Research on the method of skateboard edge grinding by combination of robot and pneumatic constant force grinding device

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Abstract. The paper presents a method of robot skateboard edging grinding based on pneumatic constant force device. To solve the problem of modeling and complex algorithm of robot end active compliance control during the grinding process, a hybrid position/force control is proposed by controlling position and force separately. That is, a kind of 2 degrees of freedom pneumatic constant force grinding device is designed to realize the constant force control in the horizontal and vertical directions, while a robot is used only for position control. Then a fuzzy PID control algorithm is proposed for smooth grinding based on the dynamic modeling of the grinding device. Experiments show that the use of fuzzy PID can effectively improve the dynamic adjustment performance of the pneumatic constant force grinding system and reduce the steady-state error. Compared with normal PID, fuzzy PID reduces the step response adjustment time of the grinding system from 400ms to within 200ms. In addition, when the constant force control is disturbed, the response adjustment time is less than 100ms and there is no oscillation, and the standard deviation of the grinding force is within 1N, which has good robustness and fulfills the requirements of edging control.

1. Introduction

Traditional grinding is a manual work, which is time-consuming, labor-intensive and inefficient. At the same time, the health of workers is affected by noise and dust of the industrial site [1]. With the rapid development of industrial robot technology, grinding processing technology by the robot becomes a key research direction in the field of mold processing [2]. For those operations such as grinding and polishing, not only the position is required to achieve the desired accuracy, but also the contact force between the robot and the workpiece needs to be controlled. Therefore, passive compliance or active compliance is used to meet these requirements [3-5]. The disadvantage of passive compliance is limited use range and poor adaptability, while the advantage of active compliance is high control precision and strong adaptability. Therefore, active compliance has become a hotspot in scientific research and engineering applications [6].

For active compliance control, researchers have proposed many effective control methods, among which the most popular methods are hybrid position/force control and impedance control. Jung S et al. [7] proposed neural network force control to compensate for uncertainty of the robot dynamics and unknown environment; in the case of uncertain model and interference. Xu Q et al. [8] proposed a sliding mode control method based on discrete time adaptive gain, which realized the precision of the
bimorph micro-gripper Force/position control. JKaramali R A et al. [9] solved the problem of hybrid position/force control robots in an uncertain environment by combining fuzzy control with traditional sliding mode control. Li Zhengyi et al. [10-11] presented an adaptive fuzzy impedance control method by estimating the environmental stiffness and establishing a neural network, which improved the dynamic adjustment performance of hybrid position/force control robots. The above literature uses different control methods to achieve active compliance control of the robot. Although a good control effect can be obtained in the end, there are problems that exist in commonly modeling difficulty and complex control algorithms, which limits its use in industrial applications. Therefore, many scholars also conducted researches on pneumatic servo systems. Qiu Z C et al. [12] designed an adaptive fuzzy control algorithm based on the delay compensation algorithm and low-pass filter, which significantly improved the control performance of the cylinder. Wang Z M et al. [13] presented a fuzzy PID controller, which solved the problem of difficult tuning and poor performance of conventional PID in pneumatic servo systems.

In this paper, the force control and position control of the grinding process are achieved separately by and the robot and the pneumatic constant force grinding device, which is to solve the problems of force-position coupling in active compliance control. At the same time, a fuzzy PID control strategy that is to realize the constant force edging of the skateboard and obtains good results, which is proposed for solving the problems of large modeling deviation, low control accuracy and slow response speed of the pneumatic servo control system.

2. Constant force grinding device design and dynamic modeling

2.1. Mechanical design of constant force grinding device
The constant force grinding device is shown in Figure 1, which consists of two horizontal and vertical modules. For vertical modules, the industrial woodcutting machine is installed on the flip-chip board, which is connected with the middle plate through linear bearings, and the front end of the cylinder piston rod is connected with the force sensor, and the displacement sensor is fixed on the side plate. The displacement sensor and the force sensor are fixed on the flip-chip board through the fish-eye connector and the connecting seat. The main components of the horizontal module are the same as the vertical direction. The horizontal push plate is connected with the middle plate and the moving bottom plate. The front end of the cylinder piston rod is connected with the force sensor, and the displacement sensor is fixed on the bottom plate. The displacement sensor and the force sensor are connected with the lateral push plate through the connecting seat and the fish-eye connector. When working, the vertical and horizontal cylinders output thrust to drive the two modules to move vertically and horizontally.

