Track Planning and Pressure Control of Robotic Gasbag Polishing Technique with Improved Polishing Tool

SHIMING JI, MINGSHENG JIN, LI ZHANG, XIAN ZHANG, YINDONG ZHANG
The MOE Key Laboratory of Mechanical Manufacture and Automation
Zhejiang University of Technology
Hangzhou, 310032, CHINA

Abstract: - In order to obtain well-proportioned surface quality and high polishing efficiency of free-form mould, a robotic gasbag polishing technique using an improved spinning-inflated-gasbag polishing tool is proposed in this paper. The improved polishing tool consists of three detachable modules, which are the drive, soft rubber gasbag and magnetorheology. The six degrees of freedom industrial robot with a low-cost pressure control system is used for holding the improved polishing tool and controlling the polishing process such as the path, position, orientation, pressure and rheological behavior, so as to form an automated polishing system. The flow chart of polishing track planning and the low-cost solution of pressure control of the gasbag for better pose control and pressure adjustment are presented and the key technologies are analyzed in detail. The polishing experiments of free-form mould and observation of images after polishing indicate that robotic gasbag polishing technique can achieve well-proportioned surface quality and surface roughness of Ra 5 nm.

Key-Words: - Robotic gasbag polishing; Free-form; Module design; Track planning; Pressure control; Surface quality.

1 Introduction

Before mould's application in industry, polishing is an important technique processing that must be performed for removing the traces and damaged layer from pre-machining so as to obtain a certain level of surface roughness and geometrical accuracy at last. However, polishing free-form surface mould is mainly manipulated manually at present, which is a kind of time-consuming and labor-intensive job, and requires great quantities of experienced experts and a considerable amount of high-precision skill. In addition, because of awful working condition caused by dust and noise, low efficiency of manual polishing and instable polishing quality, achieving the smooth and well-proportioned surface and geometrical accuracy is costly [1]. Aiming at such condition, it is very important to develop and establish some automated polishing techniques for more reliable and stable processing control, better movement accuracy, much higher polishing efficiency and well-proportioned surface quality.

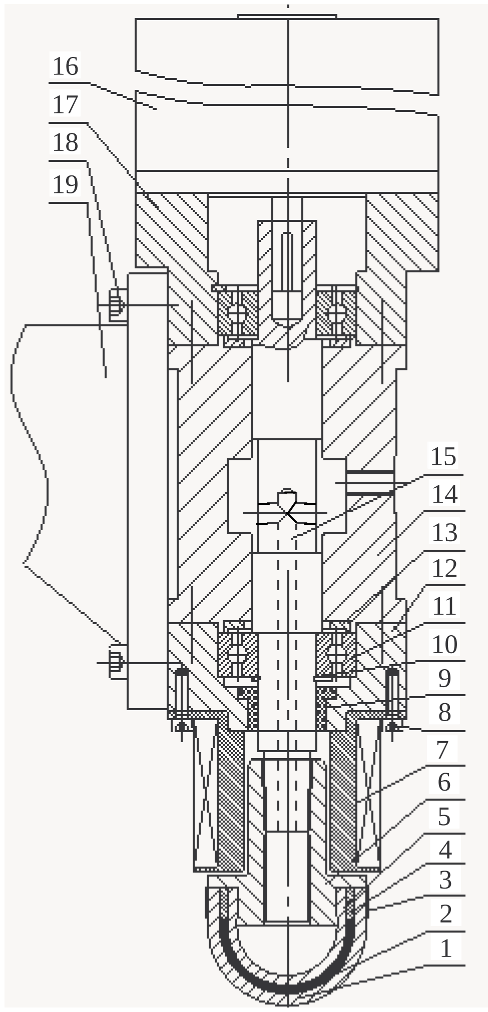
A large number of methods have been explored for implementing automated polishing and improving polishing quality and efficiency of free-form surface mould. M.C. Lee et al. developed a polishing system with a three-axis machining center and a two-axis polishing robot, which is able to keep the polishing tool normal to the die surface during operation and generate the polishing data from computer-aided design (CAD) data or teaching data [2]. D. D. Walker et al. proposed a novel flexible "Precessions" polishing tool for polishing large optics lenses and prisms which are flat, spherical or aspheric [3, 4]. N. Umehara et al. developed an apparatus for the finishing of large size silicon nitride balls by magnetic float polishing (MFP) technology for hybrid bearing applications [5]. B. S. Ryuh et al. presented a robotic die polishing station controlled by a PC and a robot controller, which has an automatic tool changer and integrated software [6]. C. H. Liu et al. designed and manufactured an automated polishing system which includes a compliance tool holder produced by a linear spring and provides various degrees of compliance [7]. Meanwhile, based on the automated polishing techniques, other researchers focused on the fields of control of robotic mold polishing using a CAD/CAM-based position/force controller that simultaneously performs stable force control and exact pick feed control along curved surface, a robotic polishing cell for mold by an automated planning and programming system, a new shape adaptive motion control system that integrates part measurement with motion control in the application of robotic polishing, a loose abrasive polishing of free-form surfaces using a robot adopting the polishing path generated from the explored scanning paths, the development of a fixed abrasive pad using the water swelling mechanism of polymer binder network for automatic die polishing, and so on [8-14].

