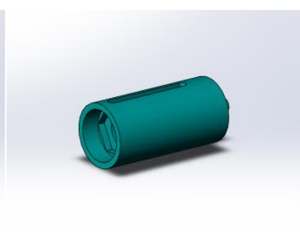

Fig. 11 Rail rod

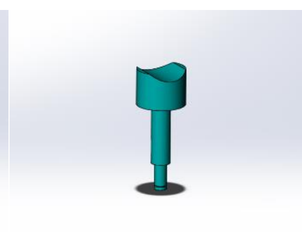

Fig. 12 supporting rod for shell

These three are components of sleeve parts: two supporting parts and a sleeve. The supporting parts could contain a ball bearing which could provide low friction during rotation, and also could hold the sleeve and ensure its movement; the sleeve has three “points” to reduce friction between laser pen.

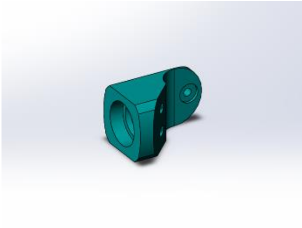
Fig. 13 Supporting part 1

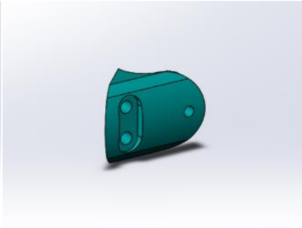
Fig. 14 Supporting part 2

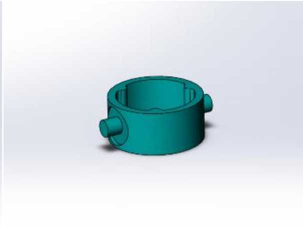
Fig. 15 Sleeve

The supporting part for worm could be fixed on the base rod by two screws, and it could support the worm and provide enough force to avoid movement during adjustment; the threaded bearing cover could be threaded into the base rod, and fix the outer ring of the top ball bearing to avoid loosening.

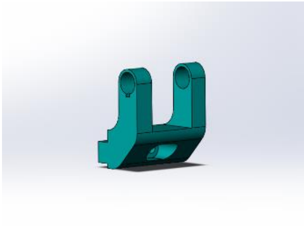
Fig. 16 Supporting part for worm

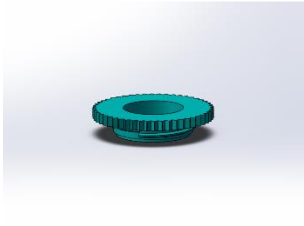
Fig. 17 Threaded bearing cover

The parts in Fig. 18 and Fig. 19 are made of Slippery Black UHMW Sheet. They are punched with a punching machine after being processed by a lathe. The base is a connecting part to connect base rod and platform, which has six holes for screws, two are to fix rod, four are to fix the platform; the platform is the supporting part for the adjustment mechanism and the fixing mechanism, they will be fixed on it and cooperate.

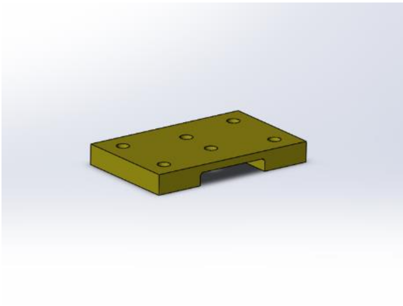
Fig. 18 Base

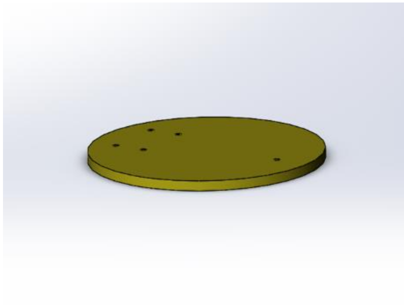
Fig. 19 Platform

The part shown Fig. 20 is made of mild steel. Just use a milling machine to make two holes on the cylindrical material into the part shown on the CNC lathe. The shell is a supporting part to hold rail rod and the bolt, the two holes are for rail screws and nuts, they could be fixed into holes and work as guides.

Fig. 20 Shell

4. Design Verification

The purpose of our virtual prototype is to show the parts intuitively and omit the shapes and dimensions that have no influence on the calculation. In the simplified model, we only keep two pairs of gears, laser pen and necessary rotating parts. We use the center point of the contact position between the sleeve and the laser pen to represent the laser coordinates. It is used to analyze and verify whether (1) the accuracy and (2) the range of the adjustment system designed by us meet the requirements. The position change of the center point and the angle change of the laser pointer relative to the vertical state when the two gears rotate respectively are calculated by MATLAB, which is used to check our design.

First, Fig. 21 shows our adjustment range. The shadow part represents the maximum moving range of laser in our system. The range included in the circle represents the range of movement we require.

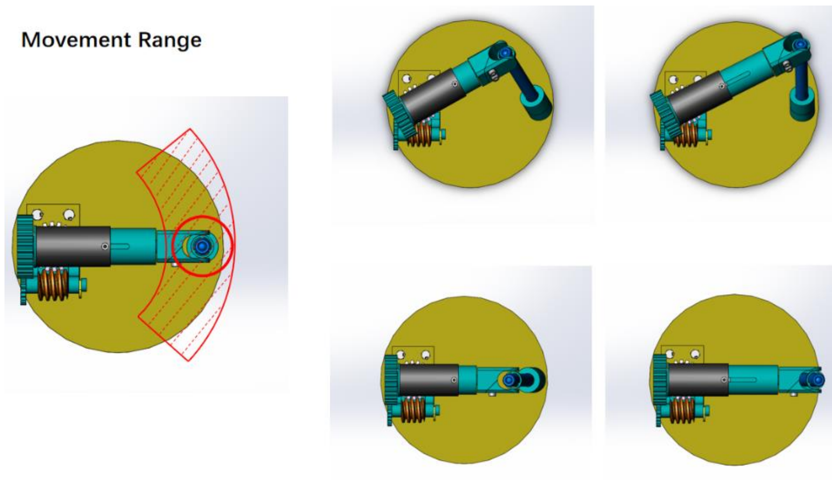

Fig. 21 Movement range

4.1 The Input, Output and Parameters set by our Simplified Model

Fig. 22 and Fig. 23 show the radius parameters of the moving range and the actual required range of the manipulator. Fig. 24 shows the length change of the manipulator.

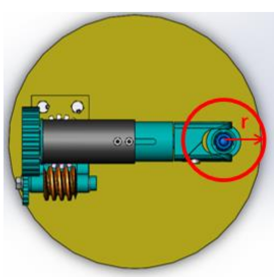

Fig. 22 Designed range

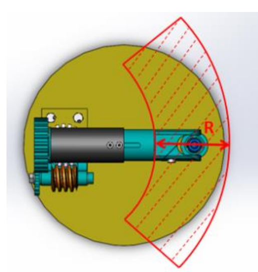

Fig. 23 Actual range

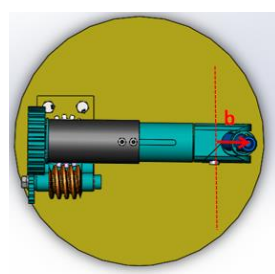

Fig. 24 Length variation of mechanical arm

And then we get:

Parameter (1): Radius of laser pen center (r): 16.75 mm

Parameter (2): Radius range of the system(R): 17.35 mm

Input (1): Change range of arm length(b): -17.35mm~17.35 mm

Fig. 25 and Fig. 26 show the deflection angle of our robot arm and the deflection angle of the laser pen based on the reference plane and line.

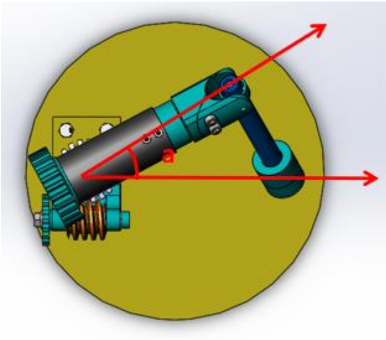

Fig. 25 Deflection angle of mechanical arm

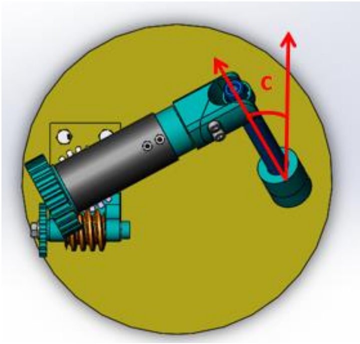

Fig. 26 Deflection angle of laser pen

And then we get:

Parameter (3): Angle range of the system: -30°~30°

Parameter (4): Expected adjustment angle of laser pen: -10°~10°

Input (2): Angle range of the system(a): -30°~30°

Output (1): Deflection angle of laser pen(c): The value range of c should be greater than be larger than -10°~10°

Fig. 27 shows the simplified length parameter of the part, which is convenient for us to establish the coordinate system and other calculation and checking in the future.

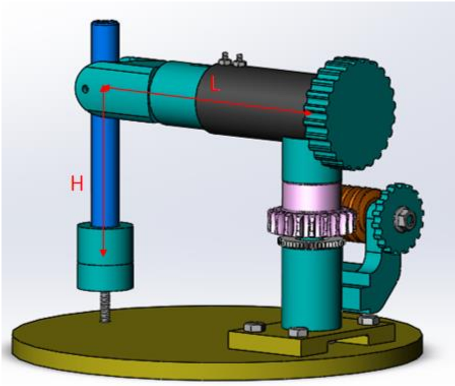

Fig. 27 The simplified length parameter of the part

And then we get:

Parameter (5): Height from the Rod to the Ball Joint (H): 95 mm

Parameter (6): Radius from the base center to the pen (L): 140 mm

4.2 Verification of Adjustment Accuracy

First, as shown in Fig. 28, we divide our adjustment system into two parts: Part A and Part B.

