A novel approach for batch production of micro holes by micro EDM

S. T. Chen\textsuperscript{a}, Y. S. Liao\textsuperscript{b}

\textsuperscript{a} Dep. of Mechatronic Technology, NTNU, No. 162, He-ping East Rd., Sec. 1, Taipei, 106, ROC
\textsuperscript{b} Dep. of Mechanical Engineering, NTU, No. 1, Roosevelt Rd., Sec. 4, Taipei, 106, ROC

Abstract

The paper proposed a novel approach of effective production of mass micro holes. A set of micro w-EDM mechanism is designed and mounted on the developed tabletop precision machine tool. The tension of micro wire is precisely controlled by magnetic force. In addition, the micro vibrations of the wire during discharging are effectively suppressed by the developed vibration suppression system. In order to fabricate the mass micro holes, the microstructure array of the high aspect ratio 10×10 micro squared electrodes with the width and the height of 21\textmu{}m and 700\textmu{}m, respectively for each electrode, and the spacing between two electrodes of 24µm is fabricated first by the proposed “reverse w-EDM” machining strategy. This micro electrodes array is employed directly to machine the mass micro holes on the same machine via the modified micro EDM peck drilling. By sequentially positioning the micro electrodes array after one drilling through process, the 900 same size micro through-holes array is successfully obtained on the stainless steel board of 0.1mm thickness. The results show satisfactory hole geometry, dimensional accuracy and surface roughness. More, it is verified that the mass micro holes can be fabricated efficiently by the proposed approach.

Keywords: batch production, mass micro holes, micro EDM

1. Introduction

Micro holes can be applied widely to various fields such as aerostatic air bearing [1], ink-jet nozzle [2-4], distributing structure of nozzles in micro-jet cooling device [5], and bio cell processor for single embryo cell manipulation [6], etc. Accordingly, various micro machining techniques such as MEMS process, laser beam, micro mechanical drilling, micro punching, micro ultrasonic machining and micro EDM, etc. have been developed to fabricate these micro holes. Some of the processes are costly, for example MEMS and laser micromachining. Some are difficult to make the hole-diameter below several microns such as micro mechanical drilling and punching.

The micro EDM is a non-contact electro-thermo machining process. The micro electrode with a cylindrical metal of 3-300µm in diameter is employed. Hence, it can be applied to fabricate the hole of micrometer magnitude. However, it is very tedious and time-consuming when a large number of micro holes are fabricated hole-by-hole. The spacing between two holes could be affected by the errors of the machine tool, and the diameter of the hole is difficult to maintain. In addition, the machining time would be very long that would seriously lower the machining efficiency. In the paper, a novel approach for batch production of micro holes is proposed. It is able to reduce substantially the process time and maintain the machining accuracy. The approach is far less costly as compared with MEMS.

2. Experiment setup

2.1. Tabletop machine tool

All processes are carried out on a precision tabletop machine tool that was developed in our previous study [7]. A set of miniature precision w-EDM mechanism was designed and applied for cutting various micro structures.

2.2 Micro w-EDM mechanism

Figure 1 shows the mechanism design of micro w-EDM. The wire-receiving spool and the wire-giving spool are driving wheel and passive wheel, respectively. A brass wire with the diameter of \( \phi 20\mu{}m \) starts from the wire-giving spool to the wire-receiving spool. In order to achieve accurate and steady operation, the wire is passed through a set of rubber holder, two sets of supporting rollers, three piece of vibration absorbers and four wire guides to reach the wire-receiving spool. The cutting region is between two precise wire guides.

2.3 Control of wire speed and wire tension

To obtain stable wire speed, a high reduction ratio micro DC motor is used and the wire runs at an extremely slow speed. The tension control of the wire by magnetic force method is proposed in the system, and it is schematically drawn in Fig. 2. A magnetic force device is placed a distance of \( d_0 \) away from the...
wire-giving spool. When the distance \((d_0)\) is reduced, the magnetic force exerted by the magnet on the steel disc will increase, and the force of attraction imposed on the wire-giving spool will also increase. Therefore, the tension of the micro brass wire will increase.

![Diagram showing wire-giving spool and magnetic force](image)

Fig. 2. Tension control of the micro wire

3. Methodology

3.1 Machining compensation

It is necessary that the CNC path is compensated for maintaining the cutting accuracy. Two kinds of compensation are applied in this study. They are the discharge gap compensation and wire diameter compensation, respectively. For the CNC path, the actual tool diameter must consist of two lateral discharge gaps and wire diameter as shown in Fig. 3(a), i.e.

\[
D = d_w + 2G
\]  

(1)

Following this, the path must be offset a tool radius as shown in Fig. 3(b).

![Diagram showing compensation of CNC tool path](image)

Fig. 3. Compensation of the CNC tool path

3.2 Reverse micro w-EDM

To fabricate high aspect ratio micro electrode, the micro w-EDM mechanism is mounted on the working tank. The micro work-piece (i.e. micro electrode for micro EDM) is clamped on the spindle and fed downward gradually against the horizontal moving wire. By so doing, the microstructure array with micro squared pillars can be fabricated from a small metal rod. For machining mass micro holes, a set of micro electrodes array is cut by the reverse micro w-EDM first. The design of electrodes array has \(10 \times 10\) squared pillars, the width and the inter-pillar spacing of each pillar are \(21\mu m\) and \(24\mu m\) respectively, and the height is \(700\mu m\). Fig. 4 illustrates the relative movement of the wire in cutting. The wire runs at the extremely slow speed from -X to +X; at the same time the work-piece moves downward as displayed in Fig. 4(a). When all layers are completed, the work-piece is moved away from the micro wire in the +Z direction and then rotated 90° for machining the other face as shown in Fig. 4(b). The finished micro electrode array is then positioned directly above the stainless steel and moved downward for machining the micro holes array by batch micro EDM as illustrated in Fig. 4(c). Finally the mass micro holes are obtained and they are shown in Fig. 4(d).

