Robot Assisted Finishing of Dies and Moulds With Automated Quality Control

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Abstract:
In the manufacturing of dies and moulds, up to thirty to forty percent of the total time is spent on hand finishing in many instances. Given the importance of die and mould industries, research efforts to reach a higher degree of efficiency are a matter of growing concern. This paper presents a robot system consisting of a 6 D.O.F. industrial robot, compliant finishing tools, end-effectors for surface inspection, and a robot controller communication with a tool path generation system. Though finish machining of complex, three dimensional surfaces is a difficult task for a robot, it is shown that this could be a suitable solution of high flexibility. Since dies and moulds are products of very high quality, the main focus has to be put on automated quality assurance and process control. The measurement and evaluation of surface waviness - which, in manual finishing, often implies a great deal of subjectivity - is, to some extent, integrated in the described robot system. Inspection of the surface enhances the efficiency and quality especially in case of machining critical parts such as dies for exterior sheet metal parts found in the automotive sector.

Keywords: *Die and mould manufacturing, automated surface finishing and inspection*

Introduction

In net shape manufacturing processes, dies and moulds are used to transform a given material into a useful part. The resulting part has to have a well-defined shape, size, tolerance, and appearance. The widely accepted use of CAD systems and improved communication between design and manufacturing has extensively computerized die and mould manufacturing. But in spite of computer aid in construction and production planning and NC-controlled milling, the finishing process is mostly carried out manually.

The concept of polishing relates to visual improvement and roughness decrease (figure 1).

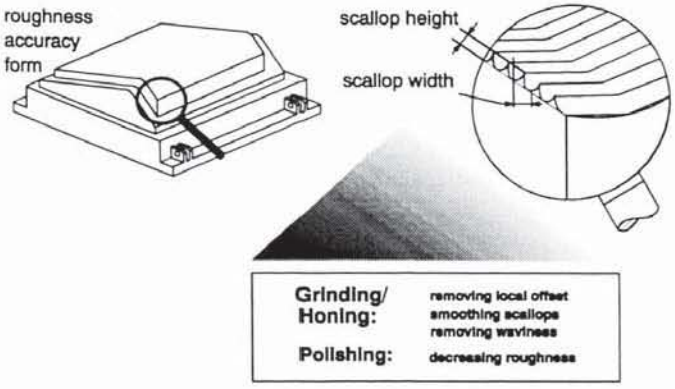

Fig. 1: Definitions and aims of finishing in the manufacturing of dies and moulds

With regard to surface roughness resulting from the milling process, a given offset has to be removed in such a way that the geometry specified in the construction phase is reached.

Hereby, errors or deficiencies in the proceeding manufacturing stages which lead to local variations of this offset (e.g. inaccurate programming, inadequate milling machine control and milling machine construction) have to be compensated.

In the final stage, the surface roughness reached has to correspond to the value specified for the workpiece. Additionally, the finished surface often has to correspond to optical requirements that, in many cases, have not even been clearly determined.

The object of the present paper is to develop an autonomous robot finishing system able to bring higher efficiency into the manufacturing process. In particular, basic approaches of automated inspection are included.

State of the Art

In view of the advantages resulting from the mechanization of this tedious, labour, time and money intensive work, automation has been attempted several times (figure 2).

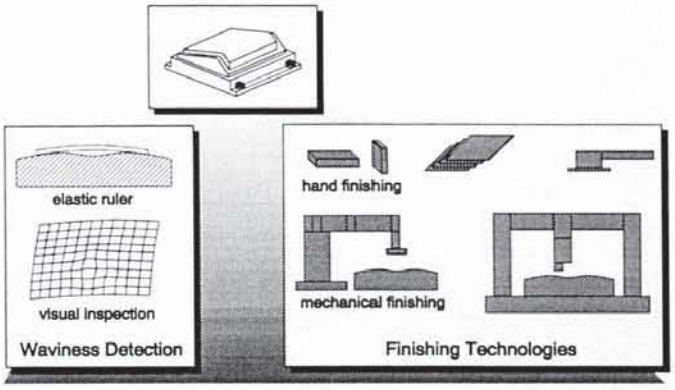

Fig. 2: State of the art

One of the two basic solutions found is the use of problem orientated polishing machines of high rigidity [1,2,3]. Though the field of operation is limited to the polishing of surfaces curved in a rather simple way, satisfying results have been obtained in some instances [4].

The second possibility is the use of an industrial robot combined with finishing end effectors. The most important advantages are a high number of degrees of freedom, easy programmability and comparatively low cost. The commercially available systems are mainly based on SCARA-Robots [5,6,7] of correspondingly reduced movability.