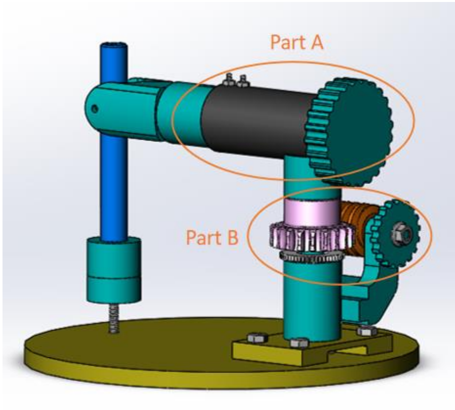

Fig. 28 Divided adjustment system

We need to adjust the gears in part a and part B respectively to adjust the deflection range of the laser pen. Because the power of this structure is hand, it is hard to calculate the accuracy of this system. Here we assume the minimum adjustment angle of hand is 4°.

The adjustment accuracy in part A is shown in Fig. 29.

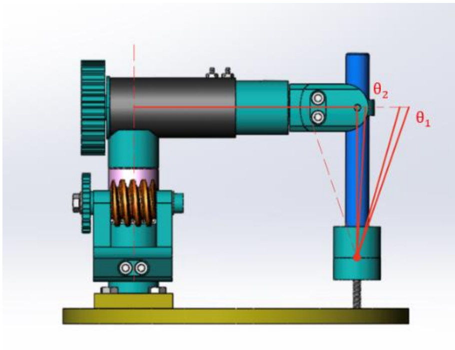

Fig. 29 Part A

Pitch of the Higher Adjusting Bolt: 2mm

Minimum Adjustment Length of R: $2mm \times (4°/360°) = 0.0222mm$

Minimum Adjustment Angle of Bolt:

$$\theta_1 = 10° - arctan(\frac{16.75 - 0.0222}{95}) = 0.0136°$$

$$\theta_2 = arctan(\frac{0.0222}{95}) = 0.0134°$$

The adjustment accuracy in part B is shown in Fig. 30.

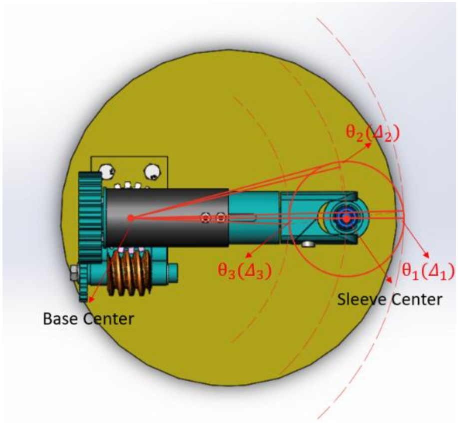

Fig. 30 Part B

Speed Ratio: 20:1

Angle per Pitch of the Worm Gear: $360°/20 = 18°$

Worm Gear Minimum Rotation angle: $18° \times (4°/360°) = 0.2°$

Adjustment Angle of the Lower Gear: 0.18°

Minimum Adjustment Angle of Worm Gear:

$$\sqrt{H^2 + R^2} = 96.47mm \tag{1}$$

$$\Delta_1 = \left(\frac{0.2}{360}\right) \times 2\pi(L + R) = 0.547mm \tag{2}$$

$$\theta_1 = arcsin\left(\frac{0.547}{96.47}\right) = 0.325° \tag{3}$$

$$\Delta_2 \approx \left(\frac{0.2}{360}\right) \times 2\pi L = 0.489mm \tag{4}$$

$$\theta_2 = 10° - arctan(\frac{16.75-0.489}{95}) = 0.287 \quad (5)$$

$$\Delta_3 = \left(\frac{0.2}{360}\right) \times 2\pi(L-R) = 0.430mm \quad (6)$$

$$\theta_3 = arcsin\left(\frac{0.430}{96.47}\right) = 0.256° \quad (7)$$

In part A and part B, our adjustment accuracy is less than 0.4°. And the adjustment accuracy can meet our design requirement.

4.3 Verification of the Range of the Adjustment mechanism

Create a rectangular coordinate system, Fig. 31 as shown.

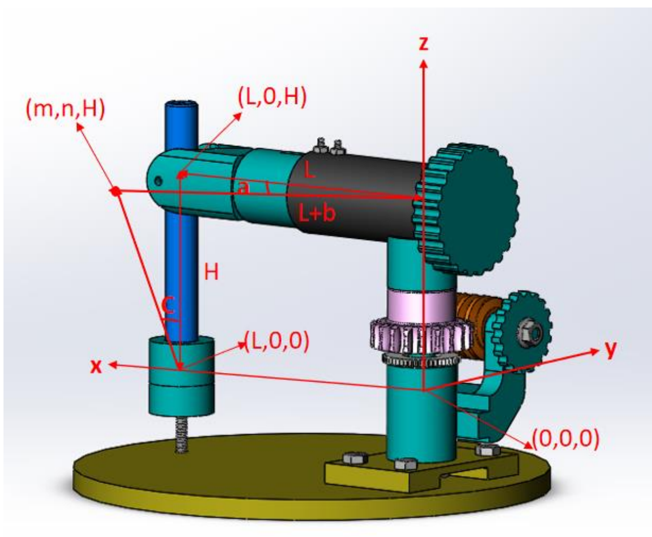

Fig. 31 Coordinate system

The center of the sleeve represents the position of the infrared light of the laser. The initial coordinate is (L, 0, H). The changed coordinate of the laser adjusted to the specified position is (m, n, H), and the deflection angle of the laser is **c**. The length of the manipulator is **L** + **b**, and the deflection angle is **a**. Hence (**m** - **L**) is the change of **x** -coordinate and **n** is the change of y-coordinate. And we can get:

$$m = (L+b) \times cos(a); \quad (8)$$

$$n = (L + b) \times sin(a); \tag{9}$$

c can be regarded as the angle between vector (m-L, n, H) and vector (0,0,1), then:

$$c = acos(\frac{H}{\sqrt[2]{(m-L)^2+n^2+H^2}}); \tag{10}$$

Put in the parameters we set, corresponding to this part of the code in MATLAB, as Fig. 32 shown.

```
m=(140+B).*cos(A/180*pi);
n=(140+B).*sin(A/180*pi);
k=m-140;

C=acos(95./sqrt(k.*k+n.*n+95^2))*180/pi;
C=real(C);
```

Fig. 32 Relational MATLAB code

Minimum Adjustment Length of R: 2mm × (4°/360°) = 0.0222mm

Worm Gear Minimum Rotation angle: 18° × (4°/360°) = 0.2°

Input(**a**): Angle range of the system: -30°—30°, unit angle:0.2°

Input(**b**): Change range of arm length: -17.35mm—17.35 mm unit length:0.0222mm

Then corresponding to this part of the code in MATLAB, Fig. 33 as shown.

```
a=linspace(-30,30,301);
b=linspace(-17.35,17.35,1564);
[A,B] = meshgrid(a,b);
```

Fig. 33 Input MATLAB code

In addition, substituting the input we set, Fig. 34 and 35 show the input data of **a** and **b**.

1x301 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	-30	-29.8000	-29.6000	-29.4000	-29.2000	-29	-28.8000	-28.6000	-28.4000	-28.2000	-28	-27.8

Fig. 34 Input value of a

1x1564 double

	1	2	3	4	5	6	7	8	9	10	11	12
1	-17.3500	-17.3278	-17.3056	-17.2834	-17.2612	-17.2390	-17.2168	-17.1946	-17.1724	-17.1502	-17.1280	-17.1

Fig. 35 Input value of b

a and **b** meet our input requirements. Finally, we take **a**, **b** as the input, m, n, **c** as the output, and draw their images respectively, as Fig. 36, 37 and 38 shown. By observing their images, we can get our range of motion.

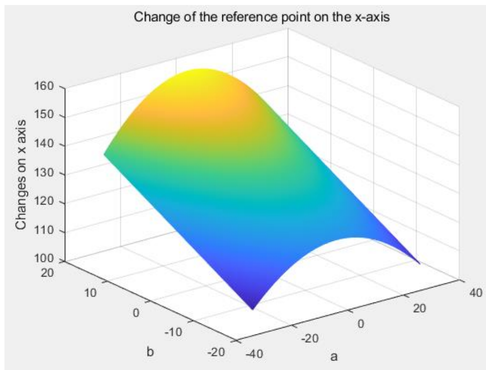

Fig. 36 Change of the reference point on the x-axis

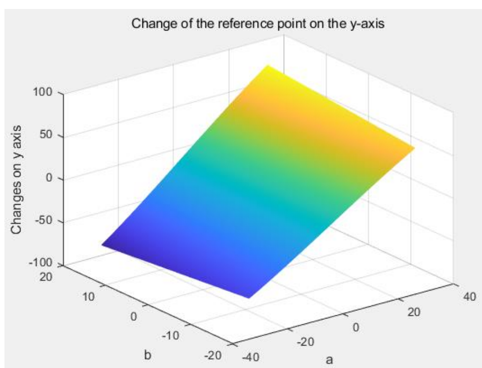

Fig. 37 Change of the reference point on the y-axis

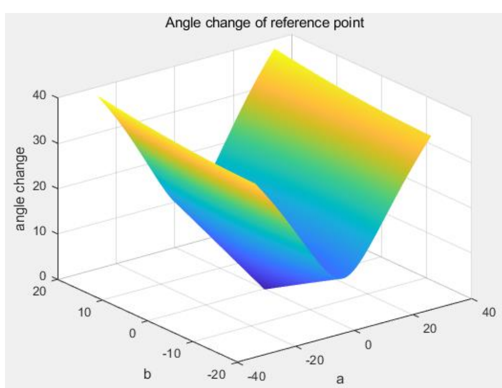

Fig. 38 Angel Change of the reference point

From figures above, we can see that the adjustment range (angle change) is about 10.36°, in the definition report, we set the requirement is 10°, thus the adjustment range can meet our design requirement.

5. Approach to Solution

We first determine the system some of the most basic requirements, such as the need to easy operation, simple structure and regulating mechanism can be removed, and the method of using the 4-3-5, after the brainstorming, we finally came up with the total 4 kinds of structures.

