# A Comparative Study of Micro-Tool Fabrication Methods Using Micro-EDM

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**Abstract**

Production of micro-features with proper dimensions and accuracy, necessitates the requirement of micro-tool. Micro-tool fabrication turns out to be a challenging task, as the dimension of micro-tool is desirable to be maintained below 100 µm. Available micro-tool fabrication methods compete among themselves to achieve a uniform cross-sectional shape with better surface quality. Micro-tool fabrication using micro-EDM is expected to provide uniform cross-sectional shape, as the process is simple and process parameters can be easily controlled. In this paper, three different types of tungsten micro-tools were fabricated in micro-EDM set-up using brass electrodes in the form of (i) guided running wire, (ii) rotating sacrificial disk and (iii) stationary sacrificial block. Subsequently, micro-structures were analyzed using Scanning Electron Microscope and also, the length, diameter and taper of the micro-tool were evaluated to reveal the best tool fabrication method in micro-EDM. The effects of pertaining input parameters, such as operating voltage, duty ratio, spindle rotation, and capacitance value in R-C circuit, on micro-tool geometry (length, diameter and taper) and surface integrity were analyzed.

Keywords: Tungsten Micro-Tool, Micro-EDM, Guided Running Wire, Rotating Sacrificial Disk, Stationary Sacrificial Block, Micro-Tool Geometry.

## 1. INTRODUCTION

With recent development in technology, miniaturized products may be a solution to satisfy the demand of growing population with available material resources, which not only decreases material requirement of the product but also improves its portability due to reduction in both weight and size. Most of the existing manufacturing processes fail to produce these miniaturized products with the required features, which forced manufacturers to select micro-manufacturing processes. Electrochemical micromachining (EMM) has certain advantages over other processes, such as better precision, higher material removal rate and more importantly absence of HAZ on final product. In EMM, micro-tools play a significant role during anodic dissolution for achieving the micro-feature with required shape, size and surface finish. Available micro-tool fabrication methods compete among themselves to achieve a uniform cross-sectional shape with better surface quality. Sometimes a specific micro-tool fabrication process yields a precise end shape of micro-tool, which is desired for a certain type of applications. Wu et. al. [1] fabricated three electrodes with diameter of 10 microns and height of 28 microns on the tip of the stainless needles for micro-ECDM using focused ion beam chemical vapor deposition (FIB-CVD). Liu et al. [2] fabricated a micro-spherical electrode using one pulse electrical discharge technology and later used for manufacturing micro-holes and micro-hemispherical cavities. Wang et al. [3] used selective electrochemical dissolution process to fabricate disk micro-tool of disk diameter 266 microns and shank diameter 127 microns to reduce taper of the micro-hole. Jain et al. [4] fabricated micro-tool with diameter of 80 microns from pure steel wire using electrochemical micromachining. Hourng et al. [5,6] manufactured a cylindrical tungsten micro-tool with a diameter of 100 microns using pulsed electrochemical machining by controlling applied voltage and duty factor. Tool rotation was found to be a significant parameter in controlling the end shape of fabricated micro-tool. Some screw scrapes on the surface of the micro-tool were also found due to the variation in local velocities on micro-tool surface. A hybrid experimental setup combining WEDG technology and pulse ECM was developed by Wang and Sheu [7] to reduce the diameter of the micro-pins below 10 microns in two-stage process. Agarose hydrogel, a quasi-solid electrolyte was used to fabricate high aspect ratio cylindrical micro-tools with high precision during electrochemical micromachining by Luo et al. [8]. Although Elsiti et. al. [9] fabricated copper micro-tools using conventional EDM, but effect of process parameters was not analyzed. In this paper, three different types of tungsten micro-tools were fabricated in micro-EDM set-up using brass electrode in the form of (i) guided running wire, (ii) rotating sacrificial disk and (iii) stationary sacrificial block. The effects of pertaining input parameters, such as operating voltage, duty ratio, spindle rotation, and capacitance value in R-C circuit, on micro-tool geometry (length, diameter and taper) and surface integrity were analyzed. Micro-structures of fabricated micro-tools were compared using Scanning Electron Microscope to identify the best tool fabrication method in micro-EDM.

