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Visual Inspection Method for Micro Tool-Workpiece Contact Detection for Micromilling Process

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One of the issues in the micromilling process is the accuracy of the tool-workpiece settings due to the small cutting tool dimensions. Micron-sized endmill requires a proper detection mechanism for detecting the tool-workpiece contact. In this project, the tool-workpiece contact detection has been achieved using large magnification visual inspection method. Digital microscope with high magnification function is used to detect the contact between micron sized endmill tool with a tool diameter of 200 µm and the workpiece. The effectiveness of the proposed method was verified in a series of experiments conducted using 3-axis computer numerical control (CNC) milling machine. A 700-900x magnification digital microscope was attached to a 3-axes linear stage and positioned in front of the tool-workpiece setting at a working distance of 5 mm to 6 mm. The experimental trials involved the machining with 50 µm in depth on a flat Poly (methyl methacrylate) (PMMA) material. The structure fabricated on the PMMA material using the micromilling process is part of the micro structures for a prototype microfluidics device used for biomedical application. The results from the experiment were analyzed in situ using measurement software. The desired depth of cut is 50 µm and the highest difference depth of cut in the machining using the visual inspection method is 8.31 µm or 16.62 %. The experiment showed some significant and promising results which have improved the accuracy of the machining profiles due to the reduced contact error between the tip of the endmill and the surface of the workpiece.

Keywords: CNC; micromilling; microchannel; microfluidics; micro tools; tool-workpiece contact.

I. INTRODUCTION

Micromilling is one of the methods currently being adopted for microfluidics devices fabrication (Lin *et al.,* 2012). Others micro fabrication technique for microfluidics devices are etching (Bahadorimehr *et al.,* 2010)and 3D printing process (Waheed *et al.,* 2016). Furthermore, a microfluidics channel structure can be in the form of a circular or rectangular microchannel shape cross sectioned (Rahim *et al.,* 2016).

The micromilling process is based on the mechanical technique of selectively removing materials layer-by-layer and can be used to fabricate microfluidics with a rectangular microchannel shape cross section. The parameters for the micromilling operation consist of spindle speed, feed rate, cut of depth and working environments which will affect the final surface quality of the machined workpiece (Arif *et al.,* 2010; Arif et al. 2014; Chen *et al.,* 2014; Raja *et al.,* 2014). Figure 1 shows some examples of microfluidic devices fabricated on PMMA, silicon substrates using micromilling process and cross section of a microchannel with a width size of 200 µm and a depth of 50 µm. The area of microchannel for the microfluidic device is vital as microchannel sizes and geometry can affect the focusing width which utilizes hydrodynamic focusing cell (Rahim *et al.,* 2016).

From recent studies, shows that micro flow cytometers with a width size of 200 µm and a depth of 50 µm are suitable for micro size cell studies which have a range of channel's size ranging from 2-120 µm (Rahim et al., 2016)

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(a) (b) (c)

Figure 1. Microfluidic device on (a) PMMA and (b) silicon (Rahim *et al.,* 2016) with a width size of 200 µm and machined using micromilling process. (c) cross section of a microchannel with a width size of 200 µm and a depth of 50 µm

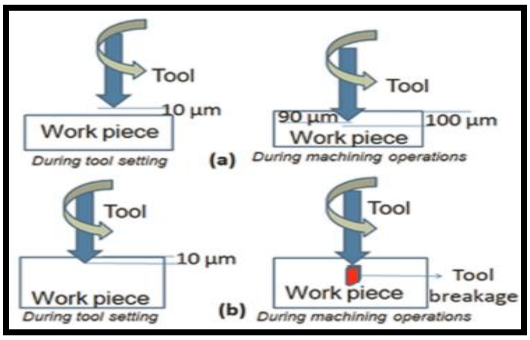


Figure 2. Contact of workpiece and tool during tool setting a) gap between tool and workpiece is 10 µm b) tool goes inside the workpiece by 10 µm (Roy *et al.,* 2016)

The process of micromilling requires that the microtool tip be aligned and positioned on the surface of the workpiece substrate. As shown in Figure 2, a significant gap between the workpiece surface and the tip of the microtool can affect the quality of the machined part such as surface roughness and the actual size of the microchannel. If the gap of tool and workpiece is 10 µm during tool setting, and the desired depth of cut is 100 µm, the actual depth of cut will be 90 µm. On the other hands, as in Figure 2(b), if the tool goes inside the workpiece by 10 µm during tool setting, tool breakage might occur and workpiece might damage (Roy *et al.,* 2016)**.** Hence, there is a need to set an acceptable tool-workpiece contact gap which allows the desired machined part quality to be obtained. Normally, for macro milling process, tool-workpiece contact can be obtained by moving the tool gradually closer to the workpiece and by pinching a piece of paper repeatedly between the tool and workpiece to identify if the contact has occurred. However, this method only suitable in conventional macro machining operation and cannot be used for micromilling operation as the thickness of paper may be greater than 100 µm, hence inaccuracies will occur. From Figure 3, if the thickness of the paper is more than 200 µm, and by using this technique, it is impossible to get the accurate depth of cut of 50 µm.