With regard to the special requirements concerning die and mould polishing, the crucial point is the inclusion of the quality characteristics of the surface to control the process. Finishing systems for the well-directed removal of an offset have mainly been presented in the field of deburring or grinding [8,9,10] or to correct the clearance distribution between punch and die [11]. In these cases requiring a lower degree of accuracy, a dimensional inspection is sufficient. However, testing technologies concerning typical faults of finished surfaces - e.g. slight waviness - are not integrated in those systems.

Tool Construction

Investigating the question which finishing technology could fulfill the boundary conditions, it was found that honing with a short or long stroke as well as surface grinding would be adequate. For this purpose, rigid and flexible cutting bodies can be used [12,13].

Based on evaluations of observations concerning manual polishing, different tools were constructed. Figure 3 shows one of the long stroke honing tools developed in case of which - in order to compensate inertial and cutting forces - two honing stones oscillate in opposing directions. The required contact pressure is produced by servopneumatically controlled pistons. The amplitude of oscillation can be changed steadily up to a length of 200 mm.

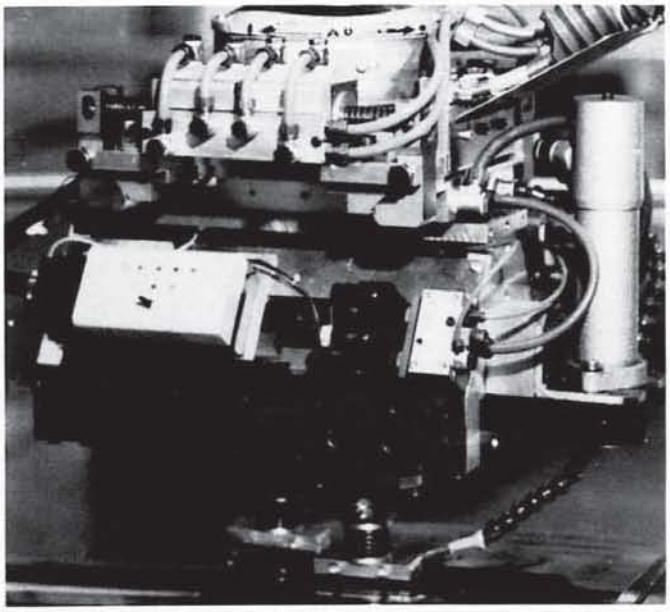

Fig. 3: Long stroke honing tool

The extended movement in connection with a high cutting speed leads to the result that the honing stone cannot follow local deformations. Thus it works solely on the elevated surface areas, hereby slowly removing the topographical fault (figure 4).

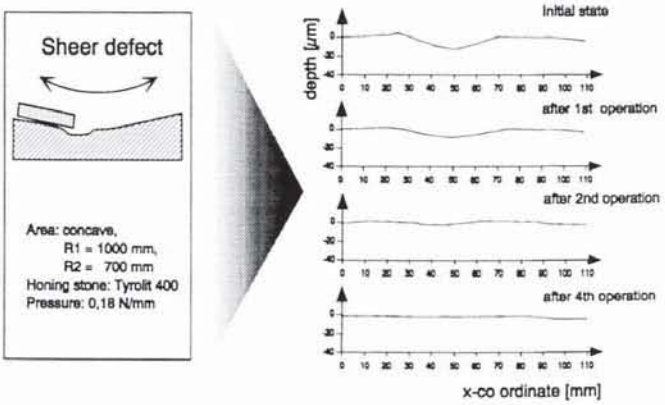

Fig. 4: Removing of a topographical fault by long stroke honing

A high material removal rate is reached by the use of grinding tools. The developed grinding end effector displayed in figure 5 has a high compliance. The control system for the contact pressure also works pneumatically. This tool is suitable both for intensive material removal by grinding and for polishing.