## 2. MICRO-TOOL FABRICATION USING MICRO-EDM PROCESS

Micro-EDM is a non-contact machining process, where repetitive electrical sparks between two electrically conductive electrodes dipped in dielectric fluid are solely responsible for material removal from work-piece, through melting and vaporization, when subjected to pulsed power supply. During the process, relatively less material is also removed from tool. Micro-EDM is considered as an effective technique for micro-tool fabrication, as material removal can be controlled by controlling machining parameters, which eventually controls spark energy locally. Comparatively thinner cylindrical micro-tools are fabricated from thicker micro-tools during micro-EDM process using a setup with three different sacrificial electrodes. Online monitoring of micro-tool was done by using a digital microscope and machining was stopped once the approximate micro-tool diameter reached below 50 microns. Finally, tool micro-structure was analyzed using Scanning Electron Microscope and accurate final average diameter was recorded.



ISBN: 978-93-80689-28-9

## 3. EXPERIMENTAL PROCEDURE

### 3.1 Experimental Setup

Experiments were conducted on Micro-Electrical Discharge Machine Tool TTECM-10 set-up, as shown in Fig. 1. The maximum travel range for bed is limited to 135 mm (X) x 60 mm (Y) x 70 mm (Z). Linear motions are controlled in the set up by an optical sensor with resolution of 0.1 micron. During the process, if there was continuous current flowing more than 0.5 microsecond, the system judged it as a short-circuit situation and return action of the tool was achieved. R-C type EDM circuit was used for providing pulsed power supply.

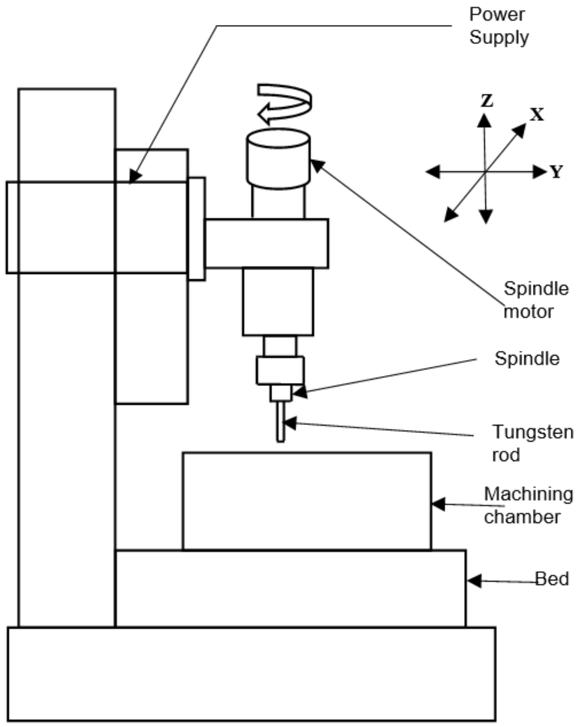



**Fig. 1. Schematic view of TTECM-10**

### 3.2 Experimental Method

Tungsten was selected for micro-tool fabrication due to its superior properties, such as toughness, rigidity, high melting point and higher conductivity values. Additionally, as it is highly resistant to chemicals, the tungsten can be used as micro- tool in electrochemical micromachining where mostly acidic electrolyte is preferred. During the process, tungsten rod of initial diameter 1000 microns was reduced to diameter below 50 microns in two steps. Initially, higher spark energy was used to reduce tungsten rod diameter from 1000 microns to 250 microns termed as rough machining. Later, lower spark energy was used to reduce tungsten rod diameter from 250 microns to 50 microns, termed as finish machining. During tool fabrication, capacitance value of EDM circuit was set equal to 10 nF initially for rough machining and later, it was changed to 1000 pF for finish machining. The resistance of the circuit was kept fixed at 1000 Ω. Different process parameters for both rough machining and finish machining processes are given in Table 2. Brass electrodes in the form of (i) guided running wire, (ii) rotating sacrificial disk and (iii) stationary sacrificial block were used for fabricating micro-tools from tungsten, as shown in Fig 2. As shown in Fig. 2(i), brass wire of 200 microns diameter was passed along the groove of pulley at a constant speed and tungsten rod was moved up and down to remove the peripheral material from overall length. The tension of the tool was maintained using a pulley system. The above process is also termed as wire micro-EDG. According to Fig. 2(ii), tungsten rod diameter was reduced by moving the rotating tungsten rod from one end to another end of the sacrificial brass block. During the process, the tungsten rod was completely dipped inside the dielectric. The process mentioned is termed as disk micro-EDM. In Fig. 2(iii), a rotating brass sacrificial disk of 1 mm thickness was used and tungsten rod was moved up and down for reducing the diameter along the overall length. This technique is called as block micro-EDM. In above three techniques, tool feed was given along positive X direction for continuing the machining process. During tool fabrication process, reverse polarity was used, i.e., tungsten was chosen as anode, whereas brass was taken as cathode. EDM oil was used as dielectric. Spindle speed was kept fixed to 2000 RPM during the above three methods for easy removal of debris. Duty ratio of 50% was maintained for removing material rapidly during rough machining, whereas it was decreased to 30% during finish machining. Initially, a number of trial experiments were carried out to reveal the feasible range of each process parameter. Finally, three micro-tools were fabricated using the above mentioned three techniques. To know the best technique, micro-structure of the fabricated tools was analyzed using Scanning Electron Microscope. At the end, the average diameter and length of the micro-tool were recorded.