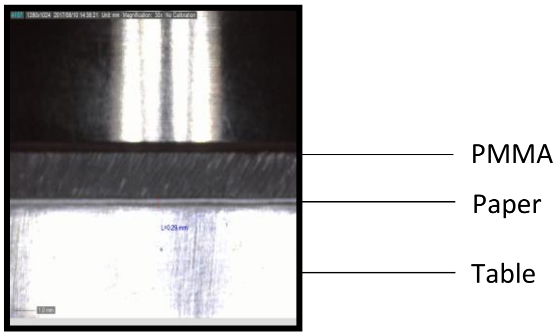


Figure 3. Tool-workpiece between paper

A recent method for tool-workpiece contact detection method for micromilling is by using accelerometer data which logged into PC where the signals are correlated to detect the tool-workpiece contact (Roy *et al.,* 2016)**.** There are other techniques for tool-workpiece contact detection, such as voltage monitoring and acoustic emission. However, all of this tool-workpiece contact monitoring require additional sensors and due to very small tool dimension, this method requires the use of a high magnification microscope for tool and workpiece contact observation (Broel-plater *et al.,* 2013; Min *et al.,* 2011).

In this study, a simple visual inspection method using a digital microscope is used which allows the tool-workpiece contact detection to be achieved with significant result. Visual inspection is adopted in this project due to its ease of use and low cost and without compromising the quality of the milled surface. The setup comprises of a 700-900x magnification digital microscope attached to a 3-axis precision linear stage and positioned in front of the tool-workpiece setting. The combination micro-movement of the tool and adjusting the position of the linear stage of the microscope allows a microscopic view of the tool-workpiece contact.

II. METHODOLOGY

The tools used in this project composed of a 200 µm diameter, two flute carbide endmill_tool. The tool edge or cutting radius for the endmill is basically in the range of 9 µm, whereas the rake angle is approximately 4^{o} (Ko TJ *et al.,* 2005). The CNC milling machine used in this project is a Mini Mill GX 5-axis desktop CNC machine. The parameter that will be will be investigated is the depth of cut. Table 1, 2 and 3 are the machining parameters of the CNC, tool parameters and the design parameters respectively. Figure

4 shows the setup for the experiment. As in Figure 4 a) and Figure 4 b), the tool used is two flute carbide endmill tool with a diameter of 200 µm, attached to the CNC's machine spindle. The digital microscope is positioned in front of the tool-workpiece setting at a working distance of 5 mm to 6 mm as shown in this figure.

Table 1. Machine Parameters

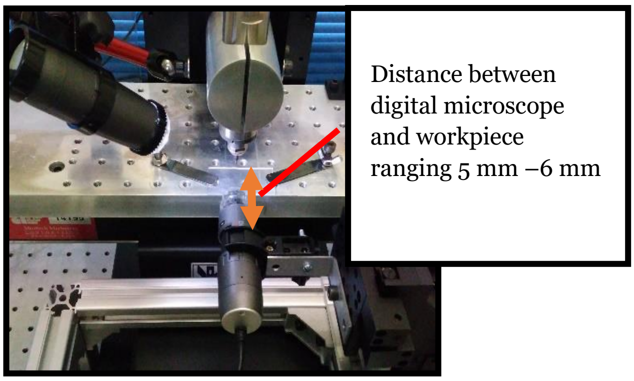
Parameters	Values
Spindle speed	10,000 rpm

Table 2. Tool Parameters

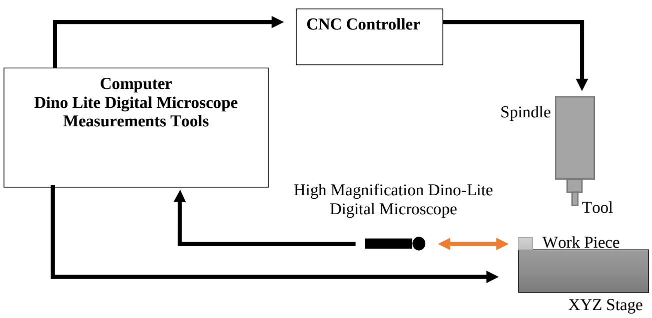
Parameters	Values
Tool Size	0.2 mm
Number of flutes	2
Material of tool	Carbide (uncoated)

Table 3. Design Parameters

Parameters	Values
Depth	50 µm
Number of channels	10

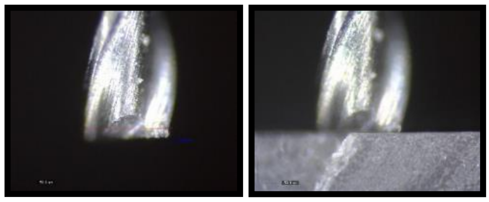


(a)



