Fabrication of micro-hole using Maglev EDM

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Abstract

The current work aims to fabricate micro-hole on a thin nickel sheet (thickness= 500 µm) using the Maglev electric discharge machining (EDM) process. The control parameters set for the operation were 12V open-circuit voltage and 2A peak current while maintaining a duty factor of 95.564%. The measured discharge voltage and discharge current were 6.64V and 900mA respectively. Tungsten micro-tool (dia. = 650 µm) and deionized water were used for the process. The fabricated micro-hole has been inspected using high-definition microscopic images. Furthermore, the pre and post-work effects on the tool have been shown through microscopic images. The voltage-current (V-I) curve indicates that the machining process is stable. The newly developed Maglev EDM feasibility to produce micro-holes on conductive materials has been confirmed in the present work.

Keywords: Maglev, EDM, micro-hole, nickel, tungsten

1. Introduction

EDM is an electro-thermal process in which sparks are generated between the electrodes, which lead to the generation of extremely high temperature plasma, while the electrodes are immersed in a dielectric fluid. The electrodes act as the workpiece and tool while the dielectric acts to be an insulator until a particular voltage is applied, leading to its breakdown and flow of discharge current due to conductive plasma. The whole process happens when the electrodes are kept at a specific distance (spark gap) from each other within the dielectric medium. The gap between the electrodes is maintained through a servo-controlled mechanism.

Several developments have been made to improve the efficiency of EDM process. Kumar et al. [1] discussed many possibilities to improve the EDM process in different domains. They also compared the process on macro, micro and nano-domain. Lin et al. [2] developed a magnetic-assisted EDM that helped achieve better productivity and surface quality. They provided a magnetic force generating system under the workpiece, which helped improve plasma interaction and debris removal.

Similarly, Joshi et al. [3] improved the EDM process by the addition of a pulsed magnetic effect to the existing system. The process provided a confined plasma and better electron movement was observed. The efficiency of the operation improved by 130 % and no tool wear was observed in dry EDM condition. The development of micro-features using EDM process has been the topic of research for the last 40 years. Masuzawa [4] presented an overview of the achieved micro-features using different manufacturing methods. Many limitations on micro-manufacturing were presented with an outline to better the EDM processes. On moving towards the micro-domain of machining, problems such as handling of micro-features, the accuracy of positioning, control over the process and repeatability of the operation act as the setbacks. Kibria et al. [5] investigated the best possible outcomes achieved on utilizing different dielectrics. They studied the effect of both normal and powder mixed dielectric conditions to compare the performance measures.

The present work discusses fabricating micro-holes using magnetic controlled servo system based EDM, i.e., Maglev EDM. It also discusses the post-machining effect on the tool. The newly developed system produces low discharge energy as compared to previously developed EDM systems. The fabricated micro-hole was inspected through an optical microscope. The pre- and post-process effects of the tool have also been discussed through microscopic images.

2. Materials and Methods

2.1. Maglev EDM

The present system implements a combination of an electromagnet and permanent magnets to control the tool movement and maintain a proper discharge gap between the electrodes. The system works on the principle of balance between dual magnetic repulsive forces. It consists of one electromagnet and two permanent magnets. The tool holder is attached with a permanent magnet which lies between the top electromagnet and bottom permanent magnet. The repulsive force acting between the electromagnet and tool holder magnet helps to move the tool towards the workpiece. On the other hand, the repulsive force acting between the two permanent magnets act as the restoring force. A DC power supply is connected to the electrodes and parallelly with the electromagnet. The arrangement will form two parallel loops having same voltage. As the tool travels towards the workpiece, it leads to voltage drop in the power supply and reduction in electromagnetic repulsive force. During this action, at a particular instance the electromagnetic force equalizes with the restoring force. At this point, the voltage further reduces and current flows through the electrodes. Figure 1 illustrates the schematic view of Maglev EDM mechanism.

In comparison with previous conventional EDM setup, the servo mechanism used were mainly lead screw based (or) gear based complex system. The current system uses simple magnetic repulsive force for tool positioning. Conventional EDM uses RC-based (or) transistor-based power supply while the Maglev EDM uses pure DC power supply. In RC-circuit, the charging of the capacitor takes time then is used for discharge and in case of transistor-based circuit, it uses logic gate control which is complex in nature [1]. Moreover, in Maglev EDM the tool retraction occurs due to magnetic action which reduces the arcing and short-circuiting phenomena.

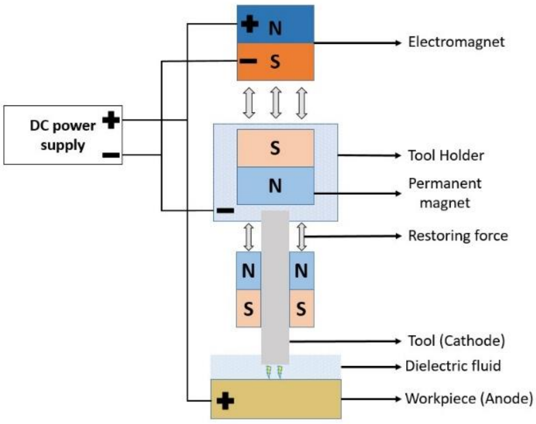


Fig.1 Schematic of Maglev EDM mechanism

2.2. Materials and Machining conditions

For the machining operation, the selected workpiece is a Nickel sheet (thickness = 500 µm) and the tool used is a tungsten rod of diameter = 650 µm. Deionized water was used as a dielectric medium for the present research. Table 1 presents the materials utilized and the machining conditions chosen for the current investigation. Figure 2 shows the microscopic image of the micro-tool used for the operation.

