Research on constant force polishing method of curved mold based on position adaptive impedance control

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Received: 21 February 2022 / Accepted: 11 August 2022 / Published online: 16 August 2022 © The Author(s), under exclusive licence to Springer-Verlag London Ltd., part of Springer Nature 2022

Abstract

The quality and life of the injected product are affected by the surface quality of curved mold, and reasonable polishing method is the key to obtain the high-quality surface of curved mold. Small polishing tool is controlled by constant displacement polishing in the conventional method of robot polishing. The polishing force is adjusted to affect the surface quality of mold during mold polishing. The shortcomings of traditional control method of robot are investigated by simulation, and the constant force control approach is proposed to maintain stable force, which is achieved by a position-based impedance control algorithm. The polishing experiments of curved mold are conducted by using two control methods with constant displacement control polishing (CDCP) and constant force control polishing (CFCP), respectively. The experimental results show that the CFCP method can maintain polishing force stability and the reduction of surface roughness in the three groups of experiments using CDCP method is much lower than that of CFCP method, respectively. The feasibility of constant force control polishing method (CFCP) is verified.

Keywords Robot polishing · Curved mold · Constant force control polishing · Adaptive impedance control

1 Introduction

The molded products cannot be separated smoothly from the mold due to the mold surface with poor quality. The manufacturing efficiency and working life of the product are affected by mold surface quality, so it is extremely vital for machining to obtain a mold surface with high quality. As pointed out in previous studies, the contact force between the polishing tool and workpiece is a key factor that affects the polishing quality [1–3]. To realize the control of constant force, scholars have investigated machining methods from a variety of perspectives [4–6]. Huang et al. [7] developed the passive compliance tools (PCTs) to grind and polish the distorted vanes, and the PCTs with passive force control can maintain reasonably constant material removal. Mohammad and Wang [8] proposed a force controllable end effector for automatic deburring, which can reduce inertial effect of polishing motor and spindle driven by microdriver. Chen et al. [9] proposed an end effector, including gravity compensation force controller and two new eddy current dampers, which were integrated into the end effector to improve the dynamic performance of the system and suppress the vibration during grinding and polishing. Tang et al. [10] proposed a multi-degree of freedom flexible terminal actuator for mold polishing robot, the polishing tool, and the workpiece changes in a constant range. However, the above constant force compensation devices possess the disadvantages of low precision, slow response, and poor environmental adaptability. So, many studies concentrate on active force control [11–18]. For instance, Tian et al. [19] proposed a
robot polishing tool position and pose generation algorithm based on force-position-pose decoupling control, ensuring constant polishing pressure during polishing process. The surface quality of the mold is greatly improved. However, the real-time performance is not excellent and the control accuracy is weak. Dong et al. [20] provide a stable control system for pneumatic polishing to achieve reliable control of the polishing force and improve the surface quality of the workpiece. Dong et al. [21] put forward an adaptive proportional-integral control algorithm to ensure contact force accuracy for polishing systems with different stiffness. Ding et al. [22] proposed a novel and practical method to detect and control the contact force using the built-in sensors (motor encoders and joint torque sensors) for actual robotic polishing in harsh conditions of strong vibration disturbance. Realizing the control process is too complicated to understand. Yuan et al. [23] purposed an improved sensorless position-based force controller for the original control system of micro-robot. It can improve the real-time control ability of the micro-robot manipulator on the basis of estimating and eliminating the dynamic coupling effect of the macro-mini-system. But this method cannot keep the constant force in the normal direction. Wu et al. [24] proposed an adaptive neural network compensator for the original control system of micro-robot. It can improve the real-time control ability of the micro-robot manipulator on the basis of estimating and eliminating the dynamic coupling effect of the macro-mini-system. But this method has limitations in polishing. Ma and Yang [25] built a dexterous 3-DOF force-controlled end-effector module through a three-legged prismatic-prismatic-spherical (3PPS) parallel manipulator. End-effector costs are more expensive.

Therefore, constant force control requires a low-cost method with a simple control process. Based on the above analysis, a constant force control polishing method (CFCP) is proposed to keep the polishing force constant in this paper. The remainder of this paper is organized as follows: The shortcomings of traditional control polishing are analyzed by simulation, and the method of constant force control polishing (CFCP) is proposed in Sect. 2. A constant force control for robotic polishing using an impedance control algorithm is described in Sect. 3. The constant force control method is validated by the polishing experiments of curved mold in Sect. 4.

