

## Research on Key Technology of Wire-Bending and Equipment Development

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### Abstract

In this paper, based on the wire-bending process, developing a DC wire-bending machine which is used to bend the wire to any angle. The DC wire-bending machine with a higher integration and production efficiency contained storing mechanism, straightening mechanism, feeding mechanism and wire-bending mechanism. The storing mechanism can be reset by itself without being adjusted manually when the feeding speed is different from the receiving speed of the processing equipment. The wire-bending mechanism for double-heads can achieve asymmetric bending. The clamping device of wire-bending mechanism is more stable and higher rotational accuracy.

**Key words:** DC wire-bending machine; Storing mechanism; Wire-bending mechanism; Clamping device

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### INTRODUCTION

In recent years, with the changes in the global economic environment and the development of Chinese economy, the machinery industry has been growing rapidly in

China. As the common manufacturing process in the field of mechanism, wire-bending is widely used in aerospace, automobile, shipping engineering, machinery and other important fields (Liu, 2011).

Although, China is a large producer of wire products, but its technical equipment is not advanced. Semi-automatic molding equipment is usually used to bend wires. It often caused work pieces failure, as a result of the accuracy of bend wires are not high or residual stress are oversize. And for equipment manufacturing industry, the accuracy requirements of wires with complex shapes become higher and higher, while the product demand is growing (Han, 2010). All of these urges a deeper research and development of the equipment and processing which is used to bend the wires. At present, the advanced equipment for wire forming in China is mainly imported from the technology developed countries such as Germany, France and Japan. While, most Chinese customers give up this way due to the fancy price and inconvenience of maintaining (Ye & Chen, 2009). Currently, Some Chinese manufacturers have also created such equipment, but they all failed to get improvement in these fields about the quality, the efficiency and the level of maintenance. At the same time, the high manufacturing cost makes it lack of market competition (Barlat, 1991).

The common Automatic wire-bending machine includes storing mechanism, straightening mechanism, cutting mechanism, feeding mechanism, bending mechanism, etc.. But we don't have equipment with a higher integration and automatic production lines with high and production efficiency at present (Lu, 2013). The specific reasons are as follows.

Firstly, the traditional bending mechanism uses single-head to bend (Masaki & Akihiko, 2006). But the production efficiency is slow. Currently, there is some bending mechanism with double-heads in the market. But it cannot achieve asymmetric bending, meanwhile, its efficiency is low and maintenance is inconvenient.

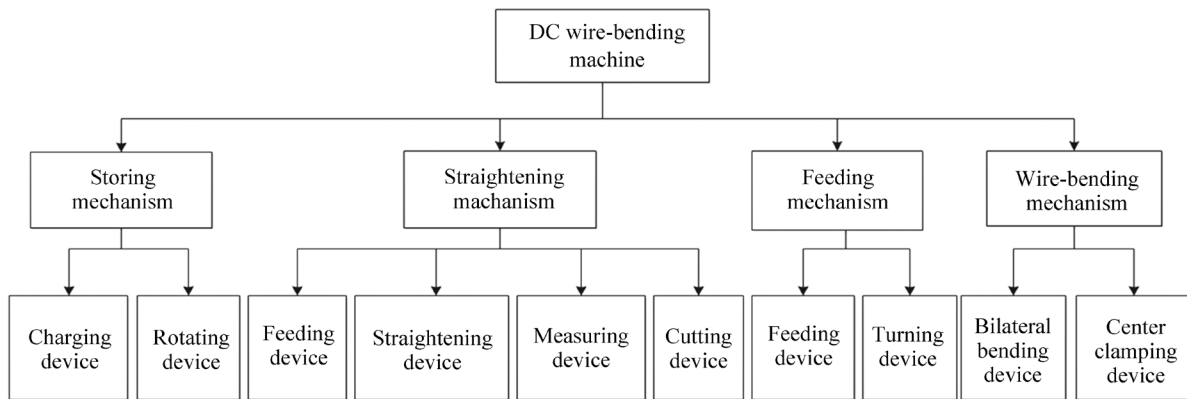
Secondly, the wire-bending machine needs to be equipped with the clamping mechanism which is used to clamp and whirl the wire (Webster, Romano, & Cowan, 2009). However, the existing clamping mechanism is complicated, results in difficult maintenance, unstable powertrain and lower rotational accuracy.

