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Robotic finishing process – An extrusion die case study

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ABSTRACT

Current automated finishing techniques are almost not applicable on parts with free form surfaces and function relevant edges, as commonly found in moulds and dies. The finishing of these tools has to be done predominantly manually. In this paper a robot integrated finishing process is presented and the essay focuses on the automated finishing of a real extrusion die. Integrated into the six-axis robot, a pneumatic compliant spindle has been adopted in order to deburr and grind the large spectrum of free-form topographies.

Initial experiments verified the predictability of generated surface qualities in dependency of identified main process parameters. In sequence, based on an empiric parameters model, an extrusion die was automatically finished resulting in superior surface quality. Furthermore, evaluations were conducted to quantify the existing robot accuracy issues during the experiments.

Introduction

The tool and die making industry is spread all over the world. While countries such as Brazil, China and India have a high growth potential in the field of small and simple tools, High-Wage Countries have to fight for their reputation of high quality and complex tools which results in a high demand for innovation and improvement. With an average annual turnover of 13 billion € and more than 7000 companies (95% of them being SMEs/SMBs), the tooling industry represents an important economic sector in Europe [1].

The finishing of moulds with surfaces suitable for gloss or even high gloss applications is predominantly done manually which is very time-consuming, costly and dependent on the skill and experience of the manual worker. Manual finishing of injection, extrusion and die casting moulds can take up to 50% of the total production time which represents around 12–15% of the manufacturing costs [2–6]. In order to remain competitive against low-wage countries, the tool and die maker has to keep shorter delivery times with increasing requirements on form and surface quality. Further improvements increasing the efficiency of this process will need a combination of the application of an automated solution supporting the manual worker as well as the corresponding process knowledge of the finishing process.

This paper focuses on the automated finishing of a real extrusion die applying the combination of a six-axis robot to substitute the craftsman's arm, a pneumatic compliant spindle, to implement a pressure control applied by the grinding tool with respect to the surface, the process and the programming of the robot arm movement through CAM software according to the most appropriated main grinding and deburring parameters (tool orientations, cutting velocities and cutting forces). The first step of the investigation was to identify and quantify the process parameters influence to the surface quality that would be applied in the real extrusion die finishing. The gathered information allowed verifying simultaneously the predictability of generated surface qualities in dependency of identified main process parameters. Based on an empiric parameters model, a real extrusion die was finally finished automatically, taking into account the established parameters for a projected surface quality. Furthermore, due to difficulties encountered during the trials, a sequential and simple evaluation of the robot accuracy in similar conditions of the experiment was conducted to identify and understand robot behaviour and quantify deviations.

State of the art

The so-called finishing technologies include all manually applied processes such as grinding, lapping and polishing which are misleadingly simply referred to as "polishing" in industry. Scientific approaches to realize robot assisted finishing were started more than 30 years ago [3–15], since articulated robots gained more acceptance in industry. Despite of various published

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and partially promising results there is still no commercial automated solution which could cover most of the use cases in the tooling industry available.

It can be stated that apart from industrial solutions to automate the grinding process of welded joints on ship propellers, aircraft wings or bathroom fittings by belt grinding and/or wheel polishing from similar products, the analysis of the state-of-the-art showed that neither from scientific investigations nor from industrial developments a suitable approach can be derived to support the complex, multi-stage process of finishing of free-formed steel surfaces. Due to the application of abrasive tools unsuitable to automated processes of cavities or of over-engineered system the existing finishing cells in the market are not capable to achieve the necessary surface finishing requirements from the tool and die making industry. Almost entirely all finishing steps in this industry sector, as in many other ones, still have to be conducted manually. From an analysis of existing equipment and present and past investigations in robot finishing a set of requirements was derived addressing further automation of the finishing process with the application of a robot cell. For a reproducible and stable process the following main topics have to be further developed and tested: robotic cell hardware equipment, robot programming and finishing process technology. The developed solutions should strongly regard the main requirements of the typical companies that offer manual finishing services, presenting an automated solution system with simplicity and robustness to handle the finishing process accompanied by primarily low costs in the acquisition and maintenance.

Experimental setup

Geometry features and characteristics of the aimed extrusion die

The selected extrusion die (Fig. 1) was milled in a 5 axis CNC-machine and the aim was to automatically finish it during the experiments. This extrusion die, applied in the manufacturing of aluminium profiles is made from the commonly applied steel 1.2343. As in other branches of the mould die making industry the steel was tempered prior to the milling process to a hardness of approximately 52 HRC. For deburring and to enhance the surface quality prior to application of the die in the extrusion machine, the marked cavity surfaces (see Fig. 1) have to be manually finished with the use of rotational grinding cloths (SiC P40).

