Proceedings of the 6th WSEAS International Conference on Robotics, Control and Manufacturing Technology, Hangzhou, China, April 16-18, 2006 (pp277-283)

Design of Spinning-inflated-gasbag Polishing Tool and its Automated System for Free-form Mould

SHIMING JI, MINGSHENG JIN, LI ZHANG, QIAOLING YUAN, YALIANG WANG
The MOE Key Laboratory of Mechanical Manufacture and Automation
Zhejiang University of Technology
Hangzhou, 310032
CHINA

Abstract: - A new polishing method for mould free curved surface called gasbag polishing technique is introduced in this paper, in order to reduce the polishing time and improve the polishing quality. Firstly, the design of two kinds of spinning-inflated-gasbag polishing tools used in different automated systems is analyzed in detail. Secondly, CNC polishing system and Robot polishing system utilizing passive and self-driven tool are presented respectively. Thirdly, the details of polishing experiments using gasbag polishing tool, the figure of surface quality compare after final polishing process between the conventional and gasbag polishing method and the best value of surface roughness are given based on experiments, observations and measurements. Lastly, through a discussion based on theoretical analysis and experimental research, it achieves a conclusion that gasbag polishing technique has particular advantages compared with conventional polishing methods—making polishing tool match free-form surface well when working; enhancing the efficiency of polishing; getting well-proportioned surface quality and good value of surface roughness.

Key-Words: - Gasbag polishing technique; Polishing tool; Polishing system; Free form; Surface roughness; Surface quality.

1 Introduction

With the development of the mould industry and its related manufactures, these demand the equipments for high quality and efficiency in machining of free-form surfaces made. In order to achieve a smooth and planar surface before mould's application in industry, polishing must be performed. However, polishing a mould which has free-form surface is a time-consuming and labor-intensive job, and requires great numbers 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, obtaining the required roughness and smoothness is costly. Aiming at such condition, extensive work is being carried out to investigate possible methods of designing and implementing automated polishing system, which has more reliable and stable process control providing better movement accuracy and achieving higher surface quality.

R.G. Bingham et al. reported a new robotic polishing machine containing a bulged tool with internal pressure control for automatically grinding and polishing aspheric optics [1]. M.C. Lee et al. developed a polishing system composed of two subsystems, 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 [2]. C.H. Liu et al. designed and manufactured a compliance tool holder produced by a linear spring, which provides various degrees of compliance and holds a rotary electric hand grinder to the CNC spindle so as to form an automatic polishing system [3]. Moreover, an intelligent polishing system including a pneumatic polishing head which improves the surface quality of sculptured die surface, a robotic polishing cell for mold manufacturing, a six-axis high precision machine tool and its application in machining aspherical optical mirrors, a non-contact polishing tool utilizing a magnetic compound fluid (MCF), An oblique ultrasonic polishing method by robot for free-form surfaces, etc. were proposed [4-10].

Based on above-mentioned research outcomes and theoretical analysis, a novel gasbag polishing technique possessing various degrees of freedom of CNC or Robot system with a spinning-inflated-gasbag polishing tool which adopts soft rubber gasbag full of air inside and wrapped around by cloth outside for free-form mould is present. However, under the normal rigid automatic 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 processing procedure. Conventional polishing system has low rotation and orientation precision, and is hard to restrain mechanical vibration well and achieve a good compliance to the curved surface, thus result in the impacts between the polishing tool and the local areas of mould surface. Gasbag polishing technique which is based on flexible polishing principle can make polishing process more stable and effective because of cushioning of soft rubber gasbag. Also, the wiped off process of this tiny cleavage of the mould surface makes the free-form surface more subtle and well-proportioned composed of a lot of cleavage plane and weeny netlike structures.

This paper is organized in the following manners. In the second section, two kinds of spinning–inflated–gasbag polishing tools are analyzed in detail. CNC polishing system and Robot polishing system utilizing passive and self-driven tool are presented respectively in the third section. In the fourth section, the details of polishing experiments using gasbag polishing tool, the figure of surface quality compare after final polishing process between the conventional and gasbag polishing method and the best value of surface roughness are given based on experiments, observations and measurements. In the last section, a discussion of gasbag polishing technique's main superiority and difficulty based on theoretical analysis and experimental research is given.