Robotic gasbag polishing technique for free-form mould including an improved gasbag polishing tool, a six degrees of freedom industrial robot and a pressure control system is proposed in this paper for obtaining well-proportioned surface quality, high polishing efficiency, and certain level of geometrical accuracy. The robotic gasbag polishing system is used for holding the improved polishing tool and controlling the polishing process such as the path, position, orientation, pressure and rheological behavior. In order to ensure the robotic gasbag polishing more effective and intelligent, a special flow chart of polishing track planning and a low-cost solution of pressure control of the gasbag for better pose control and pressure adjustment are presented. The polishing experiments of free-form mould, observation of images after polishing indicate that robotic gasbag polishing technique can achieve well-proportioned surface quality and surface roughness of Ra 5 nm.

2 Robotic Gasbag Polishing Technique

2.1 Improved gasbag polishing tool

The authors of this paper have developed two kinds of spinning-inflated-gasbag polishing tools for polishing free-form surface mould [15]. In order to achieve fine airproof capability, obtain high precision of polishing, gain rapid response of pressure regulation, and exchange detachable modules for different sizes of rubber gasbag and magnetorheology device more easily, an improved gasbag polishing tool is designed, whose detailed mechanical structure is shown in Fig.1.



1. gasbag Ⅰ 2. magnethorheological fluid 3. clamp
4. airproof ring 5. gasbag Ⅱ 6. connecting piece
7. electromagnet 8. bolt Ⅰ 9. dustproof ring
10. baffle ring 11. bearing 12. coping Ⅰ
13. snap ring 14. joining part 15. shaft 16. electromotor
17. coping Ⅱ 18. bolt Ⅱ 19. robot connector

Fig.1 2-D drawing of improved gasbag polishing tool

The improved polishing tool consists of three detachable modules, which are the drive, soft rubber gasbag and magnetorheology. The drive module includes the components of electromotor, shaft, copings, joining part, dustproof ring, robot connector, bolts, baffle ring, bearing, which provides rotation and pressure of the polishing tool , connection with six degrees of freedom industrial robot’s end-effector by robot connector, and connection with soft rubber gasbag module or magnetorheology module by the morse taper of hollow shaft. The soft rubber gasbag module is composed of gasbag, clamp, and connecting piece, seen in Fig.2 (a). The magnetorheology module contains two gasbags full of magnethorheological fluid in the interlayer, clamp, airproof ring, connecting piece and electromagnet fixed on the coping Ⅰ by bolts, seen in Fig.2 (b).

Module design enables different sizes of soft rubber gasbag module and magnetorheology module to be exchanged fleetly and expediently, so as to deliver different ranges of continuously-variable polishing spot size and utilize one of the two polishing control methods which are type of pressure control, and type of magnetorheology and pressure control, shown in Fig.2.