5.1 Concept 1

The concept 1 has a detachable mechanical arm mounted on the joint surface (Fig. 39). It uses two bearings that are vertical in space to orient the alignment device's direction. If we fix the component on the mount surface directly, we cannot adjust its direction conveniently. Therefore, a spherical pair is used to fix its position and adjust its direction at the same time. On the adjusting device we extend the adjusting lever to get better accuracy. In this solution, we can control the three supporting rods' angles to make the

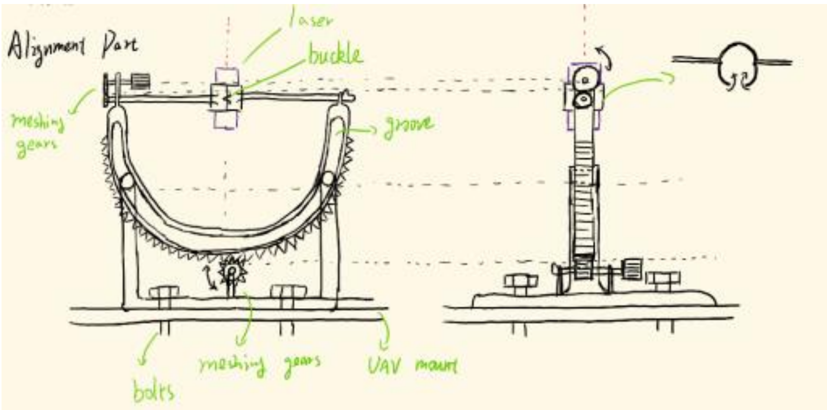

Fig. 39 Gear adjustment

component point at presupposed direction. After the adjustment is completed, turn the screws on the spherical pair to increase friction force between the shell and the ball. This will fix it to point at the goal. Then remove the arm from mount surface to reduce the weight of UAV.

5.2 Concept 2

The concept 2 is constructed with double-gear system as the alignment system and connecting rod system as the fixture system (Fig. 40). For the alignment system, all the components are connected with the frame while the frame is fixing on the UAV mount with four bolts. By turning two meshing gears, the angles of x-z axis and y-z axis can be changed to alignment. Using gears of different transmission ratios, the accuracy of angle changing is determined and adjustable. For the fixture system, four rotating rods will allow the angle changing of the laser and by fastening the screws of the joints and releasing the buckle, the laser will be fixed after alignment.

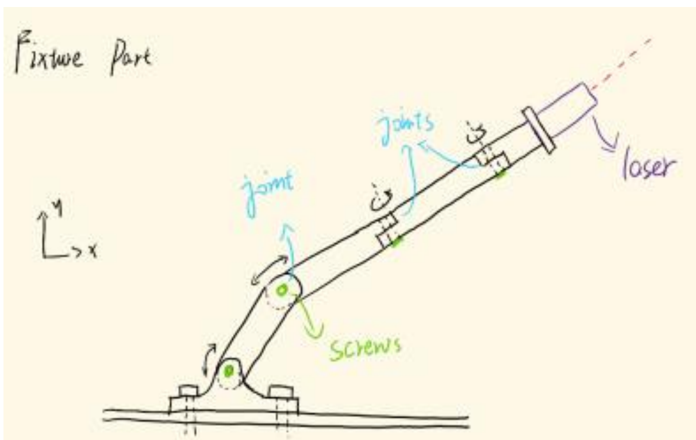

Fig. 40 Robotic arm adjustment

5.3 Concept 3

The concept 3 has two platforms the UAV platform and the platform on which the laser is placed are linked by a ball joint (Fig. 41, Fig. 42), which can ensure that the distance between the centers of the two platforms remains the same, so that only the laser angle is changed without changing the spatial position. Two four-strait structures are connected to the laser platform perpendicularly to each other, and two joysticks are extended. First, adjust the two extending joysticks to adjust the vertical and horizontal rotations. After the adjustment is completed, tighten the joint by tightening the ball joint nut, and use the

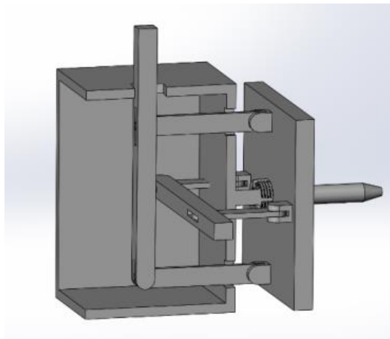

Fig. 41 View 1 adjustment by 4 links

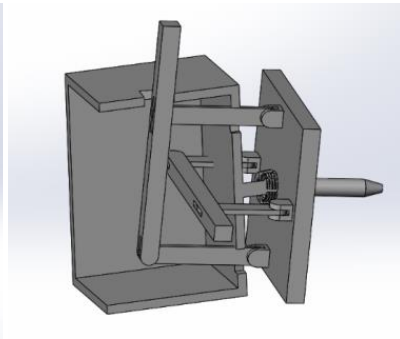

Fig. 42 View 2 adjustment by 4 links

friction to fix the UAV platform and the laser platform.

5.4 Concept 4

The concept 4 is as shown in Fig. 43 and Fig. 44. Three bolt columns are fixed on the surface of the UAV and pass through the sleeve on the plane equipped with laser. By rotating the bolt, the three sleeves can move up and down in the vertical direction. The three bolts are connected with the laser platform through the spherical joint, and three sliders with an angle of 120 degrees are added into the laser platform to adapt to the distance change between the platform and the bolts when the platform rotates. Therefore, we can adjust the position of the triangle accurately by rotating three nuts to adjust the laser direction.

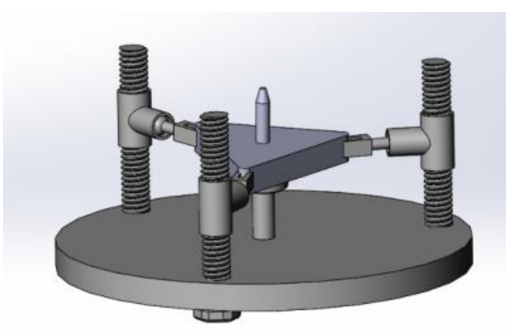

Fig. 43 View 1 Height adjustment method

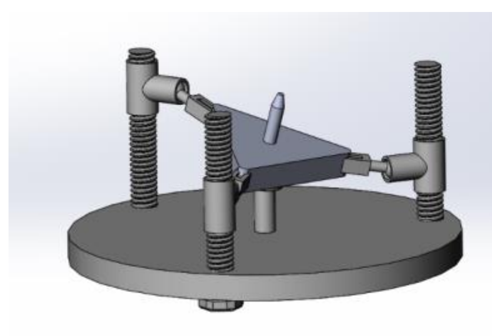

Fig. 44 View 2 Height adjustment method

5.5 Final Prototype

Finally, we used the decision matrices to evaluate whether these four systems meet our requirements, including light weight, easy to operate, safe, simple structure, high efficiency, and so on. The scoring content and results are shown in Table. 2.

		concept 1		concept 2		concept 3		concept 4	
	Weight	individual score	weight score	individual score	weight score	individual score	weight score	individual score	weight score
light weight	6	6	36	7	42	7	42	10	60
easy to operate	7	9	63	9	63	9	63	9	63
safe	10	10	100	9	90	9	90	9	90
simple structure	8	10	80	8	64	9	72	10	80
high efficiency	6	10	60	10	60	10	60	10	60
reusable	4	8	32	6	24	6	24	6	24
easy to disassemble	7	10	70	6	42	7	49	8	56
low impact	8	10	80	8	64	8	64	7	56
low cost	6	9	54	7	42	8	48	8	48
reliable	8	9	72	9	72	9	72	7	56
high precision	10	8	80	9	90	9	90	9	90
Final score			727		653		674		683

Table.2 Decision matrices

In the end, we get multiple designs to get the final design (Fig. 45), which is a prototype to show our thoughts and the theory we used, so it is a little bit different from the final design. It is easy to disassemble, easy to adjust and relatively simple in structure.

1. Laser movement controlled by robotic arm fixture

2. Fixing laser with ball joint

3. Gears can be used to control robotic arm deflection

4. We can use the bolt thread to control the elongation and shortening of the arm

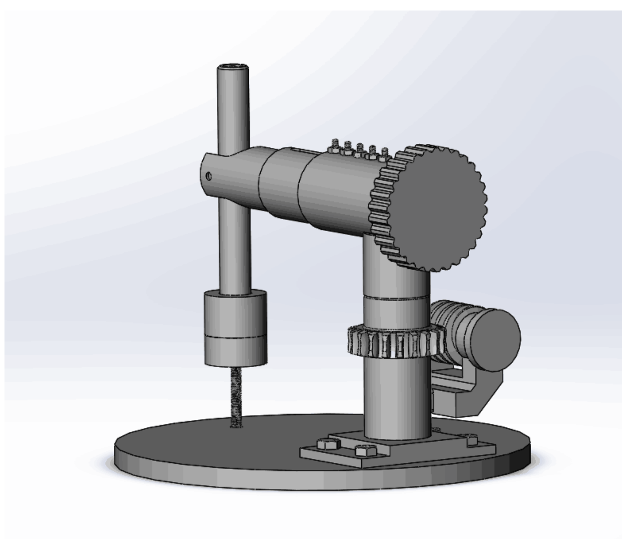

Fig. 45 Prototype of AS-1, a threaded bolt manipulator

It fully meets the specifications of the problem statement. As well it is easy to manufacture.

6. Conclusions and Recommendations

So far, the proposed design meets all the requirements in the problem definition and it is the most optimum plan considering the cost, the materials, and other aspects in this project. However, if there is another project with different requirements or there are better choices of the materials found, here are the recommendations.

For the design of the adjusting bolt, since the low yield of the alignment systems, step cut will make sure the high precision which is applied in this project.

Once it comes to special cases that the yield become high, considering the cost of step cut, washers should be the better choice which can fit the basic function of reducing connecting area and save much money as well. But the precision will be lower than our design

For the design of the supporting part, if there are screws with high friction or more reliable design, the number of screws can be reduced by one.