Finally, in the process of the mechanism which is used to store and feed the wire, the wire will be pushed or the tension will be building up when the feeding speed is different from the receiving speed of the processing equipment. In this situation, the mechanism which is unable to reset by itself needs to be adjusted manually. This way not only reduces the production efficiency, but also increases the labor costs.

In order to solve above problems, the research is based on the wire-bending process to develop a DC wire-bending machine which is used to bend the wire to any angle. It is a fully automatic machine with storing, straightening, cutting, feeding and wire-bending mechanism to improve the integration, automation and precision.

## 1. PROCESS ANALYSIS

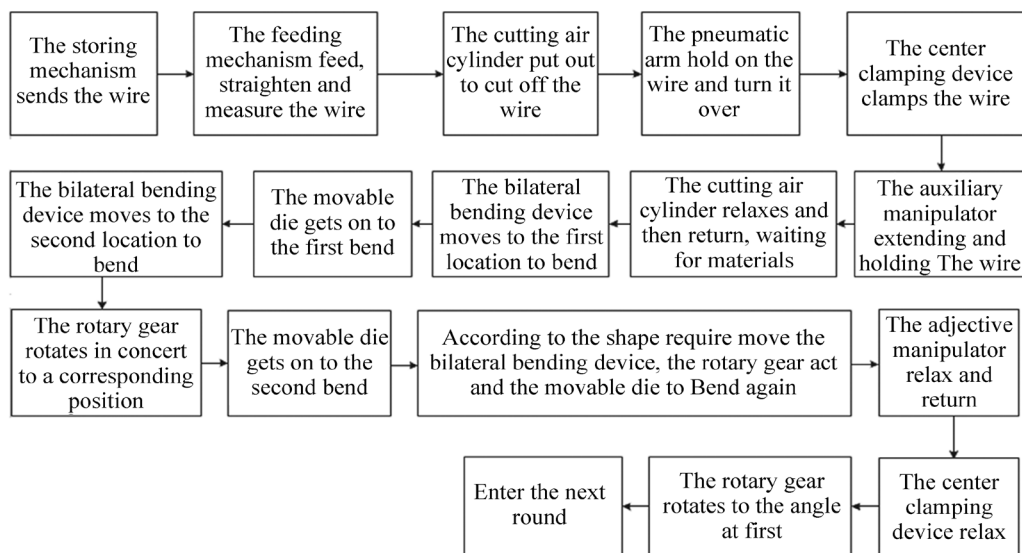
The DC wire-bending machine consists of storing mechanism, straightening mechanism, feeding mechanism and wire-bending mechanism. The structure diagram is shown in Figure 1.



**Figure 1**  
**The Structure of the DC Wire-Bending Machine**

By analyzing the process of bending the metal wires, the bending process can be achieved: at first the wire to be processed will be sent by the storing mechanism, then it will be straightened and measured by the straightening mechanism, after measured the wire will

be cut by the cutting device. Afterwards the wire cut will be transmitted to the bending mechanism to be bend. Finally, the switch device will put the formed wire out of the bending area. The bending process is shown in Figure 2.