2 Polishing Tool

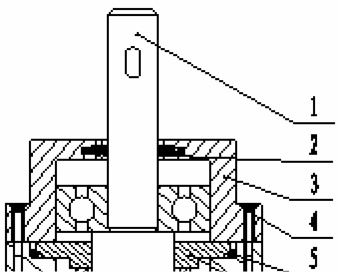
2.1 Passive spinning-inflated-gasbag polishing tool

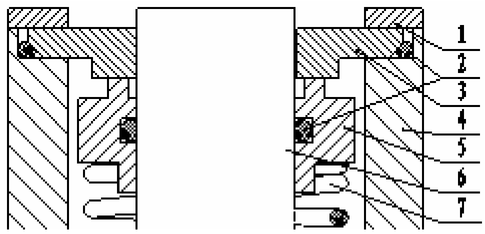
The structure of this design is logical and ingenious, and the control of this polishing tool is simple. As passive spinning-inflated-gasbag polishing tool hasn't self-driven machine, the spinning motion is offered by drill press applied in planar workpiece or CNC used to polish free curved surface mould. Fig.1 shows the tool's particular structure by 2-D assembly drawing.

This tool is composed of shaft, gasket, airproof ring, ventholes (one is entrance and the other one is exit), connecting piece, rubber gasbag, etc. The connecting piece not only makes the polishing cloth and rubber gasbag fixed with the help of clamp but also fastens the shaft firmly through the action of screw thread and bolt. Part of the shaft is hollow and in its vertical position there is a hole, which makes the gas transferred from airproof device to rubber gasbag. When the shaft rotates, the outline border of the tool named sleeve shouldn't move along with it because the sleeve has two ventholes which should hold still when the tool is operating. In fact, because of the existence of friction between the shaft and the gasket installed in the copings and the influence operated by means of centrifugal force, the sleeve of tool will rotate tardily. So it should be fixed to the motionless part of the CNC.

The path and control of the gas's transmission are explained as follows. Firstly, air compressor comes into being gas of certain pressure. Secondly, the gas is transferred to the venthole (entrance) via throttle which adjusts the pressure manually or automatically by computer. Thirdly, the gas runs into the airproof device, then the hollow shaft, finally the rubber gasbag. The venthole (exit) is also connected with throttle which regulates the flow of gas by opening the valve to a determinate caliber when the tool needs to reduce the pressure during the operation.

For the sake of obtaining controllable pressure accurately, the tool should have fine airproof capability. Fig.2 is the principle drawing of the airproof device. The material of the static ring fixed on the sleeve is bronze. And, the dynamic ring which rotates along with the shaft is made of stainless steel. Based on the material quality, it is known that the rigidity value of bronze is less than stainless steel's. So, when the dynamic ring rotates in high speed, the working face of dynamic ring contacted with the rigid stainless steel contacts with the stainless steel closely, which can gain an excellent airproof effect.





1. coping 2. airproof ring 3. static ring
4. sleeve 5. dynamic ring 6. shaft 7. spring

Fig.2 Airproof device

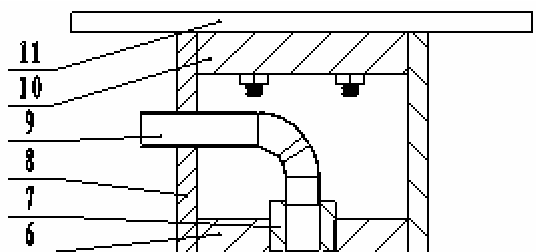
2.2 Self-driven spinning-inflated-gasbag polishing tool

Compared with the tool presented in section 2.1, this self-driven tool doesn't need extrinsic power and can be installed on the articulated robot.

Fig.3 displays the tool's detailed mechanical structure. The robot connector joins the Motoman-NL20 articulated robot and the self-driven tool so as to form a polishing system. The baffles are connected with crossbeams and electromotor by bolt. The SMC tie-in is hollow which can pass the gas and part of it is helical matched with the inner screw thread of shaft. Besides, the helical part can rotate around the axes of another part of the SMC tie-in fixed on the crossbeam . The electromotor drives the straight bevel gear through coupling, then passes the motivity to the hollow shaft, at last to the rubber gasbag. The polishing cloth, gasbag and connecting piece are fastened by clamp. Otherwise, the connecting piece connects with the hollow shaft by locknut.