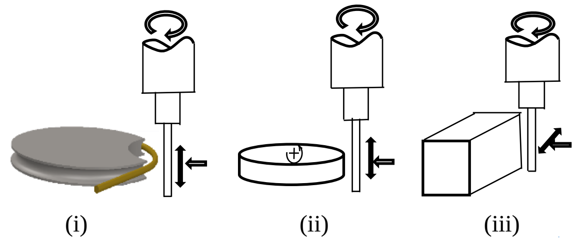



**Fig. 2. Micro-tool fabrication methods using micro-EDM (i) guided running wire, (ii) rotating sacrificial disk, (iii) stationary sacrificial block.**

Chemical composition of tungsten material is given in Table 1.

**Table 1. Chemical composition of tungsten tool**

| Element | K | C | O | W |
|---|---|---|---|---|
| Weight % | 0.01 | 0.01 | 0.03 | 99.95 |

**Table 2. Experimental layout**

| Sl. No | Process name | Nature of Machining | Process Parameters | | | | | | | Response Parameters | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Voltage (V) | Duty ratio (%) | Capaci-tance (nF) | Spindle speed (RPM) | Horizontal feed rate (μm/s) | Reciprocating feed of tungsten rod (μm/s) | Wire feed (mm/s) | Initial diameter (μm) | Final diameter (μm) | Micro-tool length (mm) | Taper angle (º) |
| 1 | Wire micro-EDG | Rough | 170 | 50 | 10 | 2000 | 0.5 | 2 | 0.4 | 1000 | 43.995 | 1.795 | No particular trend |
| | | Finish | 140 | 30 | 1 | | 0.1 | 5 | 0.2 | | | | |
| 2 | Disk micro-EDM | Rough | 170 | 50 | 10 | 2000 | 0.5 | 2 | - | 1000 | 48.338 | 1.287 | 0.19123 |
| | | Finish | 140 | 30 | 1 | | 0.1 | 5 | | | | | |
| 3 | Block micro-EDM | Rough | 170 | 50 | 10 | 2000 | 0.5 | 2 | - | 1000 | 36.357 | 1.541 | 0.42567 |
| | | Finish | 140 | 30 | 1 | | 0.1 | 5 | | | | | |

## 4. RESULTS AND DISCUSSION

Fig. 3. shows the shape of the micro-tools fabricated by above mentioned three different techniques using micro-EDM. Micro-structures of the fabricated micro-tools were compared and possible reasons were investigated for each technique.

Fig. 3(a) shows the SEM image of micro-tool fabricated by wire micro-EDG. It can be seen that the shape of micro-tool was not uniform over the entire length. During the process, brass wire of 200 microns diameter was continuously fed, which was passed over a stationary pulley. Wire feed was maintained at 0.4 mm/s and 0.2 mm/s during rough and finish machining, respectively, so that machining was done using fresh brass wire and wire strength did not diminish due to tool wear. Reciprocating feed of tungsten rod along Z-direction and horizontal feed in positive X direction were kept fixed to 2 micron/s and 0.5 micron/s during rough machining to ensure more material removal from the periphery of tungsten rod. Later, reciprocating feed and horizontal feed were adjusted to 5 micron/s and 0.1 micron/s during finish machining. In rough machining, the larger craters were formed after each spark due to impart of higher spark energy and in order to maintain the constant spark gap, tungsten rod must be fed at higher value in comparison to finish machining. Wire tension was maintained during the process for better shape accuracy. During machining, tungsten rod dimension got decreased both along longitudinal direction and diametrically. The final average diameter was found to be equal to 44 microns and micro-tool length was diminished to 1.795 mm. Although no particular trend for taper angle was observed, the desired shape accuracy of micro-tool was not achieved. Possibly, the parameters, such as wire feed, horizontal feed and reciprocating feed of tungsten rod need to be optimized for better micro-tool shape. Selection of thin wire may improve the overall shape accuracy.