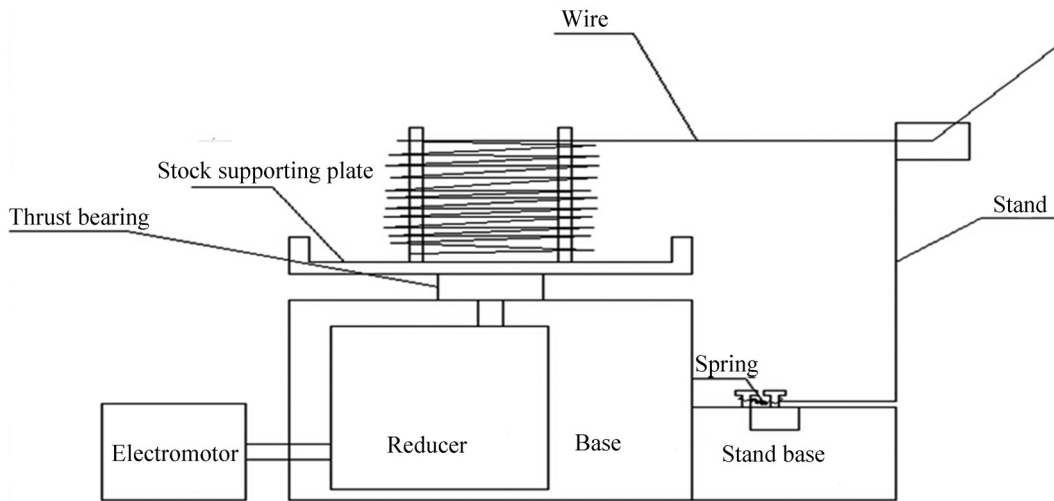
**Figure 2**  
**The Process of the DC Wire-Bending Machine**

## 2. DESIGN CALCULATION

### 2.1 The Design of the Storing Mechanism

The storing mechanism consists of charging device and rotating device. Its role is to store and feeding. Sequence of actions is driving the charging device whirl and feeding wires to the next mechanism, when

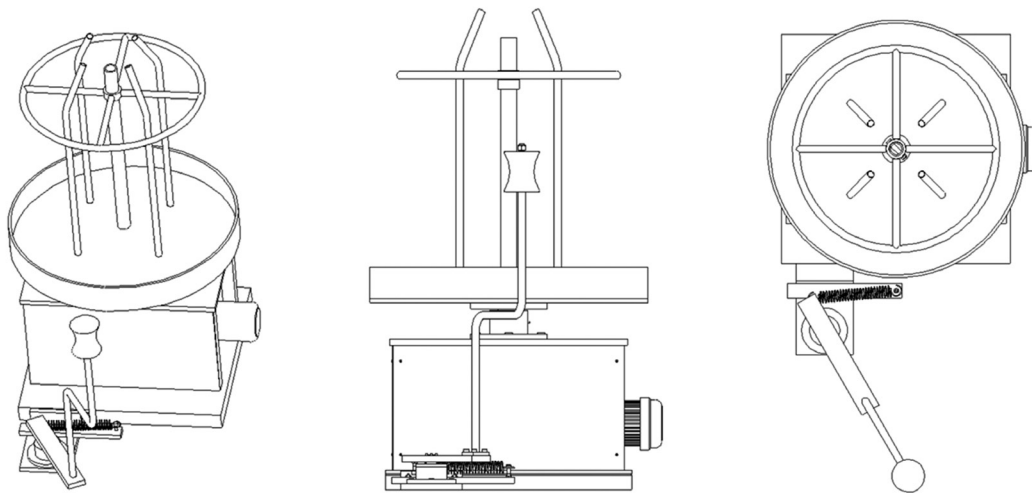
the rotating device gets the signal. As the power of the storing mechanism, the electric motor drive the stock supporting plate by the reducer, it made the wire roll from stock supporting plate to the stand, then to the straightening mechanism to straighten it. The structure diagram of the storing mechanism is shown in Figure 3.



**Figure 3**  
The Structure Diagram of the Storage Module

The stand connects with the stand base by spring tension, and the angle transducer is equipped. Keeping the stand up at a certain angle, when the straightening mechanism feeds the wire, the angle between the stand and the stand base will be changed with the stand swings.

