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The Effect of Electrochemical Micro-Milling by Rotating Magnetic Field

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Abstract:

In this work, the process of micro-channels in electrochemical micro-milling by using rotating magnet assisted helical tool is presented. The results show helical tool and Lorentz force of the rotating magnetic field that enhance the renewal of the electrolyte and machining efficiency. The feed rate can be raised under the magnetic field assisted in terms of experimental results; moreover, the surface roughness also can be reduced. The study reveals that the magnetic field assisted approach indeed can improve machining efficiency, accuracy and surface roughness. COMSOL Multiphysics is utilized to simulate with discharged voltage and the results are compared with experimental results.

Keywords: Electrochemical Milling, magnetic assisted, COMSOL Multiphysics, rotating magnetic field.

1. Introduction

Micro-engineering is the fabrication process of three-dimensional structures in the micrometer size. The convenience and value of many products can be substantially increased with reduced size and weight. With the trend towards miniaturization, micromachining becomes increasingly important in fabricating micro parts.

Electrochemical machining (ECM) [1] has seen a resurgence of industrial interest within the last couple of decades due to its many advantages such as no tool wear, stress free and smooth surfaces of machined product and ability to machine complex shape in electrically conductive materials, regardless of their hardness. When this ECM process is applied to the micromachining range for manufacturing ultra-precision shape, it is called electrochemical micro-milling (EMM) [2]. Micromachining may literally mean the machining of the dimension between 1 and 999 mm. EMM has many other advantages, such as high machining efficiency, minimal tool wear, a lack of residual stress, absence of burrs, improved surface quality of the machined product and a capacity to machine complex shapes in electrically conductive materials regardless of their hardness. Since EMM has particular micromachining advantages, it has been successfully used to manufacture various micro-parts and -devices. To overcome these difficulties, a helical tool assisted magnetic force is utilized for EMM in this work.

Magnetic force has been often used for various precision machining. The magnetic field improving the surface roughness in electrochemical polishing can be interpreted as that movement tracks of ions are deviated by magnetic force [3]. As magnetic abrasive finishing (MAF) [4], in which workpiece is kept in the magnetic field created by two poles of an electromagnet. Besides, magnetic field-assisted electrochemical discharge machining (ECDM) also been invested, the experimental results show that the magneto-hydrodynamic (MHD) convection induced by the magnetic field can effectively enhance electrolyte circulation in the micro-hole, which contributes to higher machining efficiency [5]. Nevertheless, magnetic substance in electrolytic products as metal debris will be arranged along magnetic line. Lorentz force is the force on a point charge because of electromagnetic fields. Setting for Magnetic field needs to have an included angle with the moving direction of ion to lead to Lorentz force effect. The ions will be amplified to discharge so that improves machining efficiency.

As a result, we address a process that combined with two methods to develop for rapid machining the micro channel, which provided a high machining efficiency, narrow groove width and low surface roughness in electrochemical milling by using magnetic field assisted helical tool. The investigation discusses the effect and comparison between experimental [6] and simulated results.

2. Experiments

An EMM system was established using a three-axes moving stage. A helical tool with a diameter of 200 µm was gripped in the collet of the high-speed spindle. A 1.5 mm-thick SUS304 plate was placed in a machining tank which contained sodium nitrate ($NaNO_3$) electrolyte, which had been filtered and circulated through a circulation system. Nd-Fe-B Sintered magnet was set under the SUS304 plate. The magnet would be rotated during process. Figure 1 presents a schematic diagram of the EMM process. The cylindrical Nd-Fe-B sintered magnets are adopted in this work. In general, special shape of magnets could be ordered but the cost is too high. A guass-meter is utilized to measure the magnetic flux density at seven positions without applied voltage as figure 2. Each measurement position is 3mm apart.

