CIRP Journal of Manufacturing Science and Technology 14 (2016) 55–64

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

journal homepage: www.elsevier.com/locate/cirpj

Modeling and control of robotic automatic polishing for curved surfaces

Fengjie Tian *, Chong Lv, Zhenguo Li, Guangbao Liu

School of Mechanical Engineering, Shenyang Ligong University, Shenyang 110159, China

ARTICLE INFO

Article history:
Available online 17 June 2016

Keywords:
Precision manufacturing
Robotic polishing
Compliant control
Curved surface
Surface roughness

ABSTRACT

This paper presents the solutions adopted for a robotic automatic polishing platform for finishing machining on curved surfaces to reduce cost and improve quality on such manual finishing operations. The polishing platform was built and the polishing process was studied. In order to accomplish the control of polishing force, the relationship among the robot, sensor, polishing tool (cutter) and the force impacted on the polished parts is established. On this basis, the model of removal distribution is built for each polishing path, a suitable path spacing algorithm further obtained by the same scallop height, and an effective planning algorithm of tool location is proposed. An active and passive compliance control polishing model is set up by explicit force control based on position and the methods of tilting polishing tool with elastic sponge disk. Finally, validation experiments are performed on mold parts of NAK80 steel. The experiments display that the robot achieves a relatively constant force control effect by the active and passive compliance force control. The results show that the proposed automatic polishing platform has the good ability of effectiveness and feasibility for polishing on curved surfaces, and is able of achieving a mirror effect surface and keep a good global uniformity.

Introduction

In the manufacturing industry, the requirements for high quality precision parts with complex geometries have been becoming higher [1–3]. The final surface finishes of some machined parts such as molds are usually implemented by polishing operations in order to reduce the surface roughness to a desired level. However, the polishing process after numerical control (NC) milling of these parts mainly depends on manual operations, which is not only time-consuming and easily producing severe dependence on worker's experience, but also difficult to maintain a stable polishing operation for a long time [4,5]. The intelligence and automation of finishing process on curved surfaces are regarded as an important link with high quality, efficient and low cost, which is gradually more and more valued in industry and academia. Because of the flexible characteristics, an industrial robot is very suitable for automatic polishing on curved surfaces, and the construction of automatic polishing system is mainly based on industrial robot [6–11]. Marquez et al. [6] presented the solutions adopted for a robotic polishing cell for mold manufacturing, the automatic planning and programming system based on data from a CAD system is described. Huang et al. [7] developed a robotic grinding and polishing system used to replace the manual operation of turbine-vane overhaul, and a passive compliance tool combined with an adaptive path planning approach was adopted to overcome intrinsic problems arising from part-to-part geometry variations. Therefore, no matter from the perspective of productivity, cost, or the stability of product quality, automatic polishing process is highly desirable due to the advantages of robot in force and path planning control to curved surfaces.

The polishing on curved surfaces is very complicated and many factors can affect final polishing results. For example, Nagata et al. [12] presented CAD/CAM-based position/force controller that simultaneously performs stable force control and exact pick feed control along curved surface for a mold polishing robot. Tsai et al. [13,14] developed an automatic mold polishing system integrating mold geometry process kernel, path planner, process planner, and force control robot, which influenced by the normal vector, the principal curvatures, and the effective contact area. Lin et al. [15] proposed a path-planning method using an industrial robot to generate the robot polishing path based on the cutter location data. Xi and Liao et al. [16,17] proposed a new method for modeling and predicting the surface roughness of the parts in the stone polishing

* Corresponding author. Tel.: +86 13072448369.
E-mail address: tfj9311123@yeah.net (F. Tian).

http://dx.doi.org/10.1016/j.cirpj.2016.05.010
1755-5817/

process based on the random distribution of the stone grain protrusion heights and the force balance by contact grains, and developed a complete robotic polishing/deburring system that consists of a hybrid robot and a dual purpose compliant tool head, and a model of contact stress between the polishing tool and the part is established for an automated polishing process.

During polishing process, one of the important effects on machining quality is the polishing force between the polishing tool and the machined surface, and the polishing force changes with the change of curved surface curvature, polishing force loaded on curved surfaces and the polishing tool posture [18]. In order to get the high machining quality of curved surfaces, polishing tool should have good cutting ability and flexibility. Flexibility generally includes active compliance and passive compliance. Active compliance control, also called force control, adopts a certain control strategy to actively control the polishing force on machined surfaces according to the feedback information of sensor, which can ensure the constant polishing force by robot's actively complying with the change of the machined surfaces and achieve the requirement of processing plan. Shi et al. [19] proposed a novel force control method to control the polishing force to maintain a polishing pressure constant in precise NC polishing of aspheric parts based on the magnetorheological torque-servo. Passive compliance control is that polishing tools can produce natural obedience deformation (passive compliance) on the external force by means of some compliant mechanical components that mainly absorb or stored energy (such as springs, damping, etc.) when it contacts with the parts surfaces [7,20–22]. Liu et al. [21] designed a tool holder that may provide various degrees of compliance on reducing polishing force variation. Ryuh et al. [22] presented a robotic die polishing station which includes an automatic tool changer which is specifically designed to exchange the grinding tool that the operation is completely unmanned.