And then the angle transducer will send a signal to the electromotor to drive the stock supporting device to turn. Finally, it will make the storing mechanism push the wire forward. The overall layout diagram of the storing mechanism is shown in Figure 4.



**Figure 4**  
The Overall Layout Diagram of the Storing Mechanism

**Design and Type-Selection.** Known conditions: The storing is plain round bar (hot-rolled low carbon steel wire rods GB/T701-2008), the weight of every

sheaf is 2,400 kg, the structure weight is 600 kg, the aligning speed is 0.15 m/s, the mean radius is 0.3 m, the responding time is 0.5 s.

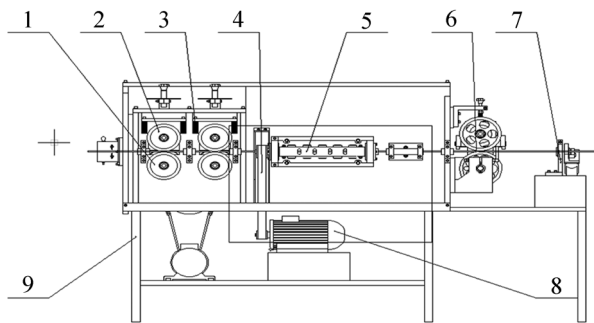
According to calculation, the design information can be achieved:

Angular velocity:  $\omega = 0.15 / 0.3 = 0.5 \text{ r/s}$ ,  
 Revolving speed:  $n = \omega \times 60 / 2\pi = 4.8 \text{ n/min}$ ,  
 Rotational inertia:  $I = mr^2 = 270 \text{ Kg}\cdot\text{m}^2$ ,  
 Required torque:  $M = I \times \beta = 270 \times 0.5 / 0.5 = 270 \text{ N}\cdot\text{m}$ .

Therefore, the stepping-motor whose rated current is 2.0 A is the best choice and hold the torque at 5.25 N·m. At the same time, choose the retarder whose reduction ratio is 60 and the max output torque is 310 N·m.

## 2.2 The Design of the Straightening Mechanism

The straightening mechanism includes: feeding device, straightening device, measuring device and cutting device. The functions of these are to feed, straight, and measure the length of the passed-wire. The action sequence: First the feeding device pushes the wire, then the straightening device straightens the passed-wire by rolling. The measuring device will give back information to the electromotor of the last mechanism to stop feeding the wire, when the length of the passed-wire reaches the goal. It will also give feedback information to the cutting device to cut the wire. The structure diagram of the straightening mechanism is shown in Figure 5.



**Figure 5**  
**The Structure Diagram of the Straightening Mechanism**

1. Feeding roller, 2. Pinch roller, 3. Spring, 4. Synchronous belt, 5. Straightening device, 6. Measuring device, 7. Cutting device, 8. Electricmotor, 9. Frame

### 2.2.1 The Design of the Feeding Device

The function of the feeding device is to push the wire from the storing mechanism to the straightening device. As the capstan, the feeding roller is driven by the electric motor. After the pinch roller finishing the compression, it will cooperate with feeding roller to move the wire to straighten device through the friction force.

**Design and Type-Selection.** Through measuring, the max resistance of the wire can be obtained, and its value is 912.616 N. So the value of feeding resistance can be set at 996 N and the diameter of the pinch roller is 160 mm.

According to calculation, the design information can be achieved:

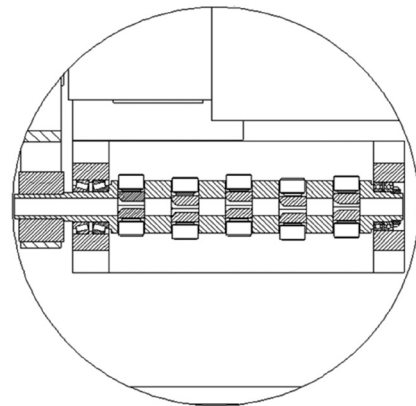
Torque:  $M = 75 \text{ N}\cdot\text{m}$ ,  
 Revolving speed:  $n = 19.1 \text{ n/min}$ ,  
 The pressure on each wheel:  $F_N = 5000 \text{ N}$ ,

The pushing power of each wheel:  $F_s = 250 \text{ N}$ .