![Diagram showing reverse micro w-EDM](image)

Fig. 4. Batch production of mass micro holes

3.3 Batch mode for micro EDM

In order to reduce the difficulty in debris disposal and increase the process efficiency during batch micro EDM, a machining mode of modified peck drilling is carried out as shown in Fig. 6. The solid line and the dotted line represent cutting feed and rapid traverse, respectively. The electrodes array will be rapidly withdrawn a specific displacement when the short circuit is detected during the EDM process as depicted by the SCR in the figure. It will then fast return to the right position to continue machining process. The machining mode also supplies an

![Diagram showing batch mode for micro EDM](image)

Fig. 5. The finished electrodes
extremely small buffer distance to avoid short circuit when the electrode returns. It is verified that the action can improve the debris disposal effectively with a pumping effect, and decrease the frequencies of short circuit during discharging in our experiment. Table 1 shows the machining conditions.

Fig. 6. Modified peck drilling in batch micro EDM

Table 1 Machining conditions for batch micro EDM

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Feed-rate</th>
<th>Electrode material</th>
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<tbody>
<tr>
<td>100V</td>
<td>0.06mm/min</td>
<td>Ultra fine WC</td>
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<table>
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<tr>
<th>Capacitance</th>
<th>Wire speed</th>
<th>Polarity</th>
</tr>
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<tbody>
<tr>
<td>1500pF</td>
<td>20mm/min</td>
<td>Negative</td>
</tr>
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</table>

The machining results comprising both the single hole and the holes array are shown in Fig. 7. Since the finished electrode is not unloaded and re-clamped, excellent relative position of the micro holes can be achieved. As a result the micro holes array is seen extremely regular. The average width and height of the hole measured by the toolmaker microscope are all 23.7µm. It is indicated that the batch process approach and the machining condition used are all appropriate for fabricating the micro holes array.

Fig. 7. The finished single hole and array holes

4. Discussions

The burr around the edge of the micro hole will depend on the shape at the tip of micro electrode. Figs. 8 and 9 show the difference after machining by the pyramid tip electrode and flat end electrode. The edge of the micro hole by pyramid tip electrode machining is cleaner than that by flat end electrode machining. It is attributed to the fact that the pyramid at the tip of electrode offers a function of guide-drilling for quick machining throughout the hole. The debris will be dispelled rapidly as soon as the hole is drilled through as shown in Fig. 8. On the other hand, Fig. 9 displays that the edge of the hole by flat end electrode machining is covered with discharge debris because there is larger area at the beginning of discharge that causes too much metal to be melted and evaporated on the surface of the work-piece.

Fig. 8. Finished holes array by pyramid tip electrode

Fig. 9. Finished holes array by flat end electrode

The surface on the wall of the hole inspected under SEM is shown in Fig. 8. The average diameter of a micro discharge cavity is about 8µm, and the relationship between the single-shot discharge cavity and the surface roughness in R_{max} is [8]

$$R_{max} = 2h_1 + h_2, \quad d = (10 \sim 20)h_1$$

(2)

Where, d and h_1 are the diameter and depth of the single-shot discharge cavity, respectively. The quantity h_2 is the protrusion height around the discharge cavity, and it is estimated about 0.5µm. Taking d=8µm, and if d is chosen as 16h_1, then

$$R_{max}=2\times8/16+0.5=1.5\mu m$$

(3)

i.e. the roughness on the surface of the wall of the hole is about R_{max}=1.5µm (R_a=0.38µm). Fig. 10 shows the appearance of the micro electrodes array after batch EDM, these micro electrodes is worn out uniformly. The above results are due to a good discharging dispersion resulted from regular and accurate micro electrodes array.

Fig. 10. Appearance of micro electrodes array
Fig. 10. Micro electrodes array after micro EDM

Fig. 11 shows the drilled-through machining times by the single electrode drilling and by electrodes array drilling for the first five drilling operations. The average time is 66.2 sec when the hole is drilled by a single electrode, and it is 1951 sec when the electrodes array is used. Thus the drilling time per hole by the batch mode micro EDM drilling is 19.5 sec (obtained by 1951/100). This is about one third of the machining time for single electrode EDM drilling (19.5/66.2=0.29), and the machining efficiency is greatly improved. It can also be seen from the figure that the machining time in completing one drilling process at the initial stage of the same electrode for EDM is longer than the later stage for both cases. This is because that some micro welding-scars adhere to the surface of the micro electrodes when the micro electrodes have been just fabricated. These micro protrusions will increase the chances of short circuit during discharging, and consequently the machining time also becomes longer. These welding-scars will be eliminated accompanying the EDM process, and the chances to incur short circuit also become less gradually. As a result, the machining time is reduced.

A similar approach for making many perforations on stainless steel had been proposed by others [2]. However in their approach the micro electrodes array was fabricated by MEMS processes first. The micro electrodes array was then taken and mounted on the EDM machine for drilling micro holes array. It is noted that more processes are required as compared with the approach in this study. Besides, it is very difficult if not impossible to keep the relative perpendicularity between the electrodes array and the workpiece. As a result, geometry accuracy of the fabricated micro holes cannot be guaranteed.

Fig. 11. Comparison of the drilling time

Conclusions

A novel approach for batch production of micro holes is proposed and verified. A very satisfactory result is obtained. Micro holes array can be fabricated more efficiently as comparing with single electrode EDM drilling. Besides, very good positional accuracy, geometry accuracy, dimensional accuracy, and surface roughness of the drilled holes are achieved.

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References