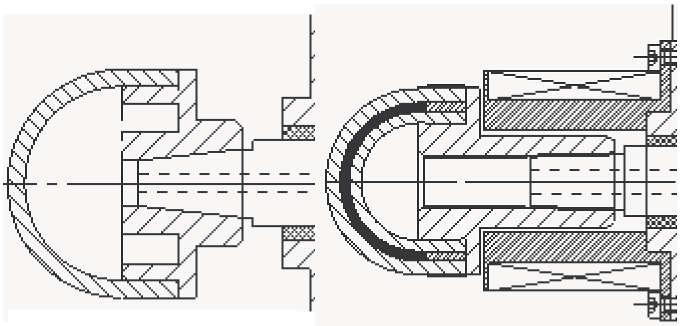


Fig.2 Two control types of polishing tool

2.2 Robotic gasbag polishing system

The robotic gasbag polishing system consists of improved spinning-inflated-gasbag tool, six degrees of freedom industrial robot Motoman-HP20, work-piece, workbench, measuring apparatus for rotation speed and magnetic field strength, DC power supply for electromotor, pressure control system, electromagnet control, PC, and measuring instruments for surface roughness, geometrical parameters or other demands.

The polishing tool is mounted on the end-effector of robot, which can move freely in 3D space along the free-form surface and keep a certain angle respect to the local normal direction, based on the robotic polishing track generated from CL data or conventional teaching mode. The polishing tool is driven by a DC electromotor whose rotation speed is 0-2500r/min. The rotation speed of polishing tool can be measured by the measuring apparatus for rotation speed and adjusted by the DC power supply based on the polishing process. The rotation speed of workbench can also be changed by the input voltage of a servo system. The gasbag is full of air and its inner pressure can be controlled on line by the pressure control system. Also, the interlayer of two gasbags is full of magnethorheological fluid which comprises of carbonyl iron powder and silicon carbide abrasives dispersed in a non-magnetic carrier medium like silicone oil, mineral oil or water commonly. During the polishing process, the rheological behaviour of magnetorheological fluid exhibits change in rigidity because of the existence of external magnetic field and its strength adjustment. The polishing cloth wreathed outside the gasbag is the working face with the action of abrasive powders.

So, the robotic gasbag polishing system can not only polish the plane or free-form curved surface mould automatically based on the polishing track containing the path, position, orientation and feeding rate, but also change the rotation speed, gasbag's inner pressure and rheological behaviour expediently in the polishing process. Moreover, the flexile polishing principle enhances the effect of compliance and reduces the polishing force variation.

2.3 Polishing parameters

During polishing, there are many parameters need to be considered, calculated and controlled calling them "3C" here. The internal pressure and rheological behaviour of the flexile rubber gasbag are the important factors in polishing process, which can influence the contact stress between the polishing tool and work-piece, local removal depth and error compensation. The diameter of the globular rubber gasbag can influence the size of contact area between the polishing tool and mould surface, but it should be neither too large nor too small. The suitable size of the globular rubber gasbag should be chosen based on the requirement of variation extent of curvature on the polished surface and material removal rate. The change of curvature in different contact points, the angular position between the axis of rubber gasbag and normal of contact area, and the rotation speed of the polishing tool may alter the contact stress, local removal depth and distribution of linear velocity of contact area. The feeding rate can influence the dwell-time of the polishing tool. The downward depth of the rubber gasbag against the surface of the work-piece can influence the size of contact area and the value of linear velocity of each contact point. The granularity and category of abrasive powder and the number of polishing may influence the local removal depth and the surface quality.

So, the internal pressure and rheological behaviour of the flexile rubber gasbag, the diameter of the globular rubber gasbag, the rotation speed of the polishing tool, the feeding rate, the angular position between the axis of rubber gasbag and normal of contact area, the downward depth of the rubber gasbag against the surface of the work-piece, the granularity and category of abrasive powder, the number of polishing and other effect factors should be chosen based on the requirement of the contact stress, material removal rate and surface roughness.

3 Track Planning and Pressure Control

3.1 Low-cost solution of pressure control

As mentioned in Section 2, internal pressure of gasbag, influences the contact stress between the polishing tool and work-piece which should be constant may as well, so establishing an accurate pressure control system is needed. A low-cost solution of pressure control system is proposed in this paper, in order to keep steady pressure. The block diagram of control solution is shown in Fig.3.