References

Appendices

MATLAB code:

```
clear

clear all

x=linspace(-30,30,241);

y=linspace(-17.35,17.35,1249);

[X,Y] = meshgrid(x,y);

m=(140+Y).*cos(X/180*pi);

n=(140+Y).*sin(X/180*pi);

k=m-140;


Z=acos(95./sqrt(k.*k+n.*n+95^2))*180/pi;

Z=real(Z);



figure(1),mesh(X,Y,Z),view(3)

title('Angle change of reference point')

xlabel('x')

ylabel('y')

zlabel('angle change')

figure(2),mesh(X,Y,m),view(3)

title('Change of the reference point on the x-axis')

xlabel('x')

ylabel('y')
```

zlabel('Changes on x axis')

figure(3),mesh(X,Y,n),view(3)

title('Change of the reference point on the y-axis')

xlabel('x')

ylabel('y')

zlabel('Changes on y axis')

Part and Assembly Drawings

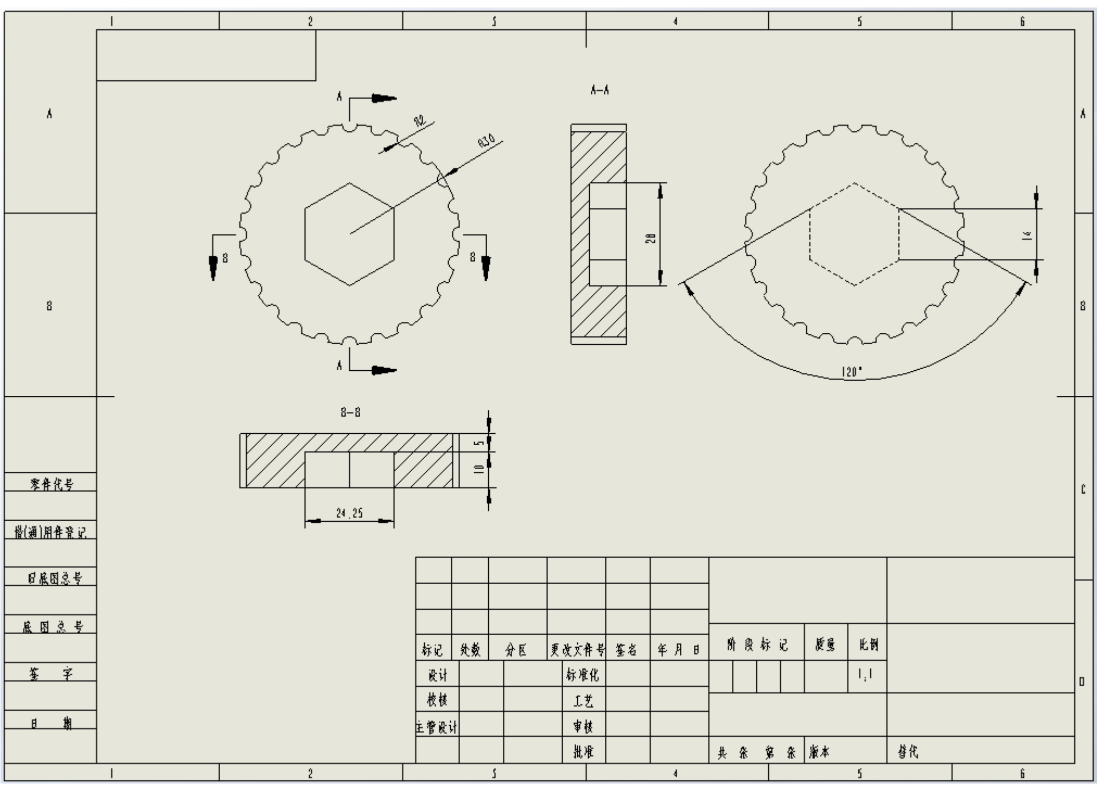

Fig. 46 the part drawing of adjusting knob

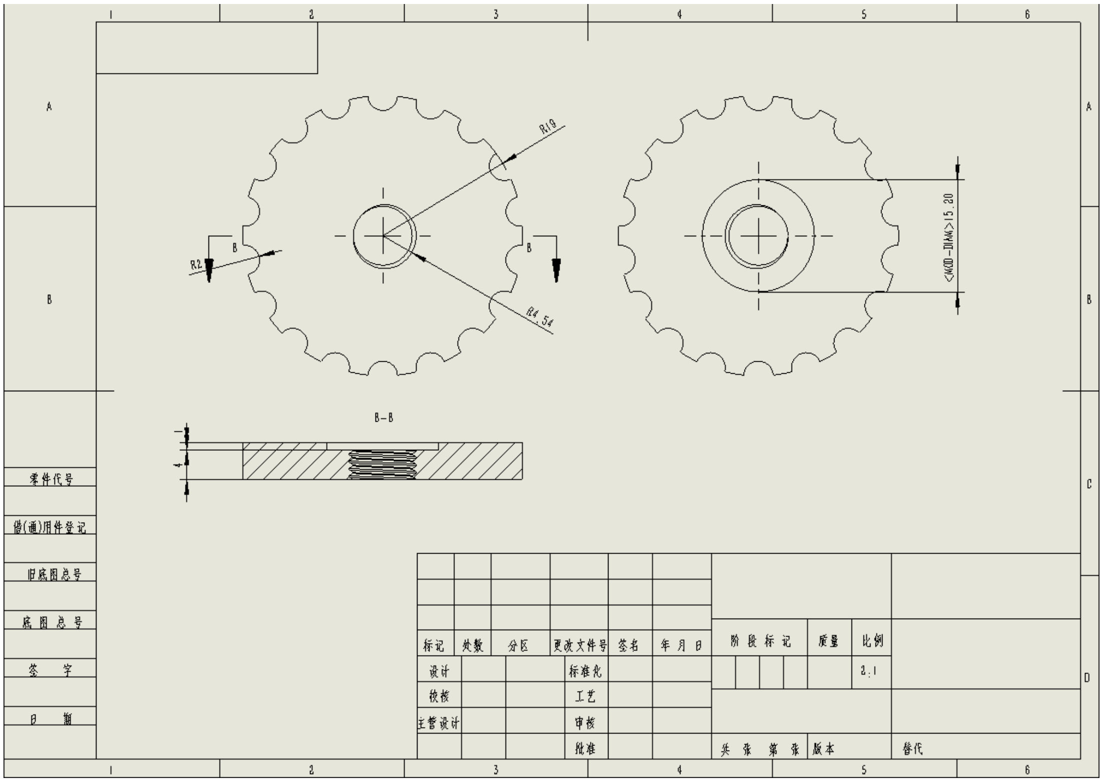

Fig. 47 the part drawing of base adjustment knob