Through compare, it is obvious that self-driven spinning-inflated-gasbag polishing tool only has one venthole, which is different from the passive tool. The way of adjusting the pressure only making use of one venthole is explained as follows. The airflow is divided into two paths when the gas generated from the air compressor approaches the master pressure controller. One path is connected with the self-driven tool' venthole and the other one is connected with atmosphere through another pressure controller which is called assistant pressure controller. Before operating the tool, it needs to close the assistant pressure controller, then open the master one and regulate it making the rubber gasbag attain original pressure defined as P_0. If the desired pressure during polishing exceeds P_0, keep the assistant pressure controller closed, then open the master one wider until attain the needed pressure. If the desired pressure lower than P_0, close the master pressure controller, then open the closed assistant one and adjust it until achieve the required pressure. Based on this situation, just continue to adjust the assistant pressure controller if the tool needs to get a lower pressure or close the assistant one and open the master one until gain the desired pressure.

Looking at Fig.1 and Fig.3, it can be considered that both of the tools are composed of two parts. The first part is a detachable sub-assembly that contains the rubber gasbag, polishing cloth, connecting piece and clamp. This enables rubber gasbag of different diameters to be fitted, in order to deliver different ranges of the continuously-variable polishing spot size. It also provides for replacement of parts damaged or worn in service. This detachable sub-assembly is connected with the other sub-assembly by the connecting piece and shaft.



3 Polishing System

The polishing head of tool has an inflated gasbag whose pressure can be controlled on line. Polishing cloth wreathed outside the gasbag is the working face with the action of abrasive powders for polishing. The polishing head is circumrotating in high speed driven by an interior electromotor, and the rotation speed can be regulated. Moreover the flexibility of working face, equivalent area contacting with the curved surface and polishing force in radial direction can be controlled by adjusting the machining deepness and gasbag pressure.

The passive polishing tool can be fixed on CNC and the self-driven tool is fixed in the terminal implement of Motoman-HP20 articulated robot, then two types of gasbag polishing experimentation flat are established. Both of the whole polishing systems are shown in Fig.4 and Fig.5.

The CNC system can measure the curved surface which is numerically integrated to give a prediction of the current surface form-displayed to the user by graphical maps. It can also be used to compensate for any process variability whilst polishing.

The Motoman-HP20 articulated robot has 6 degrees of freedom, and can move and rotate freely in 3D space. The robot and tool are controlled by computer, which can drive the tool scan-moving or swinging on the workpiece surface and achieve desired pressure in rubber gasbag.

Certainly, in the head of the rubber gasbag or in another place of the polishing tool, it can be set kinds of sensors in order to control and regulate the gasbag' pressure, tool-path, removal-rate or other parameters well

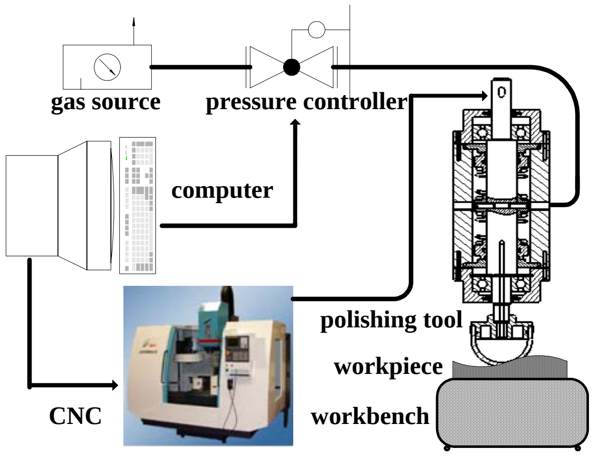


Fig.4 CNC polishing system

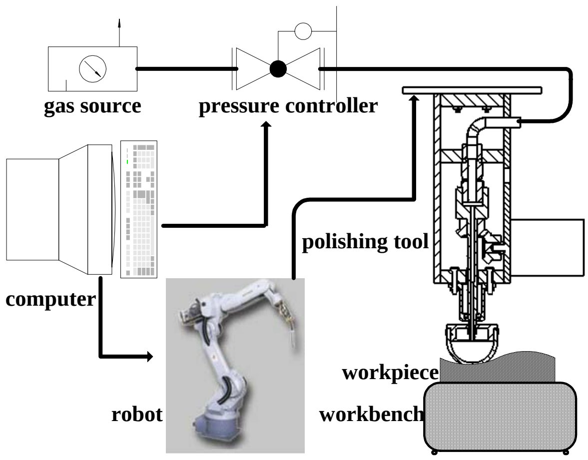


Fig.5 Robot polishing system

during process monitoring. Also, as the speed of rotation center is zero, so the gasbag as well as the tool should be operated at a certain angular position whose value is about 20 degree as a rule to achieve a larger removal rate.

