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Process modeling for robotic polishing

J.J. Márquez, J.M. Pérez*, J. Ríos, A. Vizán

Department of Mechanical and Manufacturing Engineering, E.T.S.I.I. Polytechnic University of Madrid, Spain

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Abstract

This paper presents the solutions adopted for a robotic polishing cell for mold manufacturing. Mold finishing is frequently carried out manually; these kinds of operations are iterative, time consuming and require experience. Automation can introduce cost reduction minimizing production times on such manual finishing operations. The research shown in this paper provides an overall solution without discarding aspects that could be relevant to the task considered in the mold making environment. Most of the mold makers usually employ CAD/CAM systems in order to design workpieces and to prepare the CNC programs to manufacture the parts, this CAD data can also be used to prepare programs for the actual robot finishing of these parts. In this work, an automatic planning and programming system based on data from a CAD system is described. The direct use of the paths implies difficulties of adaptation mostly when free-shaped surfaces are treated, so that the use of a constant contact force control has also been considered. To accomplish the automation of the process it is necessary to establish a behavior model of the system's variables. This fact allows the definition of the task specifications of the tools and, as a result, both the planning system and the control strategy by stages of the polishing process.

Keywords: Polishing; Robot; Automation

1. Introduction

The objective of this paper is to present a description of the practical solutions adopted for building a robotic polishing cell for molds and free-form surfaces, the modeling of the polishing process, and its advantages in comparison with traditional methods used for this kind of part. Automation of the polishing process requires four basic development steps: (1) tool paths generation is obtained from a CAD system; (2) a controller with force feedback is needed to maintain constant tracking on real surface; (3) the polishing process is modeled by means of a computer application in order to predict the roughness values reached during the finishing of the surface; (4) this application also provides algorithms for controlling the process in order to reach the target finishing grade.

Nowadays, most of the finishing processes over complex surfaces are carried out manually. The execution of these processes is highly based on the expertise of the operator who carries them out, and moreover, this kind of processes are frequently poorly modeled. The automation of the finishing operations represents the major technological barrier to reduce production costs.

Several approaches from different research groups have been trying to automate these processes. From the research works carried out in this field, it is meaningful to point out those made by Tönshoff et al. [1] who described a state-of-the-art technique in modeling and simulation of grinding processes. A theoretical model generalization on different aspects of the grinding process was proposed. Kurfess and Whitney [2] presented a predictive controller to interface with a robotic weld bead grinding system. To carry out this, a grinding model was used, this model was based on a nonlinear first-order differential equation. Kasai et al. [3] completed experimental work on polishing of optical devices and metallic surfaces, employing two roughness formation models to justify the use of flexible abrasive supports instead of rigid ones. Saito et al. [4] carried out the development of an expert planning system of the polishing process in order to establish an automatic manufacturing system for dies and molds. This system tries to be useful for schedule the polishing process and to be as similar as possible to expert performance of mold machinist. Mizugaki and Sakamoto [5] suggested a method of tool path generation from CAD system for a robot polishing system. The system was based on flat fractal curves generation and projection onto the free-form surface of a workpiece, to obtain a theoretical tool path over the surface.

In other works about systems of automated polishing, Mizugaki et al. [6] presented one of the earliest robot systems with contact pressure control using CAD/CAM data.

* Corresponding author.

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Nomenclature

c	exponent of the finishing grade evolution curve
e_1, e_2, e_3	components of the vector $\vec{e}$
$\vec{e}$	unit vector to define an orientation of the tool
F_x, F_y, F_z	components of the polishing force in X-, Y-, Z-axes
HB	workpiece hardness (Brinell scale)
i	counter for the number of operations
$\vec{i}$, $\vec{j}$, $\vec{k}$	components of the Cartesian unit vector in X-, Y-, Z-axes
j	counter for the number of passes
$\vec{n}$	unit vector normal to the surface
n_x, n_y, n_z	components of the vector $\vec{n}$
N_{it}	number of passes to reach R_{ait}
q	quaternion
q_i	quaternion components
R_a	general finishing grade measured by the arithmetic mean deviation roughness
R_{ai}	finishing grades reached in polishing operation number i
R_{ait}	practical value where R_{mi} can be considered is reached
R_f	final finishing grade after the complete set of operations (target finishing grade)
R_{fi}	final finishing grade reached after the operation number i
R_{mi}	minimum reachable finishing grade for the operation number i
R_o	initial finishing grade at the beginning of the polishing process
R_{oi}	initial finishing grade at the beginning of the operation number i
S_x, S_y, S_z	components of the dynamometer sensitivity in X-, Y-, Z-axes
TG_i	available abrasive grain size for the operation number i
TG_{if}	minimal available abrasive grain size

Greek letters

ΔN_m	minimal number of passes between roughness measurements
θ	angle to define the rotation about the unit vector

Kuo [7] used fuzzy neural networks for a robotic die polishing system. Ahn et al. [8] also used a expert system for optimizing the process. Lee et al. [9] used CAM data to control the trajectories of a polishing robot system. Su and Sheen [10] developed a process planning strategy for a very particular application. And finally, Tam et al. [11] accomplished the problem through scanning paths to polish free-form surfaces.

About the polishing processes and its variables, there is a great number of works, of which some of the latter ones are those of Lin and Wu [12] that studied the effects of polishing parameters on material removal rates and non-uniformity effects, Klamecki [13] built up a comparison of material removal rate models and experimental results in double sided polishing processes, Kim et al. [14] worked with active profiling for the polishing of large precision surfaces with moderate asphericity, Su et al. [15] made a study on smoothing efficiency of surface irregularities by hydrodynamic polishing, Hocheng and Kuo [16] and Zhao et al. [17] used the ultrasonic polishing for mold steels and free-form surfaces, and Venkatesh et al. [18] made a theory about the genesis of workpiece roughness generated in surface grinding and polishing of metals.

These works provide different partial views of the aspects involved in the complex surface polishing problem. The proposed automatic robotic polishing system intends to integrate one theoretical model for finishing parameters evolution with a control system for a robotic polishing cell to automate as far as possible the finishing operations over complex geometry workpieces. To carry out this objective one process planner and one computer aided programming system have been developed within of a CAD system environment. These applications have been presented in previous works of Marquez et al. [19,20].

2. Experimental setup

The cell is based on a six axis robot, located in front of the workbench in which the molds to polish are fixed. On the left-hand side of the robot the motorized tool storage is located. Fig. 1 depicts a layout of the polishing cell. The cell is made up of an ASEA ABB IRB-3000 robot, with the control system S3 and a personal computer where the supervision system as well as the stage planner and control system are executed. The CAD system (Autocad v14 or Euclid v3) is running on a separate workstation.

The force control instrumentation is made up of a three axis piezoelectric force sensor Kistler 9257A with force

Fig. 1. Robot polishing cell experimental setup.