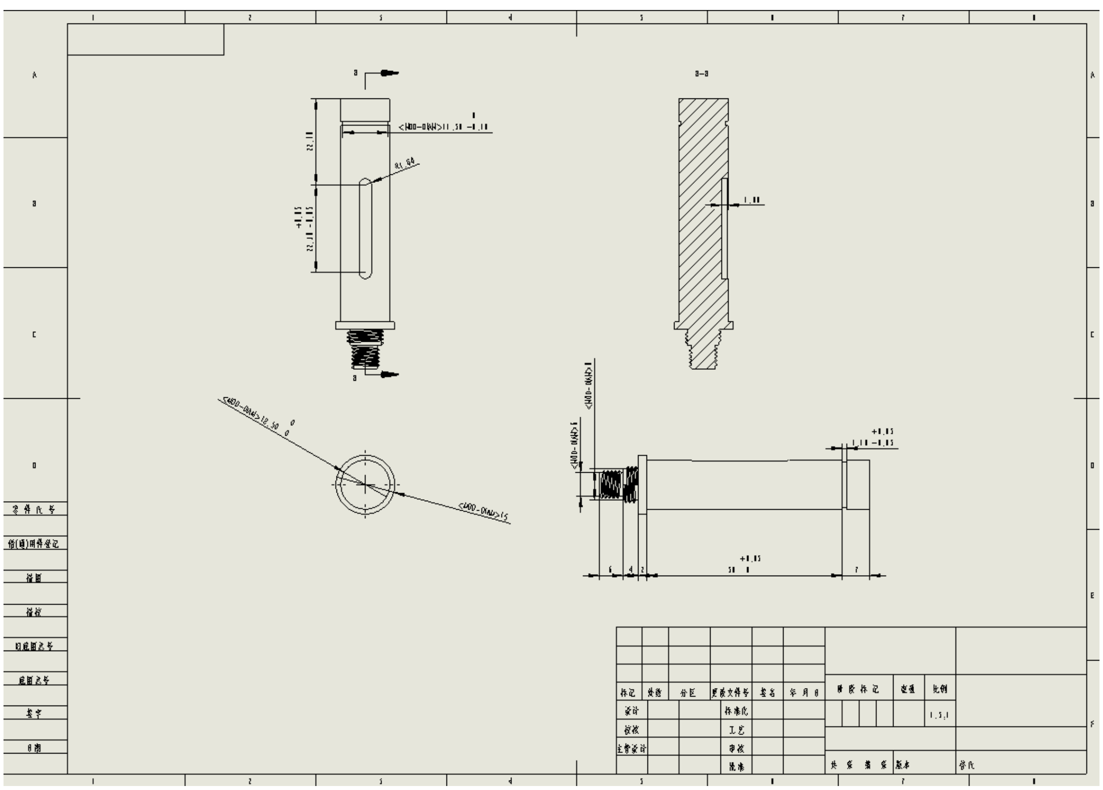

Fig. 48 the part drawing of base adjustment rod

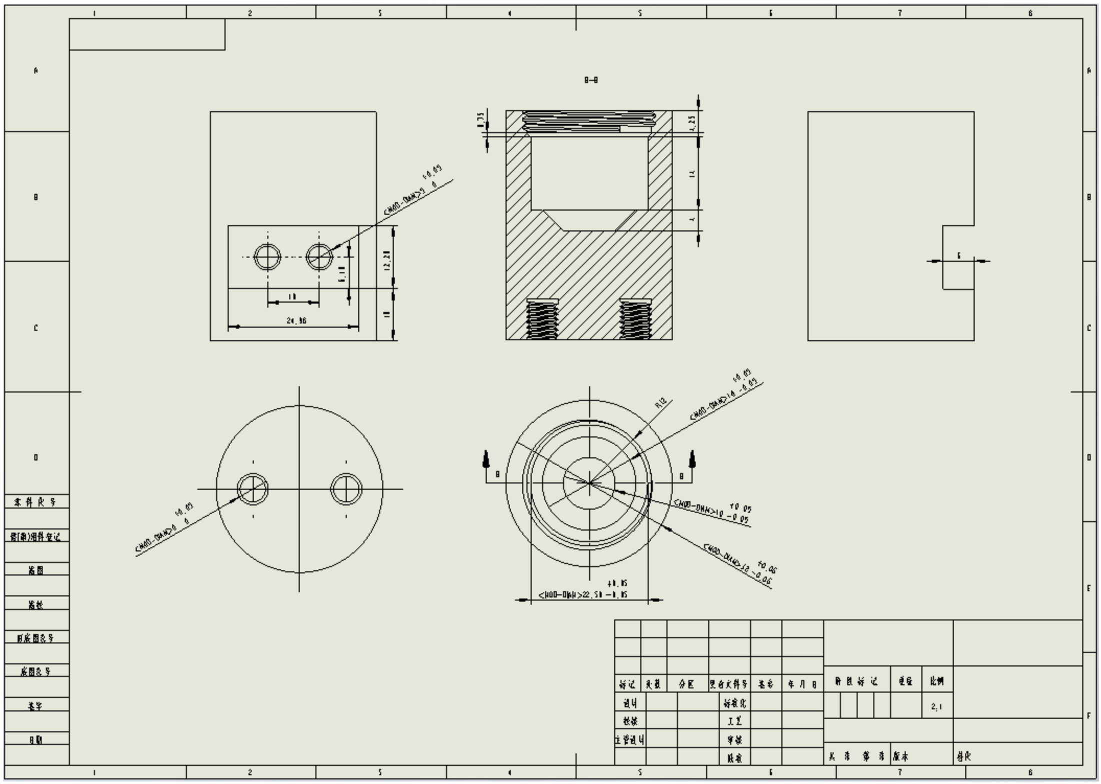

Fig. 49 the part drawing of base rod

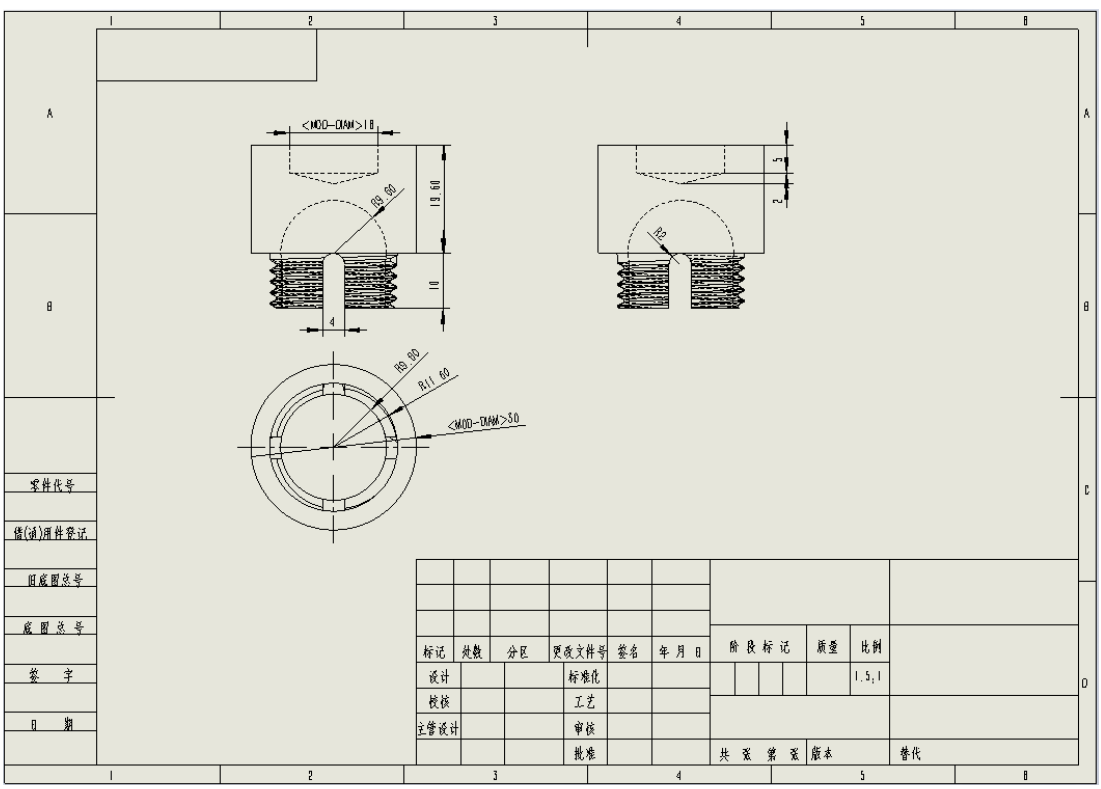

Fig. 50 the part drawing of locking structure

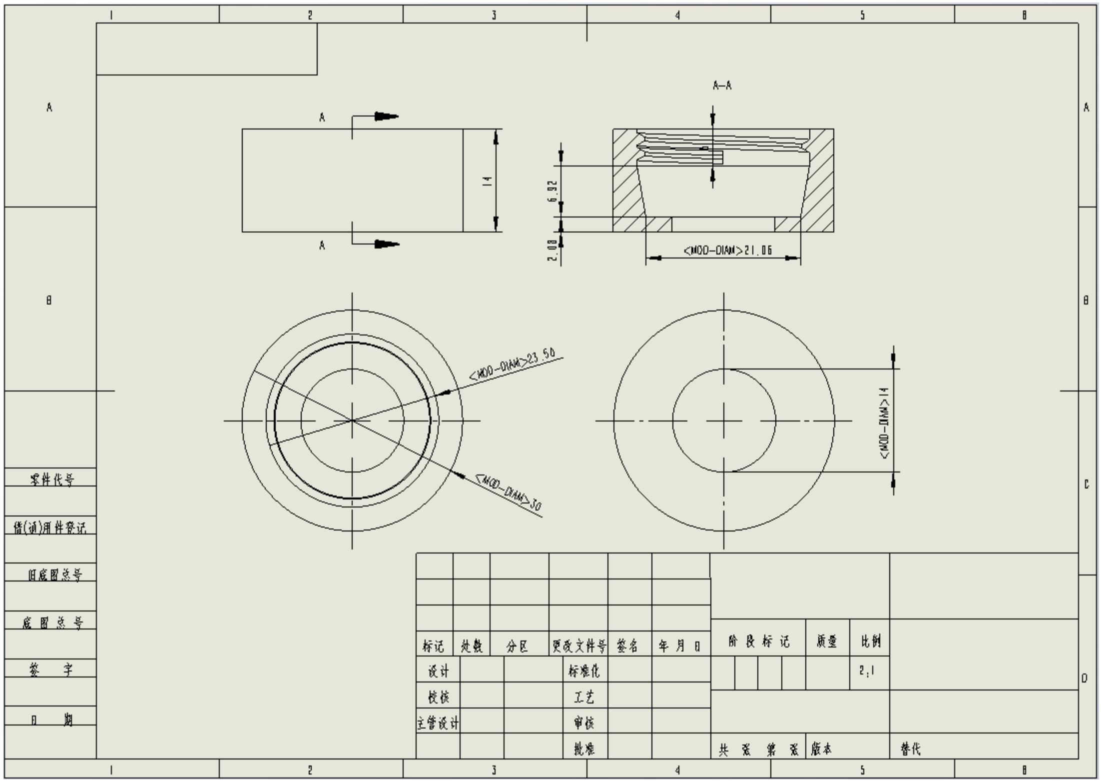

Fig. 51 the part drawing of nut for threaded ball

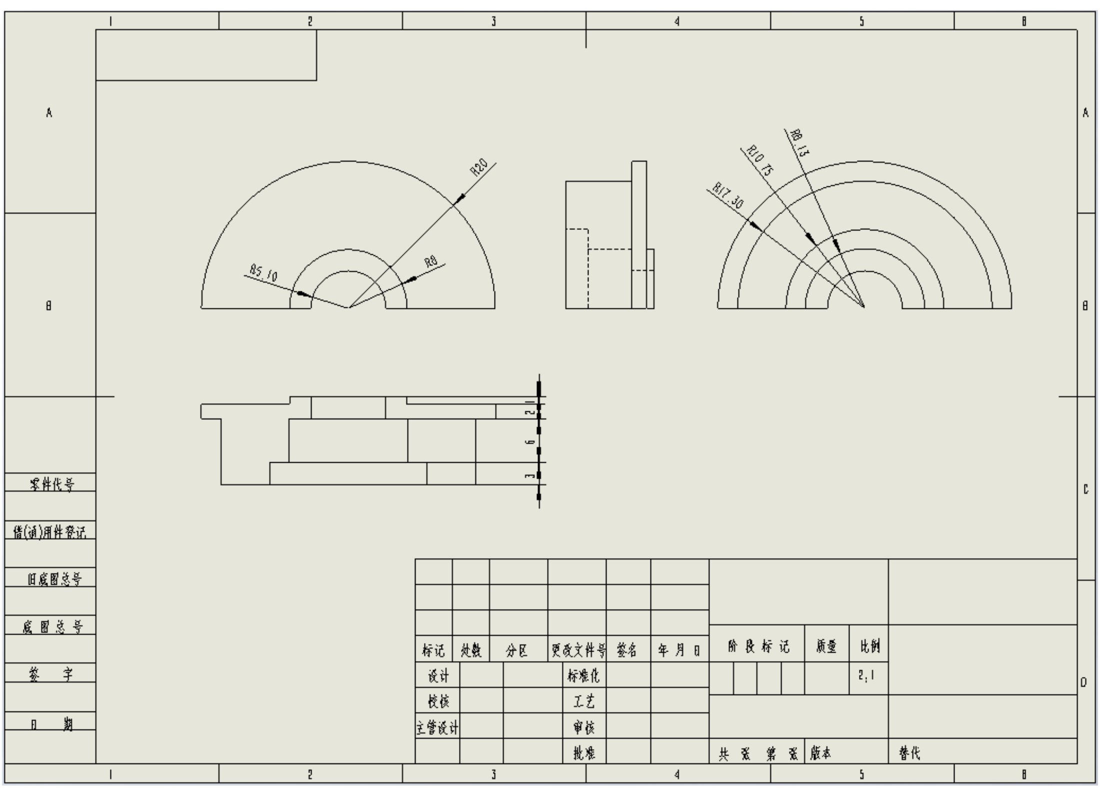

Fig. 52 the part drawing of positioning flake