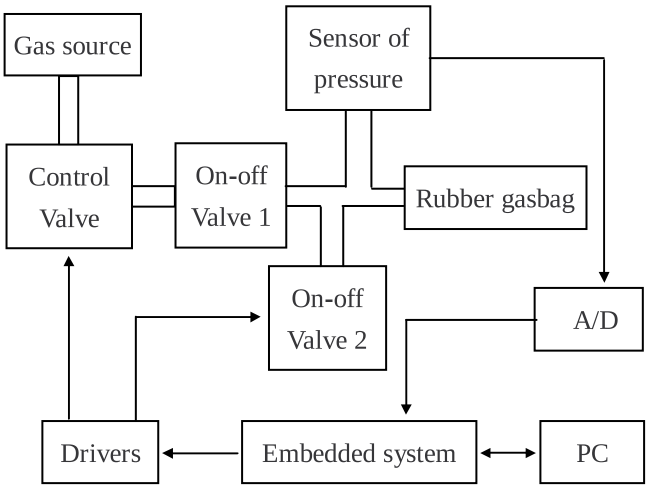


Fig.3 The block diagram of low-cost pressure control

Two high-speed on-off valves whose response time is smaller than 8ms and control method PWM are applied in this system. The on-off valves 1 and 2 are charged and discharged valve respectively. The pressure of gasbag is controlled by regulating the ‘on’ and ‘off’ times of two valves based on the generated PWM by embedded system. The sensor of pressure, two valves, and embedded system form a closed-loop control system. The block diagram of control solution is shown in Fig.3. Though, the accuracy of our solution to pressure control is little lower than the general servo valve’s, it can get the required control accuracy and has much lower cost.

3.2 Robotic gasbag polishing track planning

The Motoman-HP20 articulated robot has 6 degrees of freedom, and can drive the improved polishing tool scan-moving or swinging on the work-piece surface with the expected path until the desired surface is obtained. In order to get the polishing track such as path, position, orientation and feeding rate, a flow chart of polishing track planning is presented in this paper, shown in Fig.4.

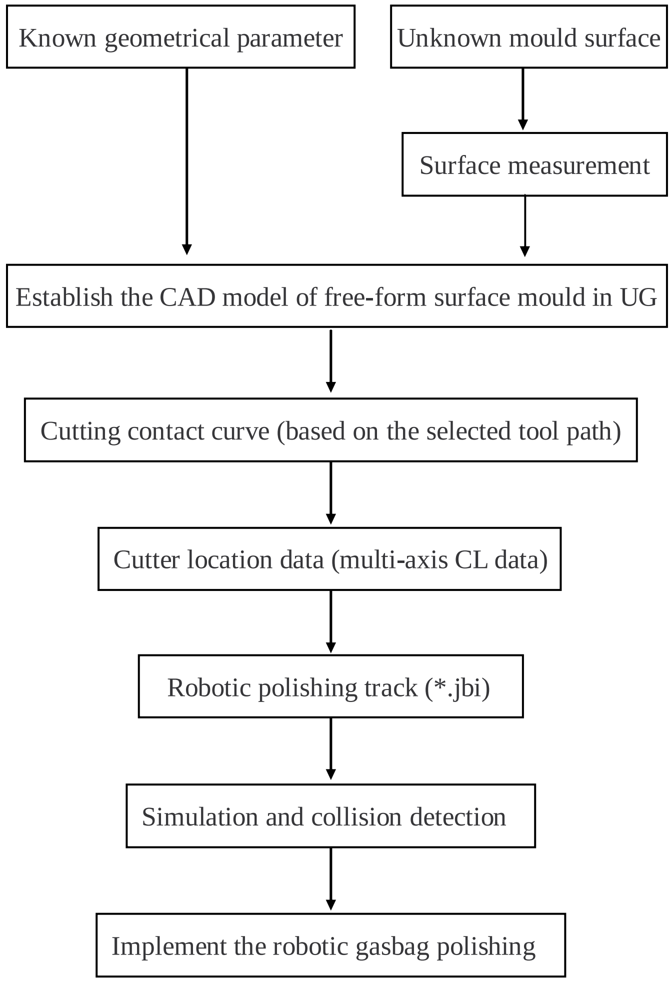


Fig.4 The flow chart of polishing track planning

If the information of free-form surface mould is known, the CAD model can be established directly under the environment of UG. If not, just utilize surface measurement by contact probe or non-contact probe to digitize the surface, and then reconstruct the surface.

Based on the selected tool path and considering the cutting tolerance and other factors, the cutting contact curve over the established surface is obtained. Then, generate the cutter location (CL) data from the cutting contact curve by the offset. The CL data consists of a position vector and its normal vector. The parameters of normal vector under the environment of UG are different from the rotary angles of robot. Meanwhile, as the linear velocity of rotation center of gasbag is zero, the polishing tool should be operated at a certain angle from the normal direction of contact area, so the transformation matrix between the CL data and robot is needed. Also, transforming the polishing data in the work coordinate system to that in the robot coordinate system is necessary during the polishing track planning.