![Figure 1. Constant force grinding device.](image)

(1) Force Sensor, (2) Horizontal Push Plate, (3) Industrial Woodcutting Machine, (4) Flip-chip Board, (5) Force Sensor, (6) Displacement Sensor, (7) Side Plate, (8) Linear Bearing, (9) Bottom Plate, (10) Double-acting Cylinder, (11) Middle Plate, (12) Moving Bottom Plate, (13) Fish-eye Connector and Connecting Seat, (14) Displacement Sensor, (15) Double-acting Cylinder.
The pneumatic circuit schematic diagram of the constant force grinding system is shown in Figure 2. It consists of double-acting cylinder, force sensor, displacement sensor, electric proportional valve, pneumatic triple parts (air pressure reducing valve, filter, oil mist device), air source, amplifier, PMAC controller (produced by Delta Tau, USA) and industrial control machine composition.

Figure 2. Schematic diagram of pneumatic circuit.

(1) Air Source, (3) (5) (16) Flow Meter, (2) Pneumatic Triple Parts, (4) (11) (15) (22) Electric Proportional Valve, (6) (17) Pressure Gauge, (7) (18) Double-acting Cylinder, (8) (19) Force Sensor, (9) (20) Displacement Sensor, (10) (21) Load, (12) Amplifier, (13) PMAC Controller, (14) PC.

The basic working principle is as follows: (1) During grinding process, a constant voltage is exerted on the electric proportional valve connected to the front chamber of the cylinder, so that the gas pressure in the front chamber of the cylinder remains being constant. (2) The pressure sensor feeds back the grinding force to the controller in real time, then the controller compares the feedback actual grinding force with the expected grinding force. (3) According to the grinding force deviation, the fuzzy PID control algorithm adjusts the electric proportional valve connected with the cylinder back cavity according to the grinding force deviation. When the actual grinding force is greater than the expected grinding force, the exhaust port of the electric proportional valve connected with the cylinder back cavity is opened to reduce the cylinder back cavity pressure. On the contrary, the air inlet is opened to increase the pressure in the back chamber, and finally realizes constant force tracking of the polished workpiece. According to the mechanical structure and pneumatic circuit schematic diagram of the grinding device, the main actuator double-acting cylinder and electric proportional valve are modeled, and the electric proportional valve flow equation, the cylinder mass flow continuity equation and the force balance equation are analyzed.

2.2. Cylinder dynamics modeling
The gas flow principle diagram of the grinding device is shown in Figure 3. The input pressure of the electric proportional valve is $P_a$, the outlet pressure is $P_d$. $P_d$ is dynamically adjusted by the size of the control signal $u$. The gas acts on the cylinder through the air pipe to generate an output force $F_n$, and finally output grinding force $F_c$.

Figure 3. Principle diagram of gas circulation.
The schematic diagram of the horizontal and vertical cylinders of the grinding device is shown in Figure 4. This paper makes the following assumptions [14] to solve the problem of modeling difficulties caused by the nonlinearity of the pneumatic system:

- Working air is an ideal gas, and its flow process is an adiabatic isentropic process.
- The working gas temperature and pressure are constant.
- Cylinder leakage is not considered.

Figure 4. Schematic diagram of valve-controlled cylinder.

The expression of the dynamic model of the vertical cylinder shown in Figure 4 is:

\[ M \dot{y} + \beta \dot{y} + F_{fy} + F_{ny} = p_{ay} A_{ay} - p_{by} A_{by} \]  

(1)

Where:

- \( F_{ny} \) is the output grinding force,
- \( F_{fy} \) is the friction force,
- \( M \) is the sum of the mass of the cylinder piston and the external connection,
- \( \beta \) is the viscous damping coefficient,
- \( y \) is the cylinder piston displacement,
- \( p_{ay} \) and \( A_{ay} \) are the pressure and area of the cylinder front cavity respectively,
- \( p_{by} \) and \( A_{by} \) are the pressure and area of the cylinder back cavity respectively.