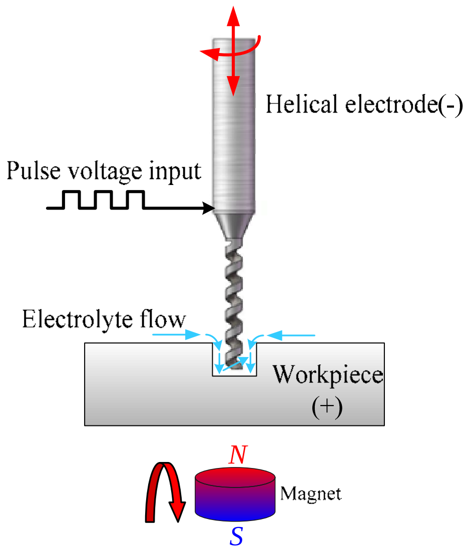

Fig. 1: The flow direction of electrolyte relative to magnetic direction.

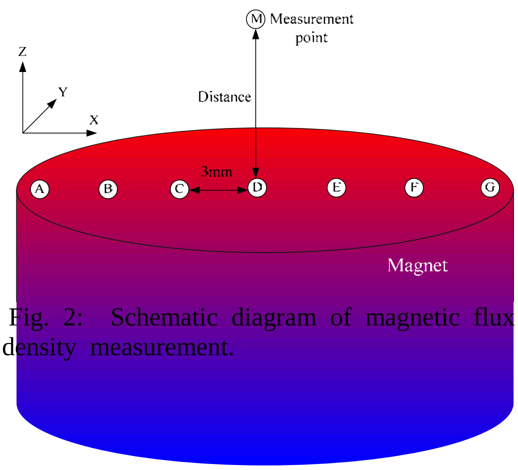

Fig. 2: Schematic diagram of magnetic flux density measurement.

In table 1, the distance means length from measurement point to magnetic surface in Z axis direction per position. As can be seen that biggest magnetic field is at position D. Magnetic flux density decrease with distance increasing. In order to realize the effect of various magnet angles, the magnetic flux density is measured by using various magnet angles as fig. 3. Each measurement angle is 10 degree apart. From Fig. 3, the magnetic flux density of different magnet angle reveals the variation as a sine period. The peak value occurs at 40, 140, 220 and 320 degrees respectively.

Table 1: Magnetic flux density of different positions (mT: milli-Teslas).

Position / Distance (mm)	A	B	C	D	E	F	G
0	474	489	491	491	489	491	472
3	170.9	341	367	371	365	338	171.1
5	145	253.4	277.7	287.4	278.3	250	144.8
7	121.1	197.8	226.9	237.8	230	201	126.9
9	99.6	149.2	171.5	182.6	174.9	153.7	97.6
11	76.6	115.2	130.8	139.3	133.8	114.4	79.8

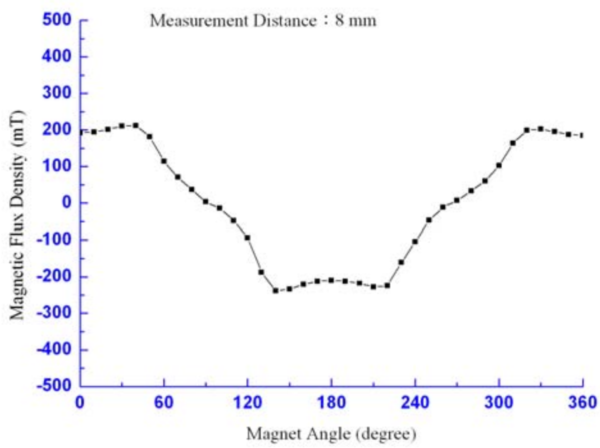

Fig. 3: Experimental magnetic flux density of different magnet angle without applied voltage.

3. Use of COMSOL Multiphysics

COMSOL Multiphysics is adopted to setup a for model electric and induction currents modules to simulate this electrochemical milling process. Fig. 4 reveals the basic units including work-piece, electrode and magnet. This electrode is cylinder with a diameter of 200 μm that is never with work-piece as the same as electrochemical machining. The meshed model of electric and induction currents modules is used free meshed as shown in Fig. 5. The distance setup from magnet to work-piece is in terms of Table 1. Besides, the difference between experimental and simulated results is applied voltage. In experimental measurement, the magnetic flux density is evaluated every 10 degree without any applied voltage. Nevertheless, the magnetic flux density is setup to analyze with applied two kinds of voltage including 5V and 8V in simulated cases.