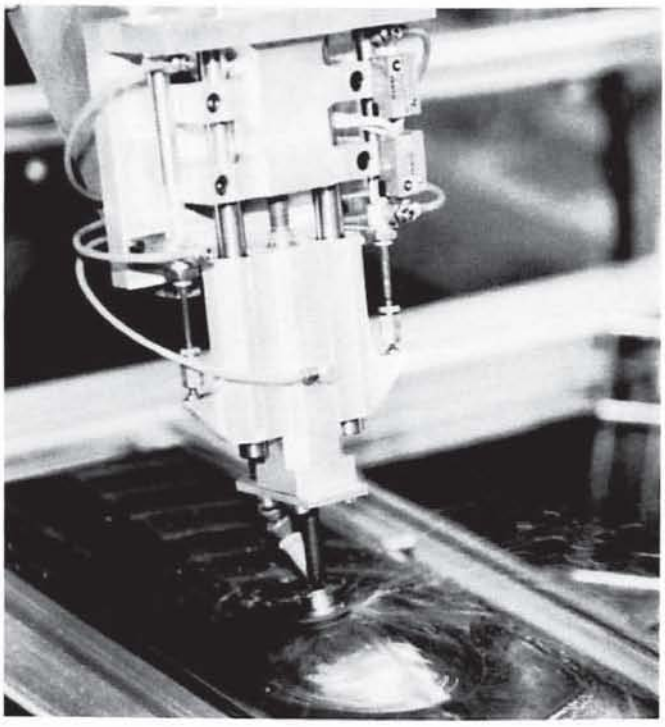

Fig. 5: Compliant grinding and polishing tool

Planning

Surface finishing is different from tasks such as assembly where criteria for good performance and successful completion are usually concrete, binary, and easy to sense and to compute. Process models are weaker than models of assembly tasks. Deciding what to do next during a task, or deciding that the task has been completed, is more difficult because the outcome of each grinding pass is uncertain [14].

The volumetric material removal rate is a function of the contact pressure, the grain size and sharpness, the tool velocity and the workpiece material. The average material removal rate is rather proportional to the power delivered to the material by the

polishing end effector. The theoretical modelling of the material removal in connection with the results obtained by experiments offers the basis to define a process model by means of which the polishing of free-formed surfaces can be described analytically.

The maximum performance of an industrial robot can be reached if CAD data is involved in robot programming. This especially applies to the machining of curved surfaces. The automated tool path generation system uses the CAD data to assign the suitable tools according to the respective surface curvature. Including the results from the material removal model, the robot control program is calculated.

Surface Inspection

The removed material during a pass depends on robot performance, cutting body sharpness, material hardness, and other parameters. With regard to the high quality requirements, the result delivered by a process fully depending on predetermined values is not satisfying in most cases. The occurrence of shape defects and waviness is not avoidable. As a result, an intermediate process inspection is required.

In order to control a polishing system, one of the main tasks is to get information about the result of the process. In manual finishing, quality assurance is effected by visual check or sense of touch or by sheering. Sheering means to press an elastic ruler, a so-called batten, equally onto the surface. Spots where the ruler is not in contact with the surface indicate irregularities. In any case the evaluation includes a great deal of subjectivity.

A basic approach to automated inspection in workshop environment was developed according to the batten described above. The sensor shown in figure 6 is based on a pneumatic gauge.

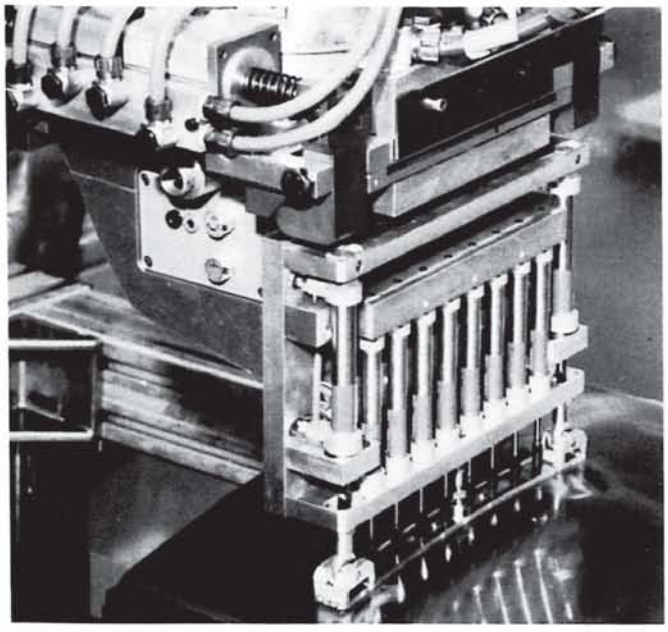

Fig. 6: Surface inspection by automated batten

The main requirements for the sensor are small resolution, especially concerning the detection of waviness, the ability to operate in an environment of sparks and honing oil, and easy evaluation.

The visibility of a surface fault is decisively affected by the local change of the radius of curvature. This means that a given depth and width of a fault will not inevitably indicate its visibility. That is the reason why this feature is a proper base for specific inspection.

The achieved accuracy of ± 3 µm is independent of the positioning accuracy of the robot. Due to the procedure of correcting an undulation fault the position and dimension of the fault can be determined by the robot itself with sufficient exactness (figure 7)[15].