Equation (1) is written in incremental form to get:

\[ (M \dot{y} + \beta \dot{y}) \Delta y(s) + \Delta F_{fy}(s) + \Delta F_{ny}(s) = \Delta p_{ay}(s) A_{ay} - \Delta p_{by}(s) A_{by} \]  

(2)

The gravity received by the cylinder is \( p_{oy} A_{oy} \), and the grinding force acting on the skateboard is:

\[ F_{cy} = F_{ny} - M_y a_y - M_y g = F_{ny} - M_y \ddot{y} - p_{oy} A_{oy} \]  

(3)

Equation (3) performs Laplace transform to get:

\[ \Delta F_{cy}(s) = \Delta F_{ny}(s) - M_y s^2 \Delta y(s) \]  

(4)

During the grinding process, the pressure of the cylinder \( by \) cavity remains unchanged, ignoring the cylinder friction \( F_{fy} \). Combine Equation (2) Equation (4) to get:

\[ (2M_y s^2 + \beta s) \Delta y(s) + \Delta F_{cy}(s) = \Delta p_{ay}(s) A_{ay} \]  

(5)

When the grinding tool is in contact with the skateboard, the force is \( F_{cy} \), and the displacement is \( y \). The environment equivalent stiffness is set to \( K_{cy} \), then:

\[ \Delta F_{cy}(s) = K_{cy} \Delta y(s) \]  

(6)

Combine Equation (5) Equation (6) to get:

\[ \frac{\Delta F_{cy}(s)}{\Delta p_{ay}(s)} = \frac{K_{cy} A_{ay}}{2M_y s^2 + \beta s + K_{cy}} \]  

(7)
According to the law of conservation of mass, the air mass \( q_{ma} \) flowing into and out of the \( ay \) cavity of the cylinder is equal to the rate of change of the air mass \( m_{a} \) of the \( ay \) cavity of the cylinder.

\[
q_{ma} = \frac{dm_{a}}{dt} = \frac{d(\rho_{a}v_{a})}{dt} \tag{8}
\]

The gas ideal state equation \( p_{a} = \rho_{a}RT_{a} \) is brought into Equation (8) to obtain \( q_{ma} \):

\[
q_{ma} = \frac{1}{RT_{a}} \left( V_{a} \frac{dp_{a}}{dt} + p_{a} \frac{dv_{a}}{dt} - \frac{v_{ap}_{a} dT_{a}}{T_{a}} \right) \tag{9}
\]

Assuming that the process temperature \( T_{a} \) and the starting temperature \( T_{o} \) satisfy the adiabatic process, then:

\[
T_{a} = T_{o}(p_{a} / p_{o})^{k-1} \tag{10}
\]

In the formula, \( k \) is the adiabatic index, ignoring the vertical fretting changes, taking the derivative of Equation (10) into Equation (9) to get:

\[
q_{ma} = \frac{1}{RT_{a}} \frac{V_{a}}{k} \frac{dp_{a}}{dt} \tag{11}
\]

Equation (8) \( V_{a} \) is approximately equal to \( A_{a}y \). Equation (11) is written in incremental form to get:

\[
q_{ma} = \frac{1}{RT_{a}} \frac{V_{a}}{k} s\Delta p_{a}(s) \tag{12}
\]

### 2.3. Dynamic modeling of electric proportional valve

The gas flow equation of the electric proportional valve can be equivalent to a one-dimensional isentropic flow process, using the Sanvile flow formula:

\[
Q_{y} = \begin{cases} 
\frac{C_{y}p_{ay}A_{y}(x)}{\sqrt{T}} & \frac{k}{R} \frac{2}{k-1} - \frac{p_{a}}{p_{o}} \frac{k+1}{k} > \frac{p_{ay}}{p_{o}} > 0.518 \\
\frac{C_{y}p_{ay}A_{y}(x)}{\sqrt{T}} & \sqrt{\frac{k}{R} \frac{2}{k-1}} \frac{p_{a}}{p_{o}} \frac{k+1}{k-1} \leq \frac{p_{ay}}{p_{o}} \leq 0.518 
\end{cases} \tag{13}
\]