4 Polishing Experiment

The polishing experiment of free-form mould is done based on the CNC and Robot polishing system. The conditions of the experiment are as follows. The diameter of the rubber gasbag is 40mm, and the rotation speed is 200~800 r/min. AL_2O_3 with the granularity W3 of abrasive powd

Table 1 Experiment conditions

Ballonet pressure *P* [Mpa]	Equivalent radius R_{eq} [mm]	Tangent speed *V* [mm/min]	Moving speed *f* [m/min]	Polishing number *N* [times]
0.1	48.52	300	8.0	30

Table 2 Roughness before polishing

Sequence number of the first direction	1	2	3	4	5
Roughness Ra [μm]	0.624	0.680	0.688	0.614	0.593
Sequence number of the first direction	6	7	8	9	10
Roughness Ra [μm]	0.722	0.789	0.722	0.783	0.821
Sequence number of the second direction	1	2	3	4	5
Roughness Ra [μm]	0.137	0.186	0.150	0.297	0.281
Sequence number of the second direction	6	7	8	9	10
Roughness Ra [μm]	0.245	0.190	0.198	0.209	0.245

Table 3 Roughness after polishing

Sequence number of the first direction	1	2	3	4	5
Roughness Ra [μm]	0.053	0.070	0.061	0.082	0.095
Sequence number of the first direction	6	7	8	9	10
Roughness Ra [μm]	0.108	0.120	0.103	0.139	0.121
Sequence number of the second direction	1	2	3	4	5
Roughness Ra [μm]	0.022	0.027	0.020	0.030	0.028
Sequence number of the second direction	6	7	8	9	10
Roughness Ra [μm]	0.033	0.026	0.031	0.035	0.037

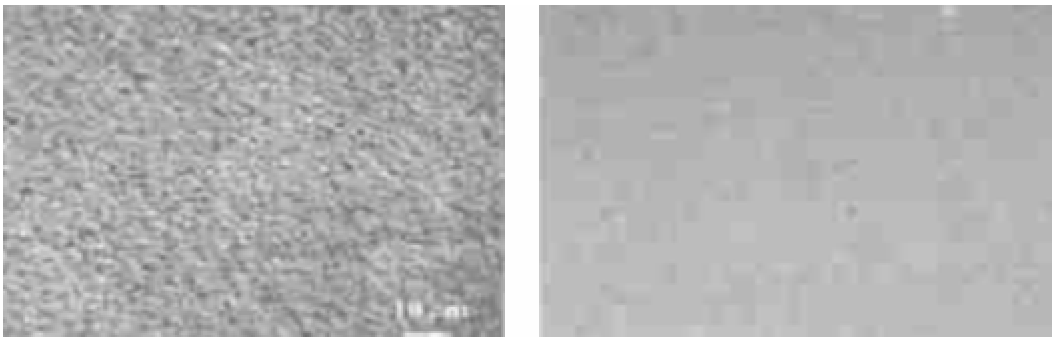
pressure is 0.1Mpa. The workpiece is the mould steel $Cr12MoV$ which is kibbled firstly. It is 20 degree between the circumrotating axes of the polishing tool and the normal of the mould surface.

The experiment conditions and results are shown in Table 1, Table 2, Table 3 and Table 4.

After polishing, we achieve the roughness Ra is 0.062 μm at the best. So we have the sufficient confidence that gasbag polishing technique can achieve well-proportioned surface quality and good value of surface roughness. Fig.6 shows the images after polishing by optical microscope.

Table 4 Roughness compare

Item / Contra	Roughness in the first direction	Roughness in the second direction	Roughness
Before polishing	Ra 0.704 μm	Ra 0.214 μm	Ra 0.459 μm



Conventional polishing　　Gasbag polishing

Fig.6 Surface quality's compare between the conventional and gasbag polishing

5 Discussions

Based on certain theoretical analysis and experimental research, gasbag polishing technique has the following advantages compared with conventional polishing methods and some automated polishing techniques:

The contact between polishing tool and free-form surface is soft and the contact area is large, so it can obtain a smooth working contact face and high polishing efficiency satisfactorily.