## 2 Analysis for control methods of robot polishing

### 2.1 Conventional robot polishing control method

Small polishing tools are controlled to machine molds at constant displacement in robotic conventional polishing methods which is constant displacement control polishing (CDCP). At the same time, the small polishing tool is only assigned to a fixed polishing path without force feedback. The robot finishes the mold surface following a grating path with constant displacement control as shown in Fig. 1.

Due to the influence of the curvature of the mold surface, the contact between the polishing tool and the mold is insufficient, causing inadequate polishing or over-polishing. The small polishing tool maintains a determinate displacement of the surface normal in CDCP method. And the small polishing tool holds a defined contact force of surface normal in CFCP method. To illustrate the superiority of CFCP method in polishing mold, the contact situation of small polishing tools with different control methods was simulated.

### 2.2 Simulation analysis of constant displacement control polishing (CDCP)

The polishing tool is controlled with the same displacement for the mold machining in the robot constant displacement control polishing (CDCP) method, which has only a fixed path in the robot motion space without force feedback.

The polishing tool is deformed due to the force load. In the constant displacement control polishing method, the deformation is used as the displacement load, and the constant deformation and constant displacement have the same effect. In order to explore the relationship between force and displacement, the pressure simulation test was carried out. And the displacements of three sets of forces that match are shown in Table 1. The center of the mold is set as the coordinate origin, and the mold is loaded with 100 N by the small polishing tool. The deformation of the small polishing tool is 8.6 μm. The deformation is 11.3 μm when a load of

| Table 1 | The correspondence between the force and displacement of the small polishing tool |
|---------|---------------------------------|
| Experiment number | Force (N) | Displacement (μm) |
| Group 1 | 100.0 | 8.6 |
| Group 2 | 150.0 | 11.3 |
| Group 3 | 200.0 | 13.6 |
150 N is applied. The deformation corresponds to 13.6 μm for a small polishing tool of 200 N.

And the simulation was carried out to discover the influence laws of the mold curvature on the contact force, contact stress, and contact area. Five different contact positions were selected in the mold, and the deformation of group 1 was applied to small polishing tool as displacement load. Figure 2 shows the contact positions between polishing tool and curved mold in simulation process. The contact force and contact area were compared in five positions of the mold. The simulations of group 2 and group 3 in the constant displacement control polishing (CDCP) method were also the same approaches.

The simulation settings parameters are as follows:

1. The contact style between the small polishing tool and the mold was defined as frictionless contact; the normal stiffness factor is 10 [26].
2. Method of meshing is automatic: the whole size of the grid is 3 mm. The local refinement to influence the ball radius is 2 mm and the unit size is 0.1 mm.
3. The bottom of the mold is fixedly constrained. The load of the small polishing tool is applied vertically to the mold surface while the tool is limited in other directions, which is similar to the actual machining situation.

The simulation flowchart is shown in Fig. 3, where the model material parameters are given in Table 2.

Three sets of displacement loads were applied to the small polishing tool, and the specific load parameters are shown in Table 1. The contact area and contact stress of simulation result are shown in Fig. 4. The contact starts from the center of the tool, and the stress in the center of contact is maximum. The contact area is related to the applied load and the mold curvature. Three groups of displacement loads were applied to the small polishing tool for the comparison of the polishing force. The polishing forces of the CDCP method are shown in Table 3.

![Fig. 2 The contact positions between polishing tool and curved mold (x=0, 25, 50, 75, 80 (mm))](image)

As the curvature of the mold surface increases from 0.005 to 0.020, group 1 of simulated polishing force decreases from 100.000 to 69.212 N. Group 2 of simulation polishing force is reduced from 150.000 to 103.571 N. The polishing force of the group 3 simulation is diminished from 200.000 to 138.000 N. And the variations of polishing forces using CDCP method are displayed in Fig. 5. From the result of simulation, the higher the curvature is, the less force of the CDCP method is with insufficient contact. In the meantime,
the contact region and contact stress between the small polishing tool and the mold would be affected.

The variation of contact region between the small polishing tool and the curved mold is shown in Table 4, and the contact area decreased with the growth of curvature under the identical displacement load. The reduction of percentage in contact area is calculated using the minimum and maximum curvature of each group. The percentage change in contact stress is calculated in the same way as contact stress.