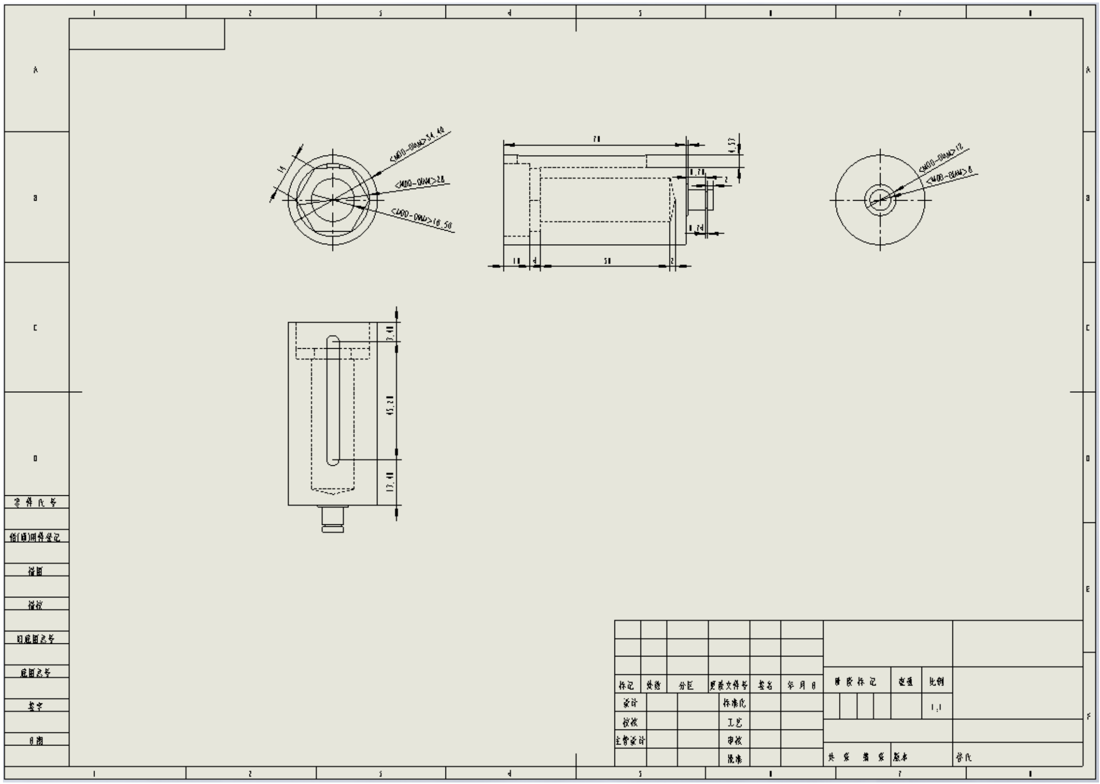

Fig. 53 the part drawing of rail rod

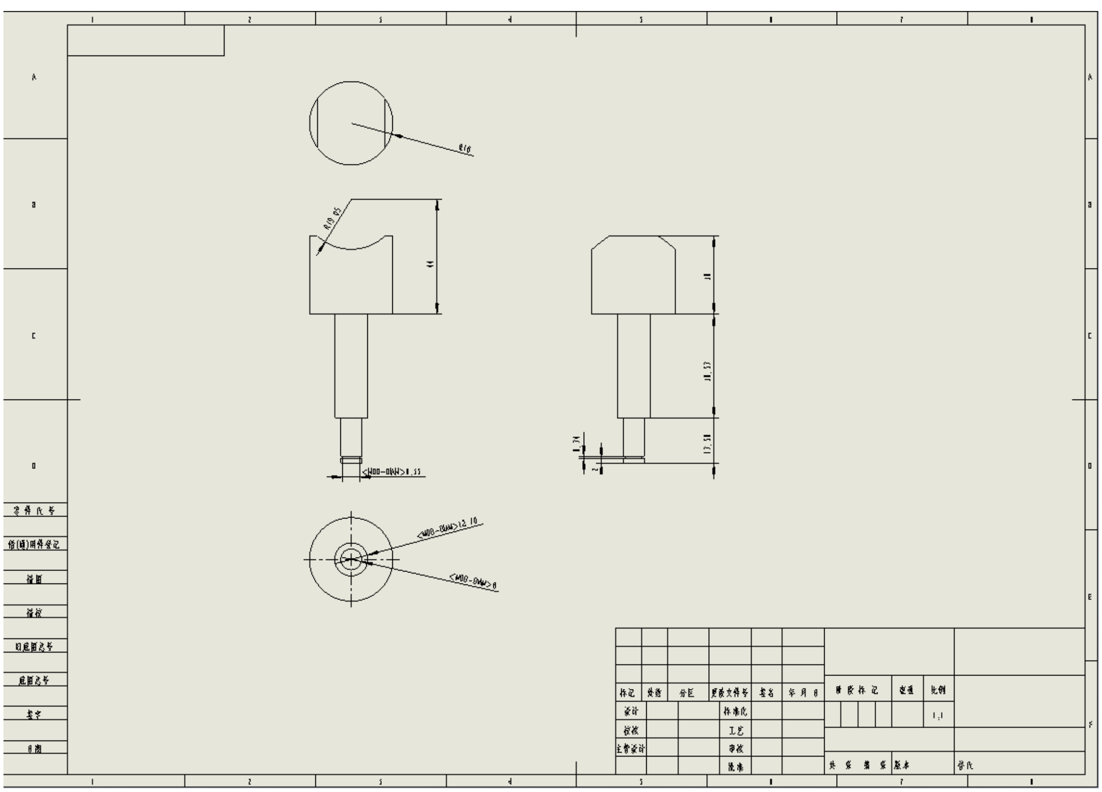

Fig. 54 the part drawing of supporting rod for shell

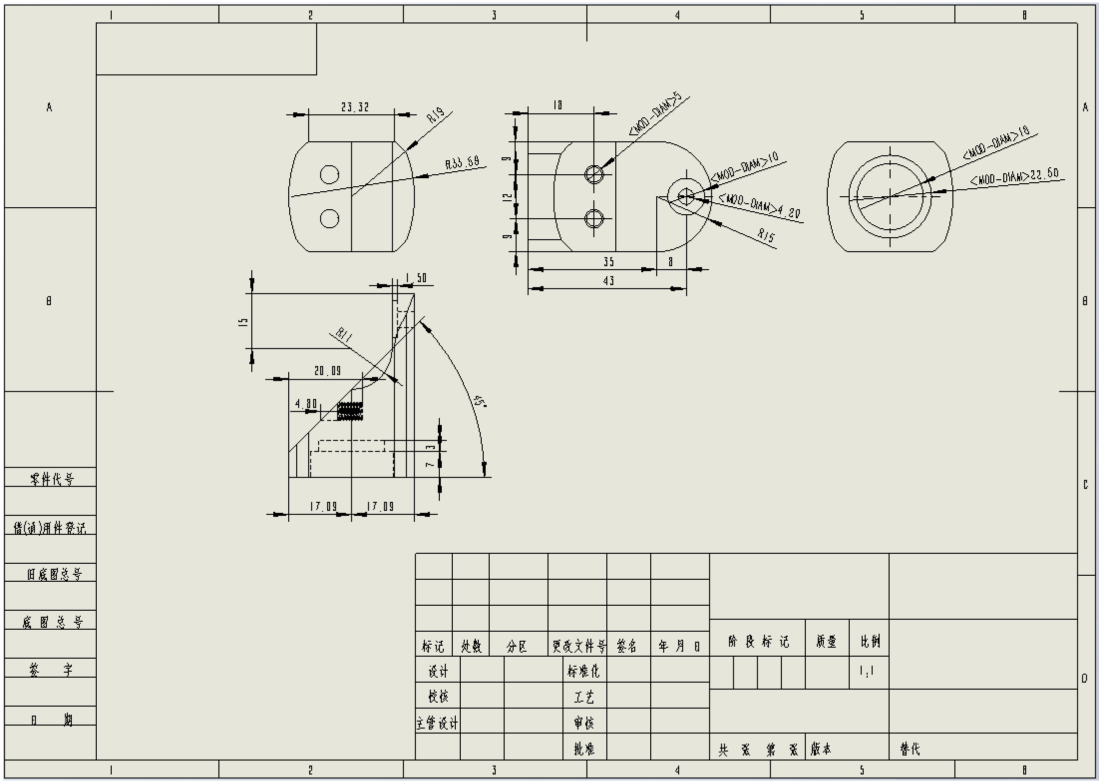

Fig. 55 the part drawing of supporting part 1

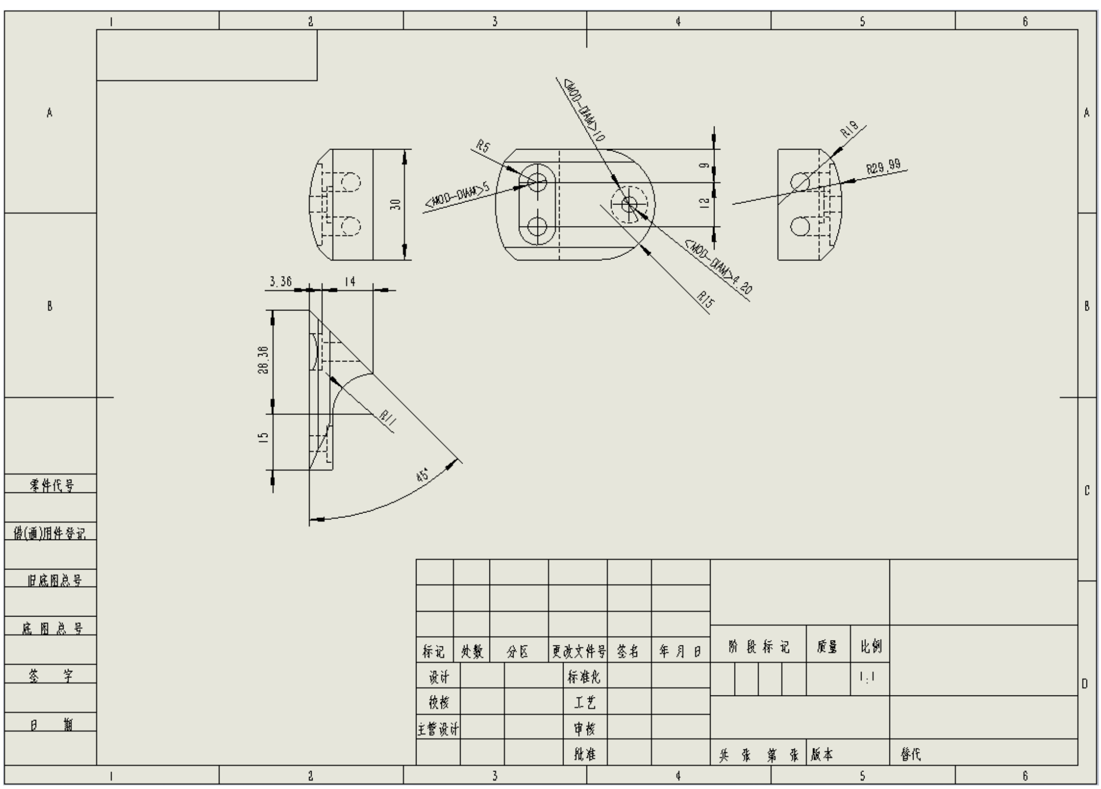

Fig. 56 the part drawing of supporting part 2

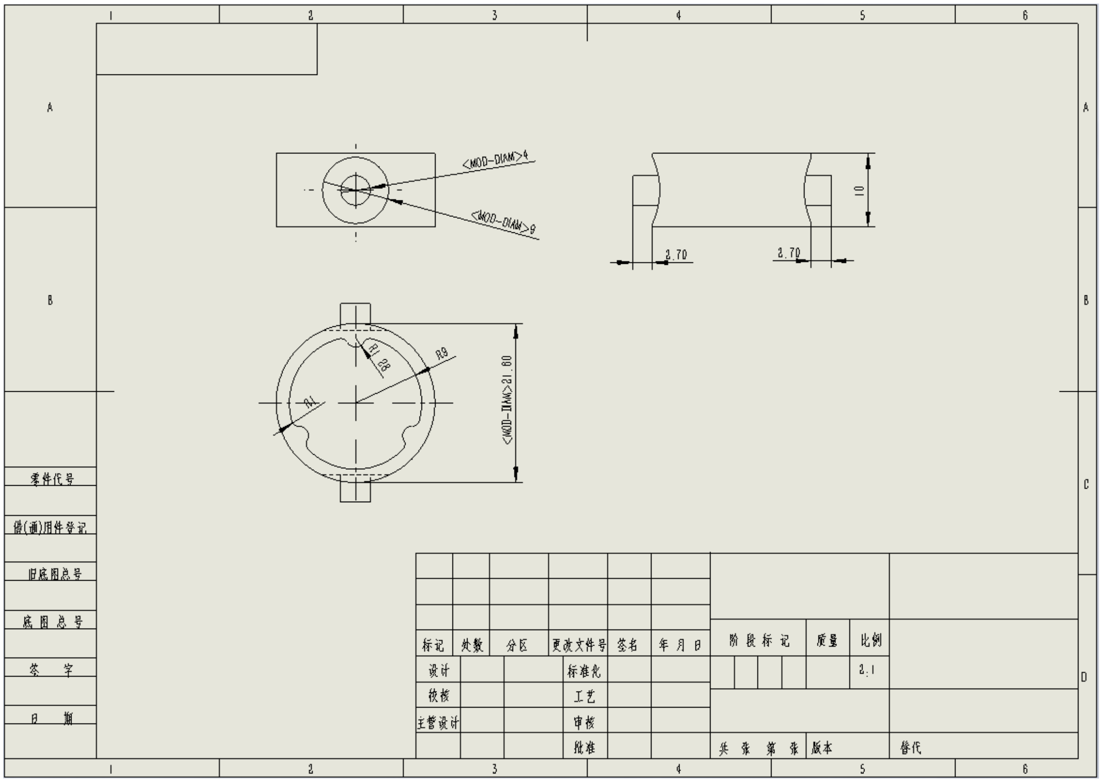

Fig. 57 the part drawing of sleeve