Therefore, the servomotor whose rated current is 2.0 A is the best choice and hold the torque at 5.25 N·m. At the same time, choose the retarder whose reduction ratio is 10 and the max output torque is 310 N·m.

### 2.2.2 The Design of the Straightening Device

The substantive role of the straightening device is to apply a high-frequency periodic alternating stress to make the wire exceed the limit of its elastic deformation. The deformation occurs alternatively in the opposite direction. When the alternating deformation is looming to a certain extent, its frequency will gradually decrease to 0 at a slower rate. Then the original bend will be offset. The device of straightening machine adopts the mould straightening mode method. While the material goes forward, the electric motor drives the mould to rotate. This method makes the wire round and revises its straightness. After finishing it, the goal of straightening can be achieved. The drawing of partial enlargement of the straightening device is shown in Figure 6.



**Figure 6**  
**The Drawing of Partial Enlargement of the Straightening Device**

**Design and Type-Selection.** Known conditions:

Those data that measured from the scene:

Straightening torque:  $M = 40 \text{ N}\cdot\text{m}$ ,

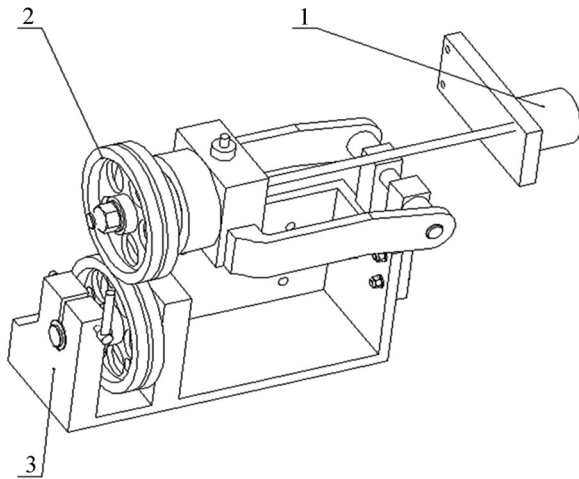
Revolving speed:  $n = 850 \text{ n/min}$ ,

Straightening speed:  $v = 0.15 \text{ m/s}$ .

Therefore, the servomotor with brake whose rated current is 2.0A is the best choice and hold the torque at 5.25 N·m. At the same time, choose the retarder whose reduction ratio is 15 and the max output torque is 55 N·m.

### 2.2.3 The Design of the Measuring Device

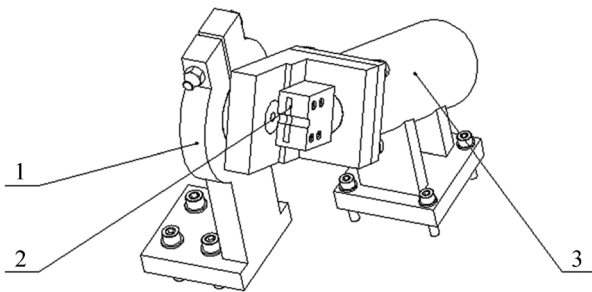
The substantive role of the measuring device is to measure the passed material and give feedback signal to the storing mechanism, the feeding device and the cutting device. The model diagram of the measuring device is shown in Figure 7. When the wire goes through the measuring roller and the pinch roller, the encoder starts to work. If the wire reaches the set length, the device will return signal and then the storing mechanism and the feeding device will stop at once. At the same time, the cutting device will cut the wire.