The extrusion die is a particular small tool if compared with similar tools manufactured for extrusion applications and can be roughly dimensioned with an external diameter of 320 mm and a height of 90 mm. The finished target geometry consists mainly of one topography mapped into the four cavities. The topography has a minimal concave radius around a value of 8 mm, restricting the size of grinding tool for an automated and as well as an manual operation.

Table 1
Generated surface roughness before and after the adopted manual finishing.

	After milling		After finishing	
	Min	Max	Min	Max
Ra (μm)	0.9	3.4	1.3	2.22
Rz (μm)	14.7	32.0	9.8	15.4

Quality criteria for the automated solution

The surface quality of the die after the hard milling process and the sequentially reached roughness from the adopted manual finishing of the investigated extrusion die is depicted in the Table 1.

It is noteworthy that in specific surface spots the previous milling process had generated even better surface qualities in means of surface roughness than the finishing process. However it became clear through the roughness measurements, that the finishing process had as principal objective to generate a more homogenous surface quality and to correct protuberant defects in the surface. Table 1 shows the minimum and maximal Ra and Rz values 115 measured in different spots of the die surface. As an initial quality criterion for the automated process a rough surface characteristic from Ra of 1.8 and Rz of 12 μm was defined.

Furthermore, to be able to give a quantitative value describing the efficiency, the process time was selected as a second criterion to guide the selection of tools and process parameters that would directly affect both criteria, e.g. abrasive tool specification, robot movement velocity, etc. The current manual process takes around 60 min to finish the whole extrusion die. This equates to a surface finishing rate around 0.15 min/cm^2 and should be achieved in the automated process to maintain comparability between the manual and automated process.

Integrated robotic solution with a pneumatic compliance spindle

Before beginning the automated finishing trials with the extrusion die, the adopted finishing solution with the robot was evaluated on flat surfaces with the same material characteristics as from the extrusion die. The objective of this preliminary test was to guarantee the functionality of the integrated robotic system with a pneumatic spindle (see Fig. 2, *left*) and manly to identify the

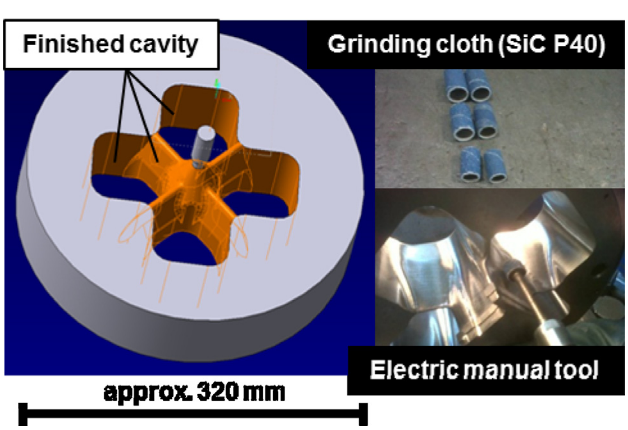

Fig. 1. Extrusion die and manual abrasive tool

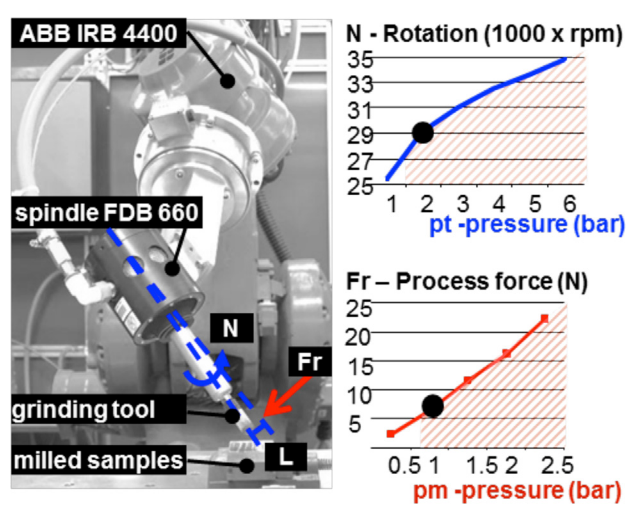

Fig. 2. Integrated robot with the pneumatic spindle grinding a milled steel sample

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