Table 1. Materials and machining conditions

(a) Selected materials	
Workpiece	Nickel sheet (thickness= 500 µm)
Tool	Tungsten (dia.= 650 µm)
Dielectric	Deionized water
(b) Parametric conditions	
Set peak current	2 A
Applied voltage	12 V
Discharge voltage	6.64 V
Duty factor	95.564%

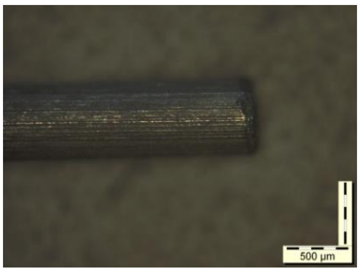


Fig. 2 Tungsten micro-tool

3. Results and Discussions

3.1. Micro-hole fabrication

Micro-holes are primarily used for fuel injectors, biomedical filters, micro-channels for micro-fluidic operations and so on. Continuous spark generation at the discharge zone between the electrodes within the narrow machining gap, a small amount of material gets ejected in the form of molten or vaporized matter. When spark comes in contact with the material surface, due to intense heating, the material is removed, leaving micro-sized craters on the surface. These continuous productions of cavities lead to the generation of the impression of the tool on the workpiece. To determine the feasibility of the Maglev EDM setup for producing micro-features, a micro-hole was fabricated at 6.64V discharge voltage and 900mA discharge current with proper repetitions. Figure 3 illustrates the voltage-current characteristics curve generated during the operation. The curve shows a discharge voltage of 6.64V with no sign of arcing or short-circuiting.

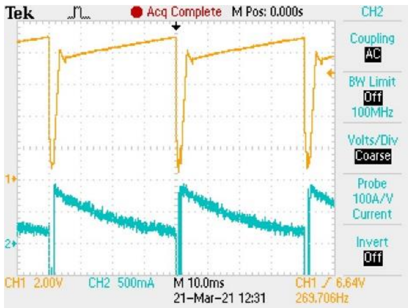
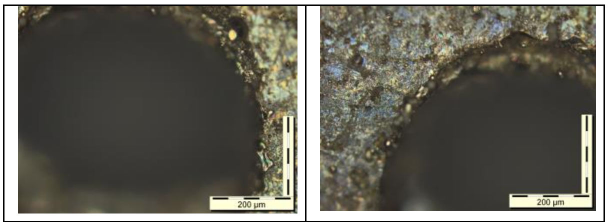


Fig.3 Voltage-current characteristics curve

Figure 4 presents the fabricated micro-hole at low discharge energy (i.e., 6.64V discharge voltage and 900mA discharge current) using 650 µm dia. tungsten tool on a 500 µm thick nickel sheet.

Fig. 4 Fabricated micro-hole

Further, on analyzing the formed microhole edges, the edges' unevenness can be easily noticed. The formation of uneven edges mostly happens due to irregular tool erosion, recast formation and lack of proper spark contact between tool and workpiece. As the tool travels through the workpiece, the lateral tool erosion creates certain amount of circularity error. Lack of flushing also leads to resettling of molten debris on the machined zone, producing uneven surface. The presence of recast material is evident from figure 5 (a & b). Moreover, both figure 4 and 5 gives a clear idea of tapering in microhole and the exit side hole shows the presence of extra material than the entry side. The current research was not assisted by a flushing system which may have led to the settling of molten material on the bottom of the hole. Furthermore, the workpiece and tool were submerged in a stagnant dielectric to conduct the investigation. Chu et al. [6] detected the presence of recast layer on microfeatures developed in EDM. Furthermore, they concluded that electrolytic polishing helps complete removal of these unwanted layers and achieve better surface quality.



(a) (b)

Fig. 5 Machined surface (a) recast layer formation (b) surface irregularity

3.2. Sharpening of tool tip

Microtools are used to fabricate micro-features in EDM. Basically, in EDM process, the impression of the tool shape is achieved on the workpiece surface. During the spark erosion process, simultaneous wear of workpiece and tool occurs, leading to microhole formation and sharpening of tool. Yamazaki et al. [7] investigated the formation of micro-rods using self-drilled holes. They prepared a 4 µm dia. micro-rod using this method and further fabricated a microhole of 5 µm dia. using the same tool.

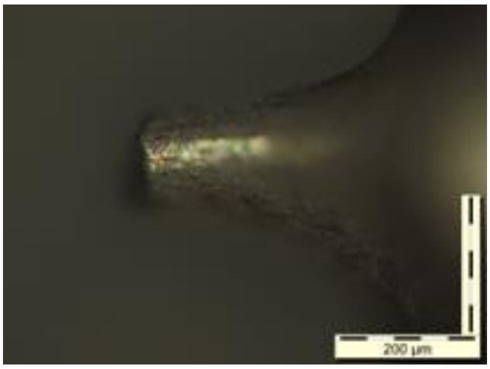


Fig. 6 Post operation tool condition

During the current investigation, the tool tip diameter reduced from 650 µm to 120 µm as shown in figure 6. Using this technique micro-tools of different diameters can be easily fabricated. Egashira et al. [8] noticed the sharpening of micro-tool to produce sub-micron dia. micro-tools. They fabricated 0.3 µm dia. straight tungsten tools using this technique.

4. Conclusions

From the above observations it can be concluded that

1. Micro-holes and micro-features can be easily fabricated using the newly developed Maglev EDM.

2. Better surface quality and reduction in recast layer deposition can be achieved by implementing a flushing system.

3. Furthermore, it is noticed that the tool sharpening phenomena helps in reducing the diameter of tool tips which can be reused for producing much smaller micro-features.

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