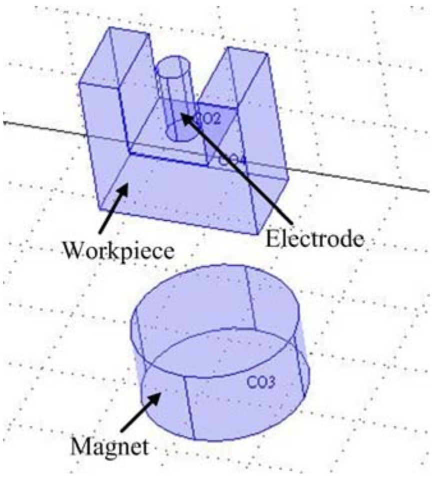

Fig. 4: A schematic view of the simulated model

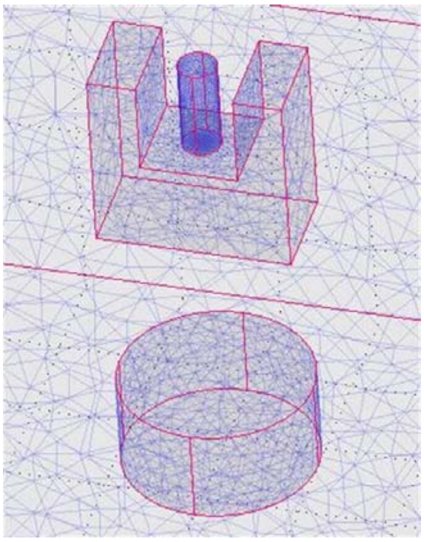

Fig. 5: The meshed model of electric and induction currents modules.

4. Results

Fig. 6 shows the simulated diagram of magnetic field and electric field with a distance of 8 mm from magnet to work-piece and the magnet placed on position D when the applied voltage is 8 V. The slice is depicted the magnetic flux density and the arrow displays electric field.

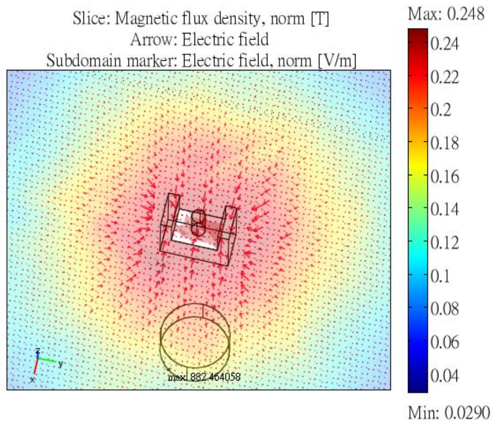

Fig. 6: The simulated diagram of magnetic flux density and electric field.

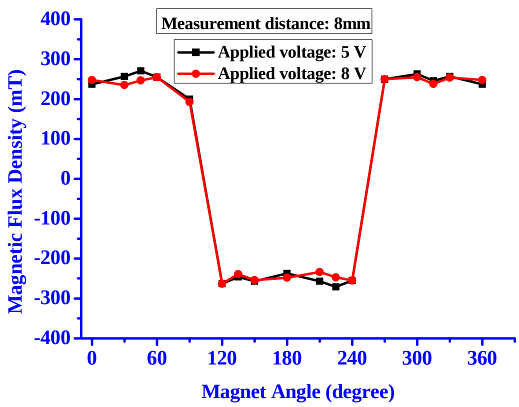

Fig. 7: The relationship between magnetic flux density and magnet angle with applied two kinds of voltage including 5V and 8V

As the same as upper simulated method, there are many data arranged. The relationship between magnetic flux density and magnet angle with applied two kinds of voltage including 5V and 8V is shown in Fig. 7. As compared with simulated and experimental diagram, the trend of experimental measurement is very similar to simulated one but less magnetic flux density. It is very useful to realize the magnetic flux density with rotating magnetic field and different applied voltage while electrochemical micro-milling by COMSOL Multiphysics since magnetic flux density of rotating magnet with applied voltage is difficult to measure.

5. Conclusions

COMSOL Multiphysics is adopted to simulate to find out magnetic flux density with different applied voltage while electrochemical micro-milling. It is helpful to this study to atone for measuring magnetic flux density of rotating magnet with applied voltage. Furthermore, the difference between experimental and simulated ones will be observed.

6. References

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