As above mentioned, maintaining a uniform removal rate is very important for precision surface during polishing processes. However, all paper show that it is not easy to flexibly achieve the target tasks by using mere force control methods such as hybrid position/force control [7,12,19,21,22] and impedance control [20]. Investigations on the model of material removal rate of curved surfaces are limited in the existing references for different polishing patterns and polishing tools. The difficulty is clear from the results that special hardware mechanisms such as manipulators, tools, sensors and measuring systems have been considered according to each manufacturing process. There also exist several problems that should be overcome at the present stage. In this paper, systematic techniques are developed for the automatic precision polishing of curved surface by robotic polishing platform adopting the active and passive compliant control structure by force-position-posture decouple control and an elastic sponge disk. The robotic polishing system platform was built. A pressure distribution model of the robotic polishing was derived and validated, and a removal rate model is subsequently proposed and testified. Then, the stepover size determination and cutter location planning strategy for uniform material removal depth were proposed. Automatic generation of planning strategy for polishing trajectory and polishing head posture for uniform material removal is given. Finally, the experiments were made and the results are reported in which the proposed polishing method has ability of achieving a precision finish to curved surfaces.

Experimental setup

As shown in Fig. 1, a robotic automatic polishing platform was built adopted the style of active and passive compliant control, whose polishing force control is used to realize the active compliance and tool with flexible abrasive tool is used to realize the passive compliance for the parts surface shape. The platform mainly consists of industrial robot, robot controller, force sensor, polishing tool with elastic sponge disk, computer and workbench. Force sensor is used to test polishing force and feedback to the platform. The platform compensates and adjusts the position and posture of polishing tool to realize constant polishing force on machined surfaces by the decoupling control of the position, posture and force according to the control strategy. Not only can effective position and posture accuracy of polishing tool be improved, but also the polishing force control can be carried correspondingly with the change of the curved surface curvature. The same removals are achieved by controlling the polishing constant force, which is used to improve the machining quality. Fig. 2 shows the flexible polishing tool. Flange is used to connect the compliant tool and the robot end, *L* connecting frame is used to achieve the coaxial between tool spindle and the *Z* axis of the robot's sixth axis, force sensor is installed between *L* holder and the right angle connector, the right angle frame is used to fix the motor, the chuck is used for the rapid clamping of elastic sponge disk, abrasive paper can be fixed on the bottom of elastic sponge disk and replaced easily.

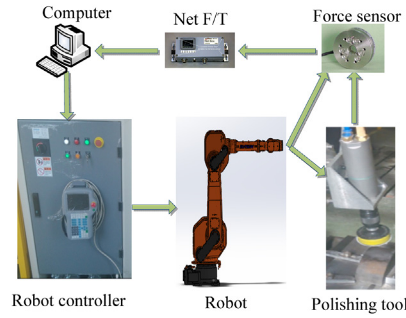

Fig. 1. Robotic automatic polishing platform composition.

The process of automatic polishing includes two parts: (1) The machined model built by CAD/CAM software is imported into the self-made path planning software, the computer generates robot language program and loads into the robot controller to implement the control for the robot's movement and the position and posture of polishing tool for machined surfaces. (2) The force sensor real-timely measures the polishing force data, and the data are amplified, filtered to digital recognizing signal and transmitted to computer by Net F/T modulator. The computer deals and compares the difference value between the preset polishing force and the actual measurement value, and calculates the correction value of position of the polishing tool by control algorithm. The correction value is transmitted to the robot controller for driving the robot to adjust the polishing tool position to keep the polishing force constant.

As shown in Fig. 3, the communication scheme among robot, sensor and computer includes two respectively control threads:

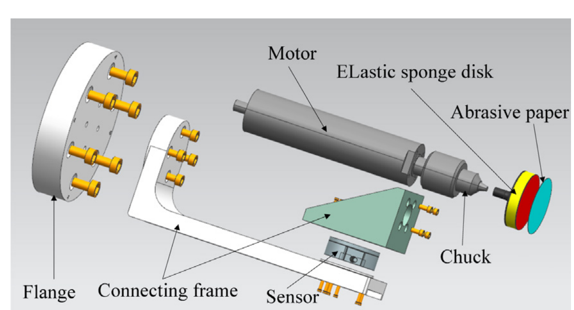

Fig. 2. Composition of compliant polishing tool.