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Deep hole drilling of polymethyl methacrylate with small diameters by actively compensating the hole straightness deviation

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Abstract
Deep hole drilling is very demanding in terms of process control and precision of the used machine tools. In particular for drilling of polymethyl methacrylate (PMMA) with small drill diameters below 1 mm specific aspects have to be considered compared to regular drilling. Instances are the low glass temperature and the poor heat transmission from the material´s viewpoint and the hole straightness deviation and the inability of proper process monitoring from the process´ viewpoint. Furthermore it hast to be evaluated individually if other manufacturing technology are possibly more suitable for the desired application.
In this paper the problems are discussed which occur when drilling polymethyl methacrylate with small diameters. On this basis the results of initial drilling tests are discussed and presented whereby the used concept for live condition monitoring of the process is introduced.

Keywords: Micro Manufacturing, Deep Hole Drilling, Polymethyl Methacrylate

1. Introduction

There is a widespread research field related to micro deep hole drilling and the associated opportunities and challenges which arise from this difficult task [1, 2]. The need of deep holes with small diameters and high aspect ratios of length to diameter increases mainly due to the demand of the medical device industry and the electronic industry. This growing need is driven by the trend of product miniaturization which has led to the development of novel manufacturing technologies by researchers all over the world [3]. One important step in machining a micro deep hole is to achieve a coaxial boring path over the entire desired depth. This is particularly important when the finished workpiece is characterized by a thin wall thickness.

In this paper the issue of a thin wall thickness is discussed which occurs by axial drilling of a transparent PMMA round stock with diameter in the same range as the used drilling bit. A machine tool is introduced to ensure a coaxial boring path for micro deep hole drilling in the PMMA fibre. First the desired micro deep hole application is proposed. The initial tests are introduced and the occurring problem of the drifting of the drill bit is analysed. In consequence of the undesirable results a correction mechanism is presented to prevent the drifting of the drill bit. This mechanism was realized in a machine tool by using optical measurement of the drill bit´s position and digital image processing.

2. Application

For a product of medical technology it is needed to axially drill a transparent PMMA round stock with varied diameters below 0.5 mm. Every fibre has a corresponding diameter of the drill below 0.75 mm. The remaining wall thickness of the round stock resulting from the different diameters is consequently below 0.25 mm. The targeted depth of the drill hole is in each case 10 mm which means it will be a blind hole drilling because the entire fibre is much longer than the targeted 10 mm. This results in high aspect ratios of hole depth to diameter up to 50. As determined in [4] other manufacturing processes besides mechanical cutting do not qualify for this application.

3. Initital results and process design

Initially the drilling process is performed with a Kugler ultra-precision micro-machine tool. Before the actual deep hole drill process starts, a pilot hole of 0.6 mm depth is machined to guide the deep hole drill. This is needed to get a reasonable drilling start and is a common procedure in deep hole drilling [2].

The process design is based on the different input parameters cutting speed, feed, rotation speed, feed speed. The resulting parameters are the hole straightness deviation as shown in Fig. 1 where m is the resulting deviation of m_x and m_y. The x- and y-components are measured to analyse if there is a pattern in the direction of the deviation. Additionally the circularity, the bore diameter and the surface quality of the finished product are measured.

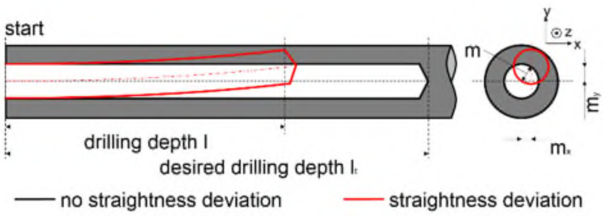

Figure 1. Hole straightness deviation

As a result of the pilot hole the drill path up to a depth of 4 mm to 5 mm is practically coaxial to the fibre. Past this depth coaxiality is no longer maintained. The drill bit is prone to drift in the material and the direction varies between the experiments without a pattern so the drift cannot be predicted. This leads to unacceptable damages to the fibre and the chuck. In the case of a drifted drill bit, damages occur to the round stock´s surface due to the thin wall thickness. Additionally the used clamping device does not allow the analysis of the process during the drilling procedure. To avoid these undesired results a machine concept [5] had to be developed to ensure a live condition monitoring of the hole straightness deviation and the possibility to actively control the path of the drill.