![Fig. 4](image)

**Fig. 4** Contact area and contact stress of simulation: a contact area; b contact stress

| Material           | Elastic modulus (GPa) | Poisson’s ratio | Density/(kg/m³) |
|--------------------|-----------------------|-----------------|-----------------|
| Curved Mold (Q235) | 212.00                | 0.30            | 7860            |
| Polishing tool (Nylon) | 8.30                     | 0.28            | 1150            |

The relative contact area of simulations was reduced by 40.94%, 46.68%, and 47.15% in groups 1 to 3, respectively. The variation trend of contact area is shown in Fig. 6a.

The contact stresses for the CDCP method simulation are illustrated in Table 5. As the mold curvature raises, the contact stress increases under the same displacement load. The contact stress increases by 30.28%, 31.72%, and 31.73% in groups 1 to 3, respectively. The variation trend of contact stress is demonstrated in Fig. 6b, where the contact stress

![Table 3](image)

**Table 3** Polishing forces of CDCP method

| Curvature | Position (mm) | 0     | 25    | 50    | 75    | 80    |
|-----------|---------------|-------|-------|-------|-------|-------|
| 0.005     | Group 1/N     | 100.000 | 97.292 | 88.956 | 73.573 | 69.212 |
| 0.006     | Group 2/N     | 150.000 | 146.214 | 133.323 | 110.014 | 103.571 |
| 0.007     | Group 3/N     | 200.000 | 194.914 | 177.691 | 146.533 | 138.000 |

![Table 2](image)

**Table 2** Material parameter

| Material           | Elastic modulus/GPa | Poisson’s ratio | Density/(kg/m³) |
|--------------------|---------------------|-----------------|-----------------|
| Curved Mold (Q235) | 212.00              | 0.30            | 7860            |
| Polishing tool     | 8.30                | 0.28            | 1150            |
increases and the effect of material removal on the surface are enhanced.

The effect of the mold curvature on the force varying under the CDCP method is evaluated by simulation. And the simulation results show that as the mold curvature rises, the force variation increases and the contact is more uneven. Therefore, a constant force control polishing (CFCP) method is suggested, and the influences of mold curvature on contact area and contact stress under the CFCP method are investigated through simulation.

2.3 Simulation analysis of constant force control polishing (CFCP)

The same displacement load is applied to different positions of the mold in the robot CDCP method simulation. However, the displacement load is changed to force load in the CFCP simulation, that means the same force is applied at each position. The rest of the constraints are also set identically. In the CFCP simulation, the forces exerted on the small polishing tool are 100 N, 150 N, and 200 N, respectively, in the groups 1 to 3 according to the values of force in Table 1.

The contact area of the CFCP simulation is shown in Table 6. Mold curvature increased from 0.005 to 0.020, and the contact area of CFCP simulation is lowered by 32.72%, 32.04%, and 32.34%, respectively, in groups 1 to 3.

As the curvature of mold increases, the contact stress rises. Greater contact stress represents more efficient material removal. The contact stresses in three groups of CFCP simulation are indicated in Table 7. The contact stress of CFCP
method simulation increased by 47.15%, 48.93%, and 48.93% in groups 1 to 3. The trends of contact area and contact stress in the various positions of mold are illustrated in Fig. 7.

The variations of contact area represent whether the polishing tool is inadequate contact with the mold surface during polishing process. The results of simulation analysis by using the two control methods can be seen from Table 8. The contact area in each group of CFCP method simulation is corresponding less than which of CDCP method.

As shown in Table 9, the contact stress in each group of CFCP method simulation is corresponding larger than which of CDCP method under the same conditions. It indicates that the material removal of the CFCP method is more efficient.

It can be seen that when the mold is applied the same displacement load, the polishing force decreases with the increase of the mold curvature. And there is less variation in contact area and larger contact stress in CFCP method compared with CDCP method. The results of simulation show CFCP method is better than CDCP in terms of polished surface contact. Therefore, the control algorithm which is the core of CFCP method will be conducted in the following.

3 Achievement of constant force control polishing (CFCP) method based on position-based adaptive impedance control

3.1 The robotic system of constant force control polishing

In order to realize the constant force polishing of robot, a device composition of robotic polishing is established, as shown in Fig. 8. The model of industrial robot is KUKA-KR-60, which is used to localize the small polishing tool. The six-dimensional force/torque sensor is an ATI Industrial Automation Delta IP60 model to acquire force data during polishing process. The force test and feedback process are that six-dimensional force/torque sensor collects and tests strain signals when the polishing tool contacts with the workpiece surface. The signal is amplified and filtered to digital recognizing signal by Net F/T modulator, then the