Here, \( Q_{y} \) is the flow through the valve port, \( p_{ay} \) is the pressure of the air supply port, \( p_{oy} \) is the pressure of the air outlet, \( A_{y}(x) \) is the minimum cross-sectional area of the valve's orifice, and \( C_{y} \) is the constant coefficient of the orifice flow of the proportional valve. \( T \) is the adiabatic temperature. The actual grinding requires a larger grinding force, so the air outlet pressure is higher. The air pressure at the air supply port is set to 0.7MP through the proportional valve, and the air pressure at the air outlet varies between 0.37MP and 0.6MP. It shows that \( p_{ay} / p_{o} > 0.518 \), so the Equation (1) in Equation (13) is established. It shows that when the air supply port pressure and the gas temperature in the proportional valve remain unchanged, the valve port flow is related to the cross-sectional area of the valve port and the outlet pressure, while the cross-sectional area of the valve port is related to the input voltage \( U_{y} \):

\[
q_{ma} = Q_{y} = f(U_{y}, p_{ay}) \tag{14}
\]

Linearize Equation (14) near the zero position and perform Laplace transform:

\[
\Delta q_{ma}(s) = k_{1y} \Delta U_{y}(s) + k_{2y} \Delta p_{a}(s) \tag{15}
\]

Combine Equation (12) Equation (15) to get:

\[
\Delta p_{ay}(s) = \frac{kK_{1y}RT_{a}}{U_{y}s - kK_{2y}RT_{a}k} \tag{16}
\]

Combine Equation (7) Equation (16) to get:

\[
G_{y}(s) = \frac{\Delta F_{y}(s)}{\Delta U_{y}(s)} = \frac{kK_{1y}K_{cy}RT_{a}A_{ay}}{(V_{ay}s - kK_{2y}RT_{a}k)(2M_{y}s^2 + \beta_{y}s + K_{cy})} \tag{17}
\]

Similarly, the open-loop transfer function of the horizontal module can be obtained:
\[ G_x(s) = \frac{\Delta F_x(s)}{\Delta U_x(s)} = \frac{kK_{1x}K_{c}RT_{a}A_{ax}}{(V_{ax}s - kK_{2x}RT_{a}k)(2M_{x}s^2 + \beta_{x}s + K_{cx})} \]  

(18)

2.4. Derivation of the overall model of pneumatic servo system

According to the results of Section 2.1 and Section 2.2, the open-loop transfer function of the grinding device is obtained. Figure 5 is the block diagram of the pneumatic servo control system model.

\[ (19) \]

Figure 5. Block diagram of pneumatic servo control system model.

Here: \( U_g = (U_{gx} \ U_{gy})^T \), \( U_{gx} \) and \( U_{gy} \) are the horizontal and vertical expected output voltages respectively.

\( U_f = (U_{fx} \ U_{fy})^T \), \( U_{fx} \) and \( U_{fy} \) are the horizontal and vertical feedback voltages respectively.

\( U = (U_x \ U_y)^T \), \( U_x \) and \( U_y \) are the horizontal and vertical actual output voltages respectively.

\( G(s) = \begin{pmatrix} G_x(s) & 0 \\ 0 & G_y(s) \end{pmatrix} \)

\( = \begin{pmatrix} 12.632 \\ 0.064s^3 + 0.82s^2 + 0.075s + 1 \\ 0 \\ 0.085s^3 + 0.76s^2 + 0.51s + 3 \end{pmatrix} \)

(19)

Figure 6. Schematic diagram of skateboard edging strategy.

3. Polishing control strategy

In the process of the interaction between the robot and the environment, the end trajectory of the robot will be affected by the external environment, calibration and trajectory errors, which will change the contact force. For force-position coupling systems, precise and complex mathematical models are required to complete the desired force control, which is often difficult to achieve in actual control.
Based on the constant force grinding device, this paper decouples force control and position control, the robot performs position control, and the grinding device performs constant force control. The control principle diagram is shown in Figure 6.

### 3.1. Fuzzy controller design

In the edging process, factors such as external disturbance and load changes can easily affect the constant force tracking effect. The traditional PID has poor robustness and poor work adaptability in nonlinear time-varying systems, while the fuzzy PID has the advantages of strong robustness, good fault tolerance, and small computational burden. The control effect can meet the polishing requirements [16]. A fuzzy PID of the constant force control system is proposed for improving the dynamic characteristics and stability of the system. The fuzzy controller takes the grinding force deviation \( e \) and the deviation change rate \( e_d \) as system inputs, and takes the PID control parameter increments \( \Delta K_p \), \( \Delta K_i \) and \( \Delta K_d \) as outputs. The schematic diagram is shown in Figure 7.