**Figure 7**  
**The Model Diagram of the Measuring Device**  
 1. Rotary encoder, 2. Pinch roller, 3. Measuring roller

**2.2.4 The Design of the Cutting Device**

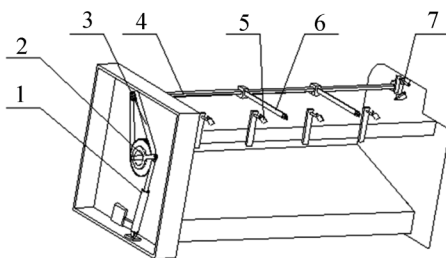
The function of the cutting device is to cut down the measured material when it receives the returning signal from the measuring device. The way is used to cut off oil cylinder through the hydraulic. The model diagram of the cutting device is shown in Figure 8.



**Figure 8**  
**The Model Diagram of the Cutting Device**  
 1. Guiding device, 2. Blade, 3. Cutting oil cylinder

**2.3 The Design of the Feeding Mechanism**

The feeding mechanism includes: lathe bed, feeding device and turn-over device. The function is to hold wire and turn-over to feed. Its action sequence is in the following order: The wire cut off is put into the blank to be machined after cutting. First it will be held by the

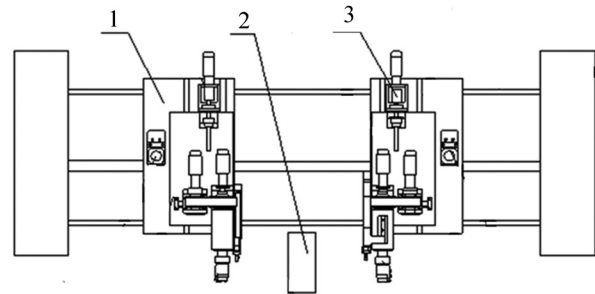


**Figure 9**  
**The Model Diagram of the Feeding Mechanism**  
 1. Cylinder, 2. Power arm, 3. Driving belt, 4. Hexagonal steel, 5. Feeding stand, 6. Manipulator, 7. Buffer

feeding device, and then it will be sent to the center clamping device after turned over by the turn-over device. The model diagram of the feeding mechanism is shown in Figure 9.

**2.4 The Design of the Wire-Bending Mechanism**

The wire-bending mechanism includes the bilateral bending device on the left and right and the center clamping device. Its function is to make bilateral bending device and the center clamping device joint to bend the wire. The action sequence of the mechanism is in the following order: First, the center clamping device will clamp the wire, then bilateral bending device move to the first location to start the first bend. Second, the rotate gear of the center clamping device will rotate to the perspective of presupposition, then the bilateral bending device move to the next location to bend the wire again. Third, the rotate gear once again rotates to the perspective of presupposition and continues to loop until the bend finished. After finishing it, the switch device will put the wire out of the bending area. The front view of the link bend module is shown in Figure 10.



**Figure 10**  
**The Front View of the Wire-Bending Mechanism**  
 1. The left side of the bilateral bending device, 2. Center clamping device, 3. The right side of the bilateral bending device

**2.4.1 The Design of Bilateral Bend Device**

The bilateral bending device include the holding device, the movable die, the stationary die, the sliding seat, the synchronous pulley retarder, the horizontal driving electromotor, the vertical driving electromotor, the electromotor of movable die and the electric motor of stationary die. The structural diagram of the left side of the bilateral bending device is shown in Figure 11.

**Design and Type-Selection**

a) Electromotor of stationary die

Known conditions:

Material: steel 20,

The nominal diameter of steel: Φ8.

According to calculation:

The needed moment to reach the yield limit:  
 $M_0 = K_1 \times \delta_s \times w = 21 \text{ N}\cdot\text{m}$ .

The needed moment after strain hardening:  
 $M = [K_1 + K_2 \times d / (d+r)] \times \delta_s \times w = 24.6 \text{ N}\cdot\text{m}$ .