(b)

Figure 4. a) Digital microscope, tool setting and workpiece configuration setup b) Diagram of digital microscope, tool setting, and workpiece setup



(a) (b)

Figure 5. a) Tool inspection b) Tool-workpiece contact

Figure 5 shows a magnified view of the tool used which is a two flute carbide (uncoated) endmill tool with a diameter of 200 µm. The workpiece material used is PMMA, and the digital microscope used, Dino-Lite digital microscope has a magnification of between 700X to 900X, by using Dino-Lite measurements tool software, the distance between tool-workpiece contact can be seen and measured. An anti-vibration table system is used to absorb vibration that may occur during machining. In addition, an ultra-clean air supply unit is used to remove small amounts of burrs and provide air pressure for cooling the heated spindle head.

The tool-workpiece contact detection process involved the micro-movement of the tool and adjusting the position of the microscope via the linear stage manipulator. The digital microscope is set and focused on the tool or workpiece at a specific magnification. As the tool is progressed in micro step towards the workpiece surface, the position of the tool is determined via measuring the gap between the tip of the tool and the surface of the workpiece. The process is repeated until a suitable gap is achieved. In this setup, the gap is set 20 µm to allows tolerance due to the z-axis tool setting error prior to the tool-workpiece contact detection. In this experiment, the milling process is done 10 times, indicated by channel 1 to 10. The target value for the depth of cut is 50 µm.

III. RESULTS AND DISCUSSION

The characterization of the microchannel fabricated using micromilling process will involve the use of a digital microscope. The microchannel for the microfluidic device must be characterized in order to determine if the design or target value for the micro channel has been achieved. The depth of cut will be one of the parameters that must be controlled in order to achieve the desired design value. The characterization is done in-situ in which the digital microscope used for contact detection is also used for measurement. Measurement software is used to capture and analyzed the viewed image from the digital microscope. The results for the measured depth of cut are shown in Table 5.

Table 5. The measured depth of cut of the microchannel and the difference compared with the designed depth of cut by using a digital microscope during tool-workpiece contact detection

Channel Number	Actual Depth of cut (µm)	Difference (µm)	Difference (%)
Channel 1	53.75	3.75	7.50
Channel 2	57.62	7.62	15.24
Channel 3	55.71	5.71	11.42
Channel 4	57.62	7.62	15.24
Channel 5	57.65	7.65	15.30
Channel 6	58.31	8.31	16.62
Channel 7	57.00	7.00	14.00
Channel 8	55.66	5.66	11.32
Channel 9	58.27	8.27	16.54
Channel 10	57.00	7.00	14.00
Mean		6.86	13.71

The results shown in Table 5 illustrated that by using visual inspection technique with a digital microscope, the mean value for the difference between the actual depth of cut and desired depth of cut is 6.86 µm or 13.71%. One of the reasons that affect the accuracy of the measured depth of cut is the interaction between the tool and workpiece during machining as illustrated before in Figure 2. Nevertheless, there were no tool breakages during this experiment. Figure 6 shows the run chart for the measured depth of cut for the 10 samples as compared to the designed value.

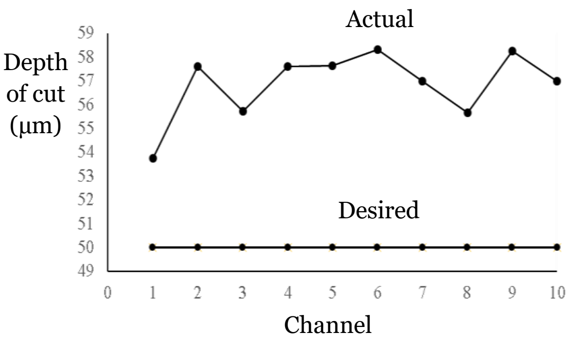


Figure 6: Run chart for the actual and desired depth of cut

The results shown in Table 5 illustrated that by using visual inspection technique with a digital microscope, the mean value for the difference between the actual depth of cut and desired depth of cut is 6.86 µm or 13.71%. One of the reasons that affect the accuracy of the measured depth of cut is the interaction between the tool and workpiece during machining as illustrated before in Figure 2. Nevertheless, there were no tool breakages during this experiment. Figure 6 shows the run chart for the measured depth of cut for the 10 samples as compared to the designed value.

IV. CONCLUSION

In this project, a simple and cost-effective real-time approach is proposed for tool-workpiece contact detection in micro milling process. The visual inspection method using a digital microscope enabled a magnified view of the interface between the tool tip and the workpiece surface. The measured depth of cut of the channels is measured in-situ using the same digital microscope as used in the visual inspection. The highest difference depth of cut in the machining using the visual inspection method is 8.31 µm or 16.62 %. From the run chart, shows that this approach provides an acceptably stable process in which no additional device attached to the system is required.

V. ACKNOWLEDGEMENT

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