4 Polishing Experiment

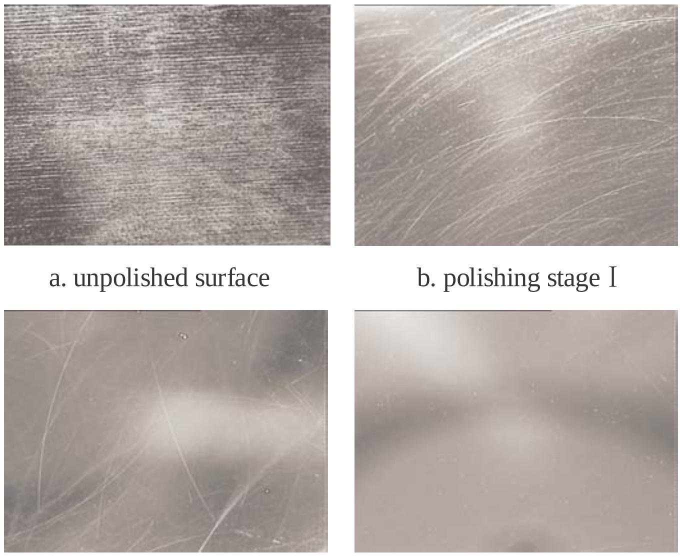
The polishing experiments of free-form mould are done based on the robotic gasbag polishing system. The experiment conditions are listed in Table 1. The comparison of surface roughness under dissimilar polishing conditions in different polishing stages is given in Table 2. Fig.5 presents the results of surface quality under different polishing stages using an optical microscope. Fig.6 shows the mirror surface images of two free-form moulds. It can be seen that robotic gasbag polishing technique can achieve well-proportioned surface quality and surface roughness of Ra 5 nm.

Table 1 Experiment conditions

Polishing equipment	Robotic gasbag polishing system
Material of work-piece	Die steel (original Ra 0.425μm)
Spindle speed(r/min)	500,1000,1500
Feeding rate(mm/min)	60, 120
Gasbag pressure(MPa)	0.10, 0.12
Abrasive powders	W3, W1.5, W0.5
Radius of gasbag(mm)	10,20
Other mediums	Coal oil and a special cosmetic

Table 2 Comparison of surface roughness

Unpolished surface	Ra 0.425μm
Polishing stage Ⅰ	Ra 0.041μm
Polishing stage Ⅱ	Ra 0.020μm
Polishing stage Ⅲ	Ra 0.005μm (Ra 5nm)



a. unpolished surface b. polishing stage Ⅰ

c. polishing stage Ⅱ d. polishing stage Ⅲ

Fig.5 Images observation in different polishing stages

a. convexity mould b. concave mould

Fig.6 Mirror surface of concave and convexity moulds

5 Discussions

The proposed robotic gasbag polishing technique can get the special polishing process such as the path, position, orientation, pressure and rheological behavior automatically through the flow chart of polishing track planning, low-cost solution of pressure control of the rubber gasbag and strength adjustment of external magnetic field.

Under the normal rigid automated rubbing condition, the surface of mould presents lots of tiny potholes and is relatively rough because of high-energy impact in local areas and being flaked off damage during the polishing procedure. Compared with the method of normal rigid rubbing polishing, the proposed robotic gasbag polishing technique based on flexible polishing principle implements a type of flexible contact polishing, makes the polishing tool match the free-form surface well and enhances the stability, efficiency and quality of polishing free-form mould effectively because of the soft gasbag's cushioning action, gasbag internal pressure's real-time control, rheological behavior's adjustment, robotic gasbag polishing system's reliable movement accuracy, mould surface's tiny wiped off process, and so on.

Certainly, how to get hold of optimal parameters combination and program effective polishing step and path that can improve the mould's surface quality and polishing efficiency needs more experiments and validation. How to choose appropriate polishing abrasive are also significant, which can depress heat accumulation, and achieve better polishing level.

6 Acknowledgement

This project is supported by National Natural Science

Foundation of China (No.50575208) and Zhejiang Province Natural Science Foundation (No.M503099).

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