![Figure 7. Fuzzy PID control system structure diagram.](image)

In the fuzzy PID controller, its control output is:

\[
U = U_1 + U_2 + U_3 = (K_{po} + \Delta K_p)e(t) + (K_{io} + \Delta K_i) \int_0^t e(t) \, dt + (K_{do} + \Delta K_d) \frac{de(t)}{dt} + \frac{1}{G(s)} + P_{0y}A_{0y} \tag{20}
\]

Among them, \( K_{po}, K_{io} \) and \( K_{do} \) are the initial values of PID parameters, and \( \Delta K_p, \Delta K_i \) and \( \Delta K_d \) are the modified values obtained by fuzzy inference.

### 3.2. The membership function and fuzzification

In a fuzzy controller, the more value elements of the input and output language variables, the higher the control accuracy, but the more complicated the corresponding control rules. If there are fewer value elements, the control accuracy will be coarser. This paper takes the fuzzy subsets of \( E, Ec, \Delta K_p, \Delta K_i \) and \( \Delta K_d \) as \( \{NB, NM, NS, ZO, PS, PM, PB\} \).

The domain of input variables is: \( Ec, E = [-3, -2, -1, 0, 1, 2, 3] \)

The domain of output variables is: \( \Delta K_p, \Delta K_i, \Delta K_d = [-3, -2, -1, 0, 1, 2, 3] \)

After many tests, the basic domains of the grinding force deviation \( E \) and the deviation change rate \( E_c \) are measured as \([-5.4, 5.4] \) and \([-0.54, 0.54] \). The value ranges of the fuzzy controller output \( \Delta K_p, \Delta K_i \) and \( \Delta K_d \) are \([-2.4, 2.4], [-1.2, 1.2] \) and \([-0.6, 0.6] \) respectively. The quantization factors \( k_e, k_{ec} \) and the scale factor \( k_u \) are [17].

\[
k_e = n/e \tag{21}
\]
\[
k_{ec} = n/ec \tag{22}
\]
\[
k_u = u/n \tag{23}
\]

Among them, the quantization level \( n=3 \).
In the control system, each language variable takes the triangular membership function, as shown in Figure 8:

![Figure 8. Membership function of fuzzy controller.](image)

3.3. The fuzzy control rules and defuzzification

When the fuzzy controller adjusts the PID parameters, it needs to formulate fuzzy rules according to the input quantities $E$ and $E_c$ and the functions of the three PID parameters. The control system is a two-input three-output system. Combining the basic idea of PID and fuzzy mathematics theory, a fuzzy rule table of three parameter correction items $\Delta K_p$, $\Delta K_i$ and $\Delta K_d$ and $E$, $E_c$ is established as Table 1.

| $E$  | NB   | NM   | NS   | ZO   | PS   | PM   | PB   |
|------|------|------|------|------|------|------|------|
| $\Delta K_p$ | PB/NB/PS | PB/NB/NS | PM/NM/NB | PM/NM/NM | PS/NS/NS | ZO/ZO/NS | ZO/ZO/PS |
| $\Delta K_i$ | PM/NB/PS | PM/NB/NS | PM/NM/NB | PM/NM/NM | PS/NS/NS | ZO/ZO/NS | NS/ZO/ZO |
| $\Delta K_d$ | PM/NB/PS | PM/NB/NS | PM/NM/NB | PM/NM/NM | PS/NS/NS | ZO/ZO/NS | NS/ZO/ZO |

Table 1. $\Delta K_p/\Delta K_i/\Delta K_d$ fuzzy rule table.

The weighted average method is used to defuzzify the fuzzy output. The formula is as follows:

$$
\mu = \frac{\sum_{i=1}^{n} x_i \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)}
$$

(24)

Among them, $\mu$ is the final output value, $n$ is the number of elements in the output fuzzy domain, $x_i$ is the value of the $i$-th element in the output fuzzy domain, and $\mu(x_i)$ is the membership degree of the $i$-th element in the output fuzzy domain.

4. Experiment and result

An experiment platform is established for verifying the constant force control effect of the grinding device as shown in Figure 9. The test platform consists of a six-axis robot (KR6R900, Produced by KUKA, Germany), a robot control cabinet, a pneumatic constant force grinding device, an air source, a PMAC controller, a PC, an electric proportional valve, a skateboard fixture and a skateboard. The output force of the horizontal and vertical modules of the pneumatic constant force grinding device is 0–100N, and the working space is 0–25mm.