| Table 6 Contact area of CFCP |
|-----------------------------|
| Position (mm) | 0  | 25 | 50 | 75 | 80 |
| Curvature     | 0.005 | 0.006 | 0.007 | 0.011 | 0.020 |
| Group 1/mm²   | 2.755 | 2.665 | 2.364 | 1.982 | 1.855 |
| Group 2/mm²   | 3.623 | 3.502 | 3.113 | 2.601 | 2.465 |
| Group 3/mm²   | 4.391 | 4.243 | 3.783 | 3.172 | 2.973 |

| Table 7 Contact stress of CFCP |
|-----------------------------|
| Position (mm) | 0  | 25 | 50 | 75 | 80 |
| Curvature     | 0.005 | 0.006 | 0.007 | 0.011 | 0.020 |
| Group 1/MPa   | 55.843 | 57.332 | 62.232 | 77.114 | 82.172 |
| Group 2/MPa   | 63.132 | 65.475 | 70.821 | 88.653 | 94.023 |
| Group 3/MPa   | 69.445 | 72.000 | 77.882 | 97.472 | 103.434 |

Fig. 7 Contact area and contact stress of constant force: a contact area; b contact stress

| Table 8 Contact area decrease ratio |
|------------------------------------|
| Experiment number | CDCP | CFCP | Difference |
| Group 1           | 40.94% | 32.72% | 8.22% |
| Group 2           | 46.68% | 32.04% | 14.64% |
| Group 3           | 47.15% | 32.34% | 14.81% |
digital recognizing signal is outputted to the computer by Ethernet.

According to the above principle of force control, the robotic system with constant force control polishing (CFCP) which mainly consists of an industrial robot (installed with six-dimensional force/torque sensors and polishing tool), a working platform, and a water recycling cooling system is built, as depicted in Fig. 9. And the robotic system is needed to combine position-based adaptive impedance control algorithm to achieve constant force control polishing.

### 3.2 Principle of constant force control

The schematic diagram of constant force control by the position-based adaptive impedance control method is shown in Fig. 10. The strategy of constant force control means that the force error of sensor is passed back to the controller and the position of the robot arm in the coordinate system is acquired. The control torque of the joint based on the inverse solution of the robot dynamics equations is calculated so that the adaptation of the robot arm position and contact force is realized.

Impedance control is a functional relationship through the difference between the current state and the desired state. The feedback force message is combined with the difference value and the appropriate coefficient matrix is calculated in the next step. The fitted control force $F_{\text{ext}}$ is corrected for the purpose of impedance control, and the second-order relationship between the fitted external force $F_d$ and the position offset $e$ is built as follows:

$$M_d \ddot{e} + B_d \dot{e} + K_d e = F_{\text{ext}}$$

where $M_d$ is the target inertia matrix, $e$ is the position deviation, $B_d$ is the mark damping matrix, $K_d$ is the purpose stiffness matrix, and $F_{\text{ext}}$ is the external force. The correct control parameters are selected in the process to achieve the ideal target impedance.

### 3.3 The implementation of position-based adaptive impedance control method

The principle diagram of the position-based adaptive impedance control algorithm is shown in Fig. 11. The finishing of the mold by the robot is categorized into two stages: approaching and reaching the mold. By analyzing the robot control mode, the schematic block diagram of the position-based adaptive impedance control algorithm is proposed, and the particular steps are as follows:

1. The contact process between the robot and the environment is divided into close and contact environment, corresponding to free and contact spaces.
2. In free space, the initial position is gained by the controller, then the speed is modulated by the controller and transmitted to the impedance controller. The control form at that moment is

$$f(x, x, t) = -k_v (\dot{x} - \dot{x}_d) + k_p (-x + x_d)$$

3. The force corresponding to the speed is calculated by the impedance controller. The mold surface is reached by the small polishing tool at high speed.

| Experiment number | CDCP   | CFCP   | Difference |
|-------------------|--------|--------|------------|
| Group 1           | 30.28% | 47.15% | 16.87%     |
| Group 2           | 31.72% | 48.93% | 17.21%     |
| Group 3           | 31.73% | 48.94% | 17.21%     |

Table 9 Contact stress increase ratio
4. When reaching the contact space, the speed is modulated by impedance control and dynamic modulation to make it run at a low speed when it is close to the environment. The current mode of control is

\[ f(\dot{x}, x, t) = -k_v(\dot{x}) + k_p(-x + x_d) \] (3)

5. When contacting the surface, only the impedance is used to control the force required to be applied to the small polishing tool.