4. Live condition monitoring and correction mechanism

In order to counteract the drift of the drill bit a clamping device is designed with an integrated correction mechanism. To measure the position of the drill bit in the material in real time during the process a two-camera system is installed on a 90° offset to detect the movement of the drill bit in both directions. The evaluation is performed with the Image Processing Toolbox and Image Acquisition Toolbox by MATLAB, which provide feedback to the machine control. The results show that the drill drifts due to the previously introduced pilot hole in the central part of the desired drilling hole, so the round stock is clamped at the beginning, thereafter it remains accessible for visual inspection and is clamped again. With the detected current position of the drill bit the second clamping area can be moved in the X and Y direction via actuators [6] so that the drill bit continues running coaxially in the fibre (see Fig. 2).

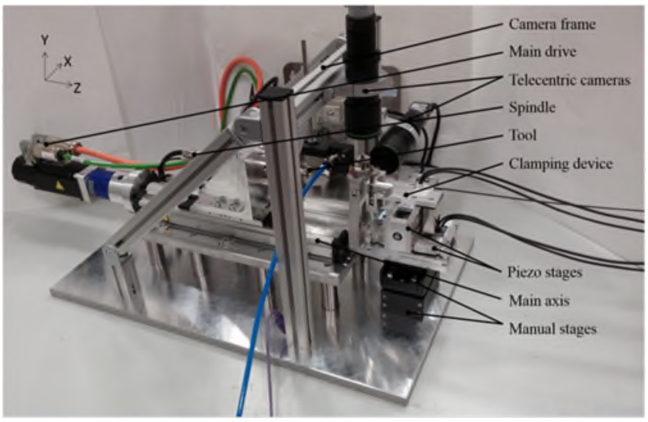

Figure 2. Micro deep hole drilling machine

The control of the main axis, the two piezo actuators and the compressed air valve for cooling are implemented by the TwinCAT automation software and the corresponding bus terminals from Beckhoff. The alignment of the drill to the fibre is carried out via the manual precision tables and the camera feedback. The current depth of the hole is computed by the digital image processing. The image processing and object recognition was implemented with MATLAB and the corresponding tool boxes for image acquisition and processing. The TwinCAT software components TE1400 & TE1410 were used to provide communication between TwinCAT and MATLAB via an ADS interface, so that the current displacement of the drill path can be reported with regard to the fibre centre. On basis of the detected current deviation from the concentricity of the fiber centric axis and the bore centric axis, the actuators are driven accordingly, so that the concentricity is maintained. The overview of the control components is illustrated in Fig. 3.

5. Operation results

The comparison of the drilling results of the Kugler ultra precision micro-machine tool and the developed deep hole drilling machine with an integrated correction mechanism shows a high improvement of the straightness deviation. The initial experiments resulted in a rejection rate of more then 50 percent due to damages of drifting drill bits. With the use of the live condition monitoring and the correction mechanism it is possible to reduce the rejection rate under 10 percent. The results regarding the circularity, the bore diameter and the surface quality are practically identical.

Figure 3. Overview of the control components

6. Conclusion and future work

This paper discusses the challenges occurring during machining micro deep hole drilling in a transparent PMMA fibre with small diameters. Results of initial drilling tests without a correction mechanism are discussed which have undesirable results. On this basis a correction mechanism is developed which prevents the drift of the drill bit in the material. This mechanism is implemented on the side of the work piece instead of adjusting the drill. The solution is enabled by the specific properties of the used material and the small dimensions of the fibre. The mechanism is realised in a machine tool and the control is implemented in the Beckhoff TwinCAT automation software. The control and the digital image processing which is implemented in MATLAB is discussed and presented. Tests with the engineered machine show that the process is possible with much better results compared to the unpredictable initial procedure without a correction mechanism.

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