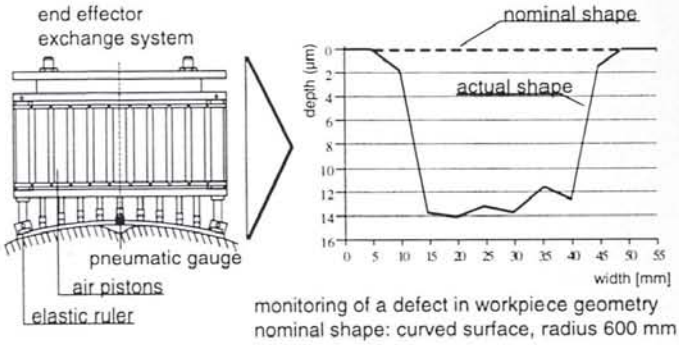

Fig. 7: Construction of the device and an example of an undulation fault measured

The automated batten is suitable for rather rough surfaces in the early stages of the finishing process. To involve visual aspects, a laser scanner is used to inspect surfaces with some reflectivity ($R_Z < 1$ µm) by observing the reflected line with the help of a ground-glass screen and a CCD-camera.

The device developed, which is handled by the robot, is shown in figure 8 schematically.

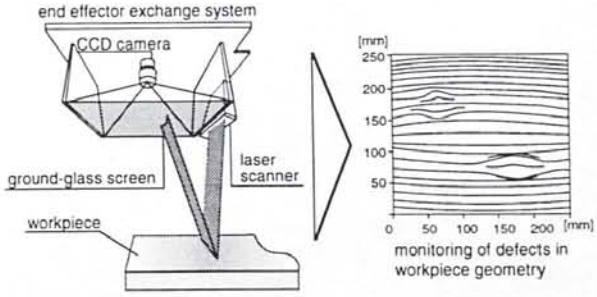

Fig. 8: Optical surface inspection by laser scanner and an example of defects detected

The experiments made show that the recognition of typical faults in finishing can be done by the robot system itself.

Quality Control Loop

The object of the present work is to develop an intelligent robot system by means of which the manual polishing of free-formed workpieces can be replaced effectively. An intelligent system is one having some autonomy. The ability to alter its behavior without outside help is an important requirement to adjust the system to changing conditions. The components to automate the finishing process and to inspect the surface make it possible to accomplish machining and inspection by a robot. The tool path generation system and the material removal simulation are integral parts of the quality control loop shown in figure 9.

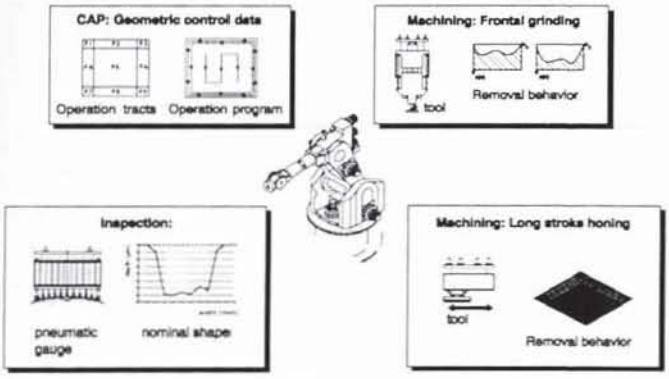

Fig. 9: Robot system for high quality finishing

A robot system for the automation of the finishing of dies and moulds only makes sense if it is able to fulfil the high quality requirements. The result of finishing dies and moulds depends on several uncertain effects such as robot performance, cutting body sharpness, material hardness and other parameters. The Influence of these parameters cannot be predetermined with the necessary accuracy in most cases. Therefore the occurrence of shape defects and waviness is not avoidable and it seems to be a good way to use an intermediate process inspection. It is the basis of the control strategy to extract relevant elements from uncertain and subjective ones (figure 10).

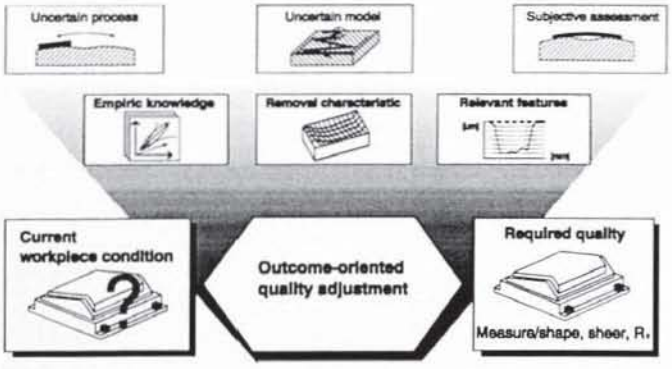

Fig. 10: Outcome-oriented quality adjustment

Its aim is not to totally penetrate the process, which could only be realized insufficiently and with great expenditure. Therefore it is important to interpret the processing's results and to include them in the process control as it is done in manual processing.

Theoretical models of material removal based on removal characteristics in connection with the empiric knowledge obtained by experiments offer the basis to plan the polishing process automatically. In order to fulfil the requirements on surface quality the results of the surface inspection are included in automated planning.

The completion of the quality control loop by intermediate inspection will enhance quality as well as efficiency and makes possible the integration of the finishing process into today's die and mould manufacturing.

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