In the manipulated space, the robot is maintained constant polishing force by adaptive impedance control algorithm, while dynamically modulating with obstacle avoidance method [27]. To verify the feasibility of the proposed method, the comparative experiments of CFCP method and CDCP method are conducted.

4 Experiments of mold polishing

4.1 Experiment procedure

Dynamic systems and stability assessment during machining are the focus of robotic constant force polishing. The framework diagram of robot to realize constant force control polishing is shown in Fig. 12. The curved mold is polished by the robot in two stages. The first stage is free space, and through impedance to control the force and through speed modulation to regulate the speed. The second stage is the contact space, where a single impedance control is applied for force control.

After the position controller represents the present robot position, the modulation strategy can be used to adjust the speed. The position controller obtains the initial position and modulates it according to the specified parameters. Then position controller obtains the response velocity, which is transmitted to the impedance controller, which calculates the corresponding force from this velocity. The speed of the robot end in contact with the surface is low, resulting in a smaller vibration force. When the end effector is in contact with the surface, constant force contact can be achieved by impedance control.

The polishing experiments of CFCP and CDCP were carried out with the same initial test conditions, respectively. In the constant displacement control (CDCP) method, the polishing force was preset to 10 N by pressure testing of the polishing tool. The robot polishing process is illustrated in Fig. 13. The polishing tool is rotated by a servo motor, and the motor power is 400 W and the
maximum speed is 3000 r/min. And the experimental workpiece is concave mold which of material is 40 Cr, and the size is 200 mm × 100 mm. The material of the small polishing tool is nylon and the diameter is 30 mm. The mass fraction of Al₂O₃ in the polishing fluid is 5%. The rotational speed of polishing tool is 1000 r/min and the feed velocity is 0.75 mm/s. And the polishing force is set 10 N in the CDCP and CFCP trials. The surface roughness measuring instrument, which of model is Mitutoyo SJ-210, is used to evaluate the surface roughness of mold after polishing.

4.2 Discussion of experimental results

In order to evaluate the influence of two methods (CDFP and CFCP) on the polishing results comprehensively, three groups of comparative experiments in two curved molds were carried out. And the experimental results were analyzed from force variation and surface roughness, respectively.

Fig. 12 The frame diagram of control algorithm realized by constant force

Fig. 13 Polishing process

The surfaces of curved molds after polishing are presented in Fig. 14. The polishing force data in polishing process are captured by the force sensor and the variations of polishing forces are presented in Fig. 15.

4.2.1 Analysis of polishing force variation in polishing process

The same trends of CDCP method are observed in Fig. 15. Most of the polishing force is between −15 and −5 N, which varies significantly. While significant force fluctuations are not observed in the CFCP method, which is nearly −10 N.

To further analyze the variation of polishing force, the average and standard deviation of polishing force are calculated for each group of experiments, respectively. The mean and standard deviation of polishing force are provided in Table 10. In the three groups of experiments using CDCP method, the differences between the mean value of polishing force and the expected value are 2.01 N, 1.97 N, and 4.52 N that are greater than the mean value of polishing force using CFCP method, respectively. The CFCP method can maintain polishing force stability from the perspective of mean value evaluation. Similarly, the standard deviation of polishing force in the three groups of experiments using CDCP method is lower than that of CFCP method, respectively, which means that the fluctuation of polishing force using CFCP method is smaller. Force fluctuations are caused by changes of surface
curvature and unevenness in the bottom of small polishing tool. The CFCP method allows for rapid adjustment of polishing force according to changes of surface curvature, and polishing force changes within 2 N. Constant polishing force is one of the important conditions to obtain uniform surface. And it can be seen from Fig. 14 that there are obvious scratches in the surface of curved molds after polishing using CDCP method.

In addition, the contact area in CDCP method varies widely during the whole process from the simulation in Sect. 2.2 so that the mold cannot be polished sufficiently. The experimental results prove the waviness of the contact force in CDCP method.

4.2.2 Analysis of mold surface roughness

Surface quality after polishing is characterized by measuring surface roughness. And surface roughness Ra is selected for the evaluation parameter of surface quality. Three points are taken in each group of experiment to measure the surface roughness Ra. The surface roughness of each point is measured three times, and the average value is taken as the surface roughness of this point. The measurement results of surface roughness Ra are presented in Table 11. The surface roughness of curved mold using CDCP method and CFCP method is about 1.1–1.5 μm and 0.5–0.6 μm. The comparison of surface roughness Ra in each group of experiment is illustrated in Fig. 16. The average reduction of surface roughness using CDCP method is 40.42% and CFCP method is 40.42% and 65.59%, respectively.