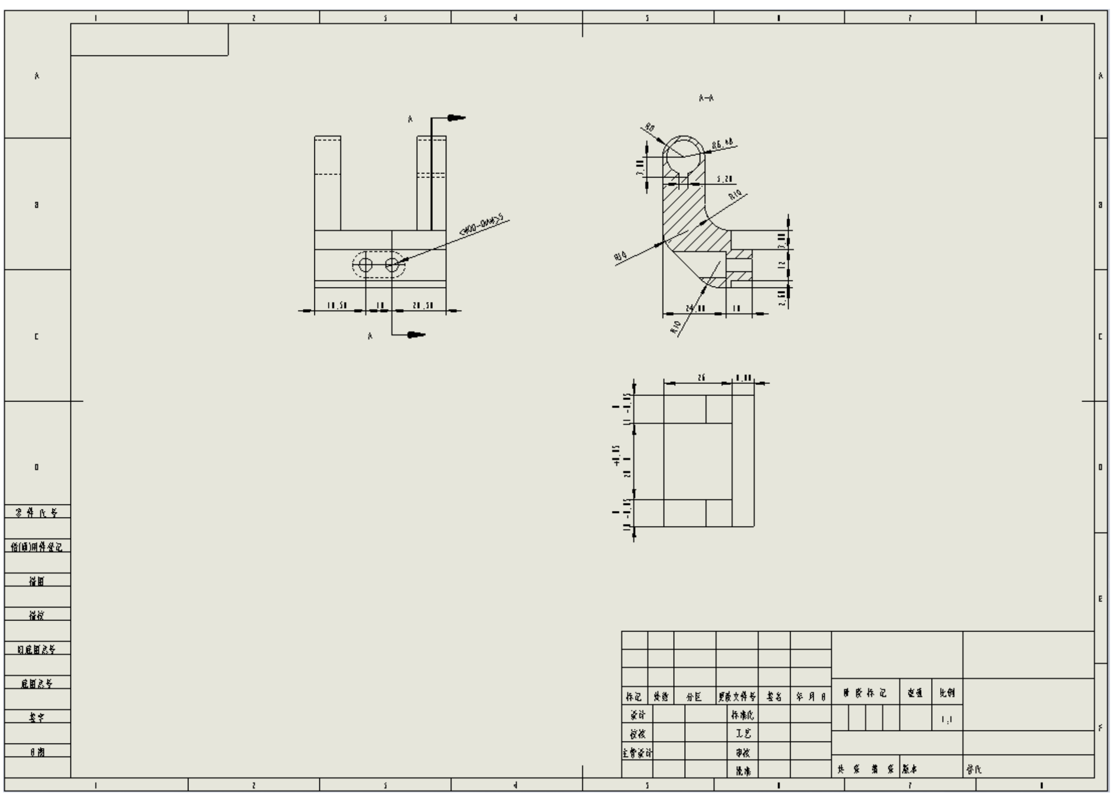

Fig. 58 the part drawing of supporting part for worm

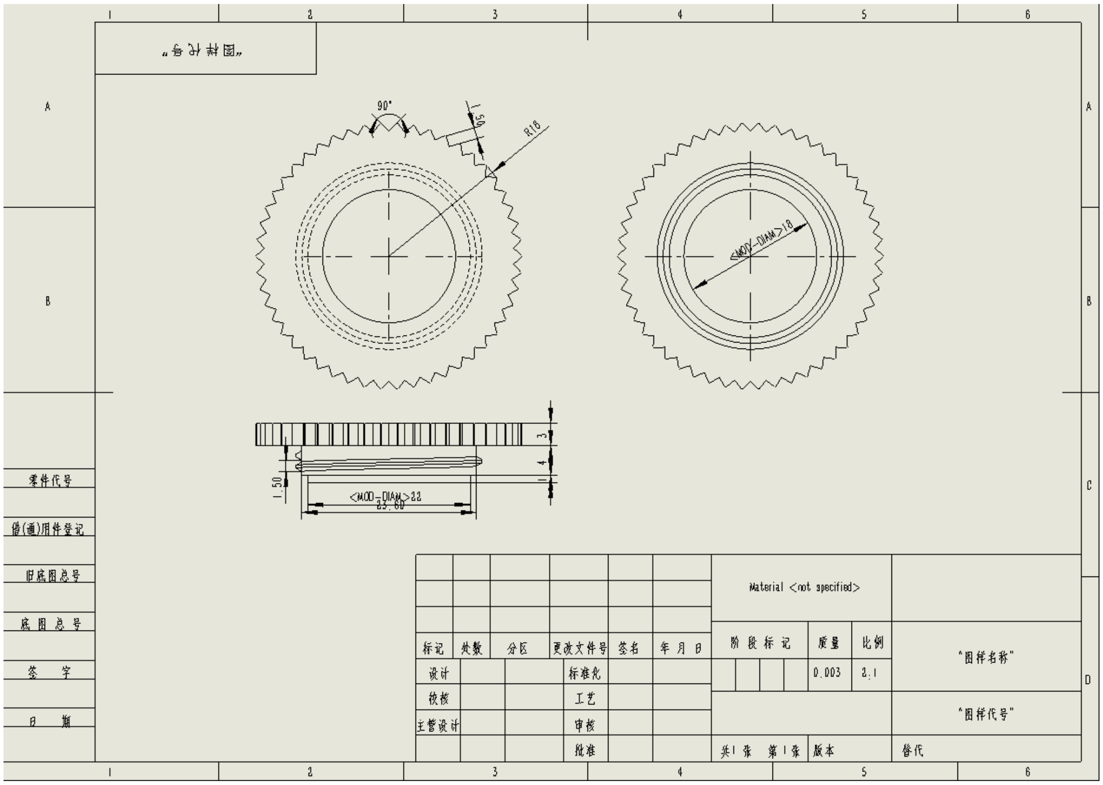

Fig. 59 the part drawing of threaded bearing cover

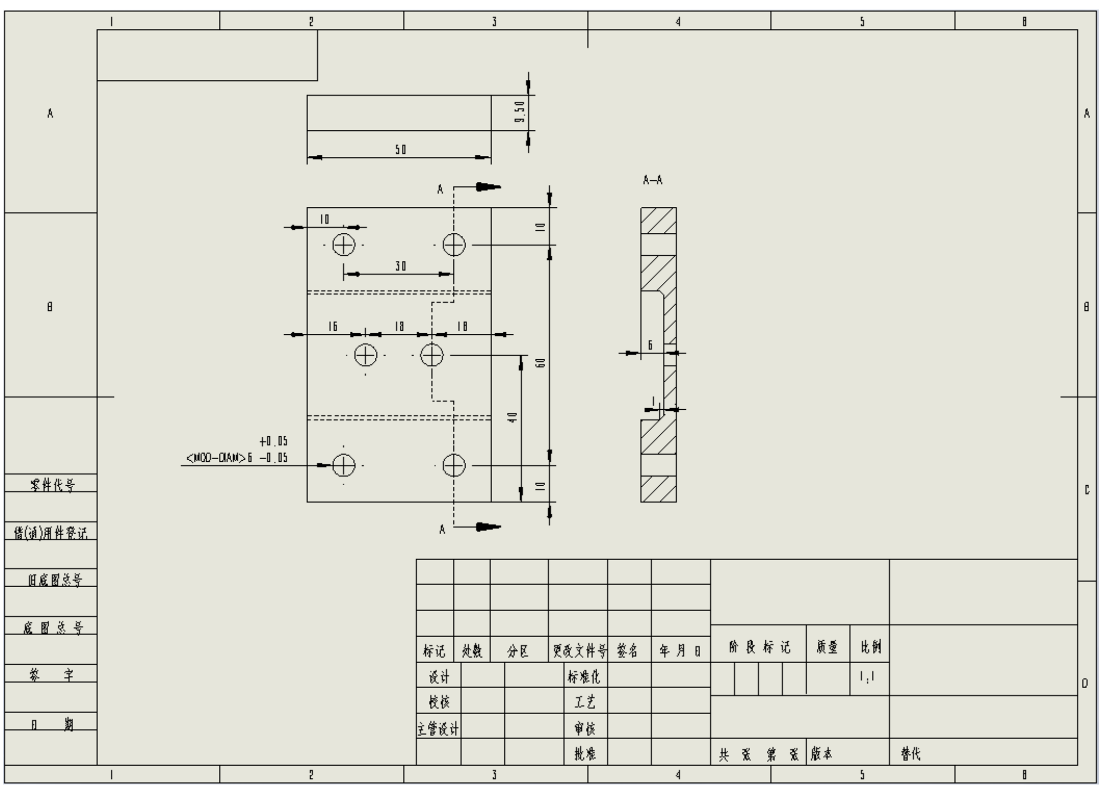

Fig. 60 the part drawing of base

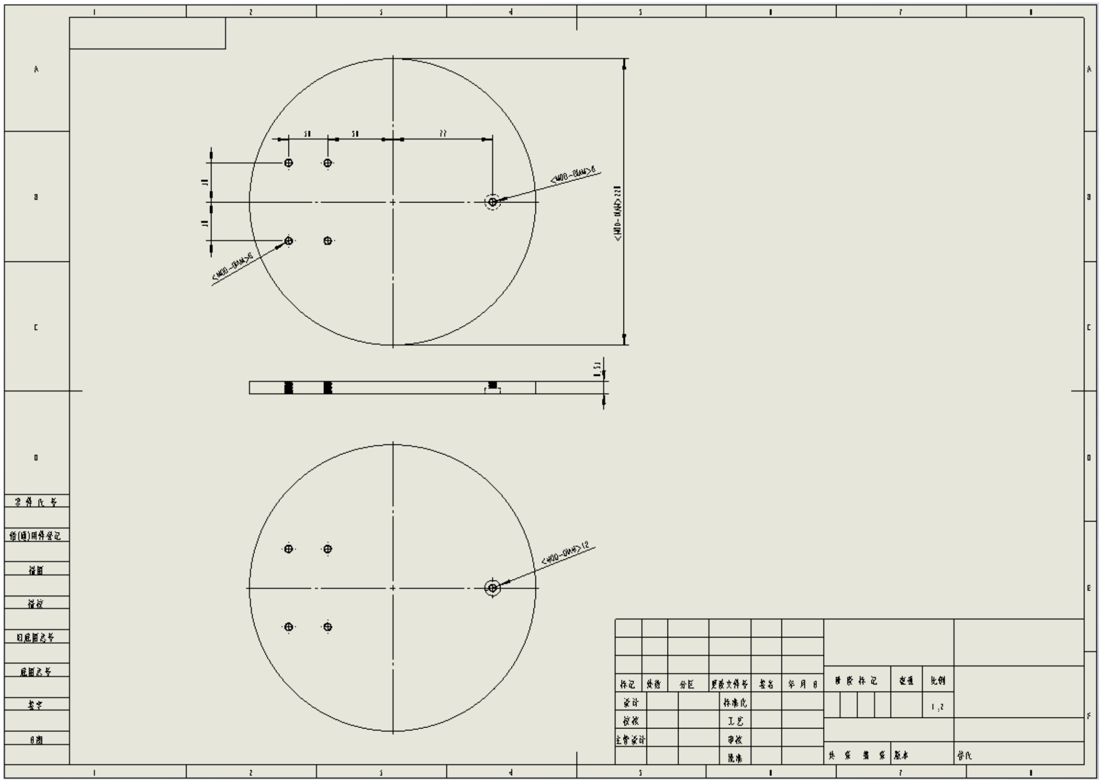

Fig. 61 the part drawing of platform

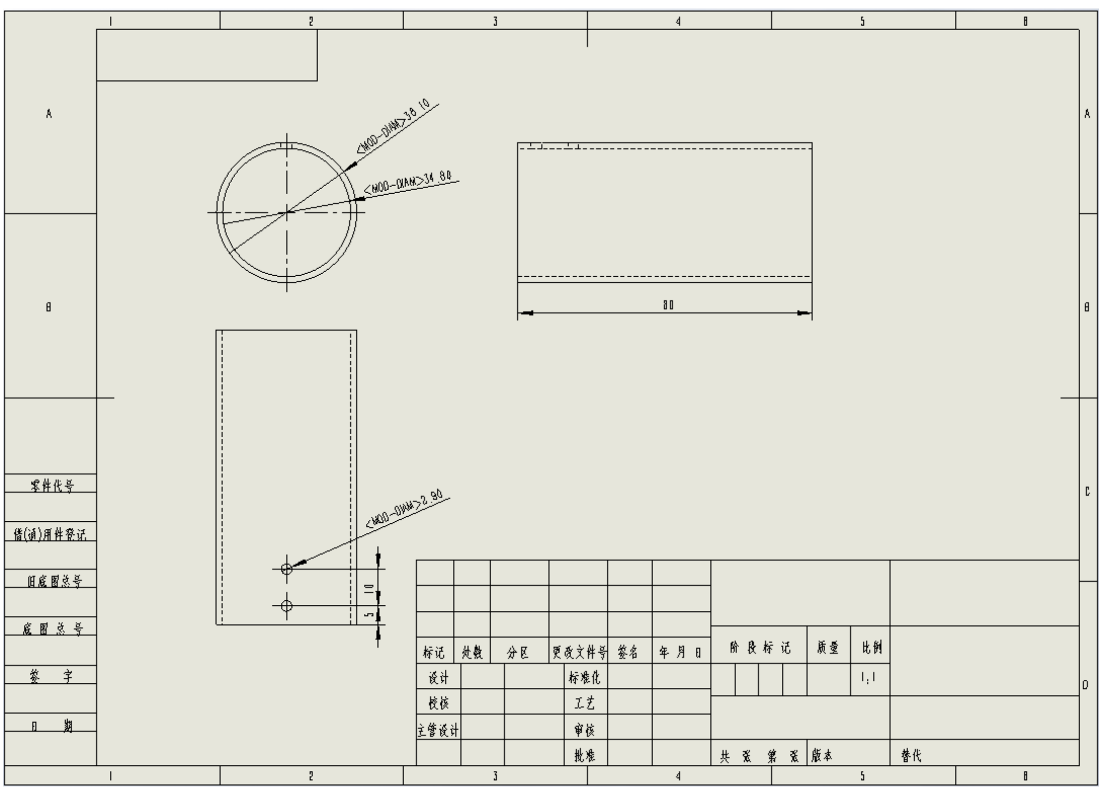

Fig. 62 the part drawing of shell