The needed moment to bend:  $M_1 = [(M_0 + M) / 2] \times K = 24 \text{ N}\cdot\text{m}$ .



Therefore, the servomotor with brake whose rated power is 400 W and rated speed is 3,000 r/min is the best choice. At the same time, choose the retarder whose reduction ratio is 25.

b) The horizontal driving electromotor

Known conditions: The responding time is 0.5 s, the movement speed is 0.5 m/s, the moving mass is 650 kg; parameters of the selected pinion and rack mechanism: The

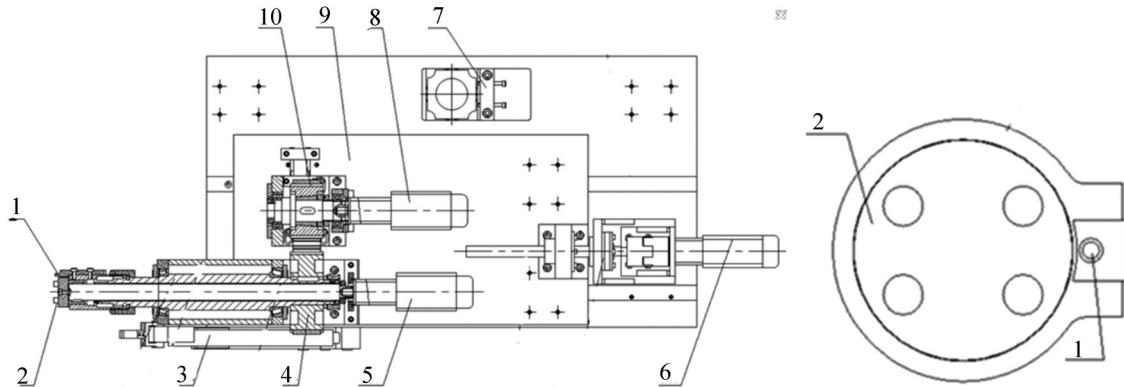
modulus is 2, the teeth is 30, the pitch diameter is 60 mm.

According to calculation:

$$\text{Starting thrust: } F = m \times a + m \times g \times \sin(20^\circ) = 872.3 \text{ N,}$$

$$\text{Starting torque: } M = F \times r = 26.2 \text{ N}\cdot\text{m.}$$

Therefore, the servomotor whose rated power is 900W and rated speed is 1000r/min is the best choice. At the same time, choose the retarder whose reduction ratio is 6.



**Figure 11**  
**The Structural Diagram of the Left Side of the Bilateral Bending Device**

1. Movable die, 2. Stationary die, 3. Holding device, 4. Driven synchronous pulley, 5. Electomotor of stationary die, 6. Vertical driving electromotor, 7. Horizontal driving electromotor, 8. Electomotor of movable die, 9. Vertical sliding seat, 10. Driving synchronous pulley

c) The longitudinal drive motor

Known conditions:

The responding time is 0.5 s; the movement speed is 0.25 m/s; the moving mass is 650 kg; parameters of the ball screw that is selected: the nominal outside diameter is 20 mm, the lead is 20 mm, the stroke is 150 mm, the rotating speed is 750 n/min, the maximum moving mass is 170 kg.

According to calculation:

$$\text{Starting thrust: } F = m \times a + m \times g \times \sin(20^\circ) = 663 \text{ N,}$$

$$\text{Starting torque: } M = 4.7 \text{ N}\cdot\text{m.}$$

Therefore, the servo motor with brake whose rated power is 400 W and rated speed is 3,000 r/min is the best choice. At the same time, choose the retarder whose reduction ratio is 4.

d) The vertical sliding seat

Therefore, the air cylinder whose travel is 145 mm, working pressure is 0.7 MPa and cylinder diameter is 15 mm is the best choice.