In the three groups of experiments using CDCP method, the reduction of surface roughness is much lower than that of CFCP method, respectively. By combining the analysis of polishing force variation, the fluctuation of polishing force in polishing process will reduce the polishing efficiency and surface quality of curved mold. The experimental results prove the conclusion obtained from the simulation of two control methods (in Sect. 2), and the curved mold can be polished more efficiently through using CFCP method.

Table 10  The mean value and standard deviation of polishing force

| No.       | Mean value | Standard Deviation |
|-----------|------------|--------------------|
|           | CDCP      | CFCP               | CDCP      | CFCP               |
| Group 1   | −7.99      | −8.51              | 3.58      | 0.65               |
| Group 2   | −8.03      | −10.44             | 3.69      | 1.05               |
| Group 3   | −14.52     | −9.26              | 5.57      | 1.04               |
| Surface roughness Ra | Control method | Group of experiment | Point 1-Ra/μm | Point 2-Ra/μm | Point 3-Ra/μm |
|----------------------|----------------|---------------------|---------------|---------------|---------------|
| Initial value        | None           | 1                   | 1.912         | 2.130         | 2.168         |
|                      |                | 2                   | 1.675         | 2.087         | 2.112         |
|                      |                | 3                   | 0.737         | 2.143         | 2.028         |
| Experimental value   | CDCP           | 1                   | 1.419         | 1.286         | 1.120         |
|                      | CFCP           | 1                   | 0.807         | 0.715         | 0.595         |
|                      | CDCP           | 2                   | 1.345         | 1.282         | 1.149         |
|                      | CFCP           | 2                   | 0.717         | 0.784         | 0.344         |
|                      | CDCP           | 3                   | 1.323         | 1.278         | 1.221         |
|                      | CFCP           | 3                   | 0.519         | 0.747         | 0.629         |

Fig. 16 The comparison of surface roughness Ra in each group of experiment: (a) group 1, (b) group 2, and (c) group 3
5 Conclusion

1. Polishing force is one of the important issues in robotic polishing of curved mold. A constant force control polishing method (CFCP) which is achieved based on position-based adaptive impedance control is proposed to keep the polishing force constant.

2. To illustrate the superiority of CFCP method in polishing mold, the contact situations of small polishing tools using CDCP method and CFCP method were simulated with constant displacement load and constant force, respectively. The simulation results show that there is less variation in contact area and larger contact stress in CFCP method compared with CDCP method; therefore, CFCP method can improve polishing efficiency.

3. In order to evaluate the influence of two methods (CDFP and CFCP) on the polishing results comprehensively, three groups of comparative experiments in two curved molds were carried out. In the three groups of experiments using CDCP method, the differences between the mean value of polishing force and the expected value are 2.01 N, 1.97 N, and 4.52 N that are greater than the mean value of polishing force using CFCP method, respectively. The CFCP method can maintain polishing force stability from the perspective of mean value evaluation. Similarly, the standard deviation of polishing force in the three groups of experiments using CDCP method is lower than that of CDCP method, respectively, which means that the fluctuation of polishing force using CFCP method is smaller. And the measurement results of surface roughness Ra show that the average reduction of surface roughness using CDCP method and CFCP method is 40.42% and 65.59%, respectively. The reduction of surface roughness in the three groups of experiments using CDCP method is much lower than that of CFCP method, respectively. The experimental results prove the conclusion obtained from the simulations of two control methods, and the curved mold can be polished more efficiently through using CFCP method.

Acknowledgements The authors would like to thank Beijing Key Laboratory of Advanced Manufacturing Technology, Laboratory of Robotics and Intelligent Systems (CAS Quanzhou) for the experimental support. The authors would also like to acknowledge the editors and the anonymous referees for their insightful comments.

Author contribution Guangsheng Chang: methodology, simulation analysis, and writing—original draft. Yinhui Xie and Jinxing Yang: date curation and validation. Yong Yang: experiment operation. Ri Pan and Jun Li: writing—review and editing and resources.

Funding This work was financially supported by the Nation Natural Science Foundation of China (Grant No. 517750010) and Scientific and Technological Project of Quanzhou (No. 2020C071).

Availability of data and materials The experimental and simulation date is transparency.

Declarations

Ethics approval This material is the author’s own original work, which has not been previously published elsewhere.

Consent to participate Not applicable.

Consent for publication The authors have read and agreed to publish the version of the manuscript.

Conflict of interest The authors declare no competing interests.

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