Two types of experiments are designed to verify the effect of the grinding platform. One is a dynamic experiment in which the robot gripping skateboard is fitted to the grinding tool at a speed of 0.15m/s along the planned trajectory, which test force response time and control accuracy. The other is a static experiment, in which the robot clamps the skateboard and fits the tool to keep still, and gives an interference force signal to the grinding device to test its robustness.

Before the experiment, the horizontal expected contact force, the horizontal cylinder front chamber pressure, the vertical expected contact force, the vertical cylinder front chamber pressure and the data collection period were set to 50N, 0.35MP, 40N, 0.35MP, and 4.4ms, respectively. Then the grinding
device returned to the relative zero position and the industrial robot gripped the skateboard to complete the polishing path planning on the polishing tool through the teach pendant, and sent the polishing path to the control cabinet. During the experiment, the robot gripped the sliding plate to move along the planned trajectory. When the skateboard contacted with the grinding tool and the actual contact force exceeded the set grinding force threshold, the grinding device started to polish. The force sensor fed back the grinding force to the PMAC controller in real time, and then the fuzzy PID calculated the analog control quantity $u$ based on the grinding force deviation and the deviation change rate. The electric proportional valve adjusted the pressure of the cylinder back cavity according to the control quantity, so that the actual grinding force could be reached quickly expected value and kept constant.

The actual grinding force curves in the horizontal and vertical directions of the dynamic experiment are shown in Figure 10(a) and 10(b). It shows that the fuzzy PID is compared with the normal PID, the response adjustment time of the grinding force from 0 N to the desired value is significantly reduced, the response is quick and the overshoot is small, and the standard deviation of the grinding force is less than 1N when it is stable. The parameters are shown in Table 2.

![Figure 9](https://example.com/figure9.png)  
**Figure 9.** Experimental platform for skateboard edging.

![Figure 10](https://example.com/figure10.png)  
(a) horizontal response curve.  
(b) vertical response curve.  
**Figure 10.** Force response curve.
Table 2. Constant force control parameters.

| Grinding direction | Normal PID response time (ms) | Fuzzy PID response time (ms) | Normal PID overshoot (N) | Fuzzy PID overshoot (N) | Normal PID standard deviation (N) | Fuzzy PID standard deviation (N) |
|--------------------|-------------------------------|-------------------------------|--------------------------|-------------------------|-----------------------------------|----------------------------------|
| Horizontal         | 396                           | 176                           | 5.35                     | 0.45                    | 1.12                              | 0.93                             |
| Vertical           | 100                           | 193                           | 3.63                     | 1.22                    | 1.18                              | 0.98                             |

The horizontal and vertical static experimental results are shown in Figure 11(a) and 11(b). In this experiment, the interference of about 8.3N and 6.8N is given to the horizontal and vertical directions respectively. It can be seen that the horizontal and vertical response times of fuzzy PID are respectively 88ms and 96ms without oscillation, while the horizontal and vertical response times of normal PID are respectively 123ms and 110ms with obvious oscillation. Based on the above experiments, the control accuracy and response time of the grinding device meet the edging requirements of the skateboard, and the fuzzy PID control is significantly better than the normal PID.

![Graphs showing horizontal and vertical force response.](image)

(a) horizontal curve.  
(b) vertical curve.

5. Conclusions

In this paper, a control method of robot skateboard edging based on a pneumatic constant force grinding device is proposed for solving the issue of modeling and complex algorithm of robot end active compliance control during the skateboard edging grinding process. The force control and position control are decoupled by designing a set of 2 degrees of freedom pneumatic constant force grinding device. The position control is completed by the robot, and the force control is completed by the pneumatic constant force grinding device. In addition, the theoretical model of the grinding device is deduced, and the force control strategy is analyzed. The fuzzy PID control is used to improve the dynamic response performance of the device.

Preliminary experimental results show that the pneumatic constant force grinding device has high control accuracy, good robustness, fast response speed. It also has the ability to set the grinding contact force to complete different grinding work requirements, and meet the design requirements. In the future, experiments and verifications will be carried out in actual production to meet the actual requirements of production, thereby improving work efficiency and improving the working environment of workers. It has broad application prospects.
Acknowledgement
This work was supported by National Natural Science Foundation of China under Grant No. U1713218.

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