The polishing force in the direction of workpiece surface normal can be easily adjusted and controlled as the change from point to point when the workpiece surface geometry varies, so the surface quality can be achieved as expected.

The control of stress and area of soft contact between polishing tool and free-form surface is attained through regulating the pressure of rubber gasbag on line. In this way, with the variety of workpiece surface curvature and surface roughness required, the extent of soft contact can be changed based on the process planning, so the working face can gain fine polishing character.

The polishing tool which is mounted on the Motoman-NL20 articulated robot or CNC can generate tool-path from teaching data or computer-aided design data by computer-aided manufacturing system. As the automated polishing tool can get arbitrary position of the tool with respect to the local surface of the mould and adjust the pressure of rubber gasbag on line, the polishing system can get constant contact stress and regulate the removal rate.

Certainly, how to setup the values of various parameters such as ballonet pressure, equivalent radius, angular position between the axis of rubber gasbag and normal of contact areas, rotation speed of the polishing tool, feed speed and the number of polishing, and get hold of optimal combinatorial parameters through large numbers of experimental research and data disposal are difficult but crucial, which can improve the mould's surface quality and polishing efficiency. How to minimize the variation of the rubber gasbag's size, namely wear, and choose appropriate polishing abrasive and liquid aiming at get good polishing level and depress heat accumulation are also significant which can get less process error. Moreover, how to program polishing step and path availably is very important which can reduce polishing time and gain smoother surface.

References:

[1] R,G. Bingham, D.D. Walker, D-H. Kim, D. Brooks, R. Freeman, D. Riley, A Novel Automated Process for Aspheric Surfaces, Proceedings of SPIE 45th Annual Meeting, Vol.4093, 2000, pp.445-450.

[2] M.C. Lee, S.J. Go, M.H. Lee, C.S. Jun, D.S. Kim, K.D. Cha, J.H. Ahn, A robust trajectory tracking control of a polishing robot system based on CAM data, Robotics and Computer Integrated Manufacturing, Vol.17, No.1-2, 2001, pp.177–183.

[3] C.H. Liu, C.-C.A. Chenb, Jian-Sheng Huang, The polishing of molds and dies using a compliance tool holder mechanism, Journal of Materials Processing Technology, Vol.166, No.2, 2005, pp.230–236.

[4] J.H. Ahn, M.C. Lee, H.D. Jeong, S.R. Kim, K.K. Cho, Intelligently automated polishing for high quality surface formation of sculptured die, Journal of Materials Processing Technology, Vol.130–131, 2002, pp.339–344.

[5] J.J. Márquez, J.M. Pérez, J. R´ıos, A. Vizán, Process modeling for robotic polishing, Journal of Materials Processing Technology, Vol.159, No.6, 2005, pp.69–82.

[6] Hao-Bo Cheng, Zhi-Jing Feng, Kai Cheng, Ying-Wei Wang, Design of a six-axis high precision machine tool and its application in machining aspherical optical mirrors, International Journal of Machine Tools & Manufacture, Vol.45, No.9, 2005, pp.1085–1094.

[7] H. Hocheng, K.L. Kuo, Fundamental study of ultrasonic polishing of mold steel, International Journal of Machine Tools & Manufacture, Vol.42, No.1, 2002, pp.7–13.

[8] K. Shimada, Y. Wu, Y. Matsuo, K. Yamamoto, Float polishing technique using new tool consisting of micro magnetic clusters, Journal of Materials Processing Technology, Vol.162–163, 2005, pp.690–695.

[9] Ji Zhao, Jianming Zhan, Rencheng Jin, Minzhong Tao, An oblique ultrasonic polishing method by robot for free-form surfaces, International Journal of Machine Tools & Manufacture, Vol.40, No.6, 2000, pp.795–808.

[10] Avery Roswell, Fengfeng(Jeff) Xi, Guangjun Liu, Modelling and analysis of contact stress for automated polishing, International Journal of Machine Tools & Manufacture, Vol.46, No.3-4, 2006, pp.424–435.