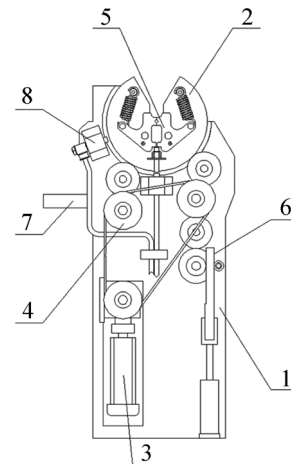
**2.4.2 The Design of Center Clamping Device**

The center clamping device includes: clamp device, transmission device and the switch device. The front view of the center clamping device is shown in Figure 12.

**Design and Type-Selection**

a) Rotate gear plate

Known conditions: The mass of the rotate gear plate is 12.13 kg, the distance between the center and the mass center is 19.5 mm, and the speed accelerated to 30 r/min in 0.1 s. The range of the positive and negative rotation is



**Figure 12**  
**The Front View of the Center Clamping Device**

1. Box, 2. Rotate gear plate, 3. Driving device, 4. Transmission device, 5. Clamp device, 6. Switch device, 7. Switch arm, 8. Switch oil cylinder

360°. The pitch diameter of the gear 1 that meshes with the center gear is 80 mm; the pinion diameter of the gear 2 that meshes with the gear 1 is 60 mm; the pinion diameter of the center gear is 220 mm. According to calculation:

$$\text{Starting torque: } T = I \times B = 0.4 \text{ kN}\cdot\text{m.}$$

Therefore, the servomotor with brake whose rated power is 400 W and rated speed is 3,000 r/min is the best choice and choose the retarder whose reduction ratio is 20.

b) Transmission device

Known conditions: the recommended preload is 65N; the max rotation rate is 30 r/min; the transmission ratio is 110; the weight is 12.13 kg; the friction coefficient is 0.2; the distance of the center and the mass center is 19.5 mm, the speed is accelerated to 30 r/min in 0.1s.

According to calculation:

Friction moment:  $M = m \cdot g \cdot \mu \cdot r = 0.7 \text{ N}\cdot\text{m}$ ,

Torque:  $T = I \cdot \beta = 2.5 \text{ N}\cdot\text{m}$ ,

The needed power with the max angular velocity:  $P = T \times \omega = 10 \text{ w}$ .

So the synchronous pulley is selected. The two pulleys have the same diameter and the pitch diameter is 75 mm. There are two closed rings on two sides. The thickness of the pulley is 17 mm, its type is XL (light load and low speed type); the electricmotor whose rated power should be 100 W, the rated speed is 3,000 r/min; and the retarder whose reduction ratio should be 30.

c) Switch device

Known conditions: the speed to switch is 60 r/min, the dial arm rotates over 180°; parameters of the selected pinion and rack mechanism: the module is 2, the pressure angle is 20°, and the pitch diameter is 40 mm, the rack travel is 166 mm.

So the air cylinder is selected. Its travel is 80 mm, working pressure is 0.7 MPa, and the thrust is 455 N.

**CONCLUSION**

Based on the wire-bending process, the paper developing a DC wire-bending machine which is used to bend the wire to any angle. The DC wire-bending machine with a higher integration and production efficiency contained storing mechanism, straightening mechanism, feeding mechanism and wire-bending mechanism.

Firstly, the storing mechanism can reset by itself without being adjusted manually when the feeding speed is different from the receiving speed of the processing equipment. The angle between the stand and the stand

base will be changed when the straightening mechanism feeds the wire, then the angle transducer will send a signal to the electromotor to drive the stock supporting device to turn. Make the storing mechanism push the wire forward to the straightening mechanism.

Secondly, the bilateral bending device and the center clamping device of the wire-bending mechanism joint to bend the wire. The bilateral bending device with double-heads can achieve asymmetric bending on two sides at the same time to bend the wire to any angle.

Finally, the rotate gear in the center clamping device will rotate to the perspective of presupposition makes the wire-bending mechanism more stable and higher rotational accuracy.

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