Fig. 3(b) shows the SEM image of micro-tool fabricated by disk micro-EDM. During the process, 1 mm thick rotating sacrificial brass disk was solely responsible for material removal from periphery of tungsten rod. Although the sacrificial brass disk got eroded during spark, the erosion of disk was distributed along its periphery due to rotating action of disk. So, the surface finish of micro-tool was found to be better in comparison to that of wire micro-EDG. As the thickness of the disk was restricted to 1 mm, it gave better localization of spark and easy removal of debris. The process also left a micro-tool of taper angle 0.19123 degree. The thickness of sacrificial disk was small enough to leave its signature on the micro-tool. The final average diameter was found to be equal to 48 microns and micro-tool length was diminished to 1.287 mm. Taper angle of the micro-tool was calculated to be 0.19123º.

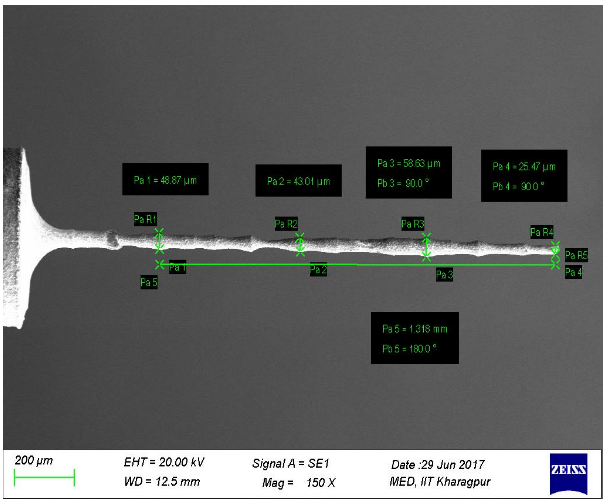
Fig. 3(c) shows the SEM image of micro-tool fabricated using block micro-EDM. During the process, the tungsten rod was completely dipped inside dielectric and a sacrificial brass block was used for machining. The sacrificial block got eroded over time due to continuous spark. To overcome the erosion of sacrificial block at a certain position, the tungsten rod was provided with a reciprocating feed along Y direction. At the end, the final average diameter and micro-tool length were found to be equal to 36.4 microns and 1.541 mm, respectively. Although the surface roughness of micro-tool was found to be satisfactory, some taper was observed in the micro-tool. Taper angle of the micro-tool was calculated to be 0.42567º. Possibly, the dimensional inaccuracy of sacrificial brass block was the reason for generated taper in micro-tool. Although it is easy to install a sacrificial block, it is difficult to maintain the shape and dimension of sacrificial block throughout the process. The shape of the sacrificial block was altered due to uneven material erosion at its top and bottom. The thickness of sacrificial brass block was large enough to leave its signature on the fabricated micro-tool.

After comparing the micro-structures of fabricated micro-tools using the above three techniques, i.e., wire micro-EDG, disk micro-EDM and block micro-EDM, it was found that disk micro-EDM could provide the best results. Unlike other two techniques, disk micro-EDM resulted into an almost taperless micro-tool with uniform diameter. The surface finish of the micro-tool was also found to be satisfactory.

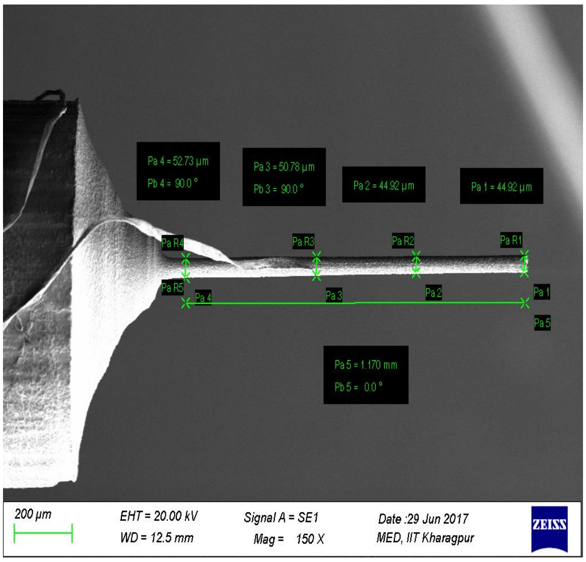
## 5. CONCLUSION

In the current paper, three micro-tools were fabricated using three different techniques in micro-EDM. Comparison among the micro-structures of the fabricated micro-tools was done using scanning electron microscope. In all the three techniques, input parameters, such as voltage, duty ratio, capacitance and tool RPM, were maintained the same. Still some precise differences in tool micro-structures were observed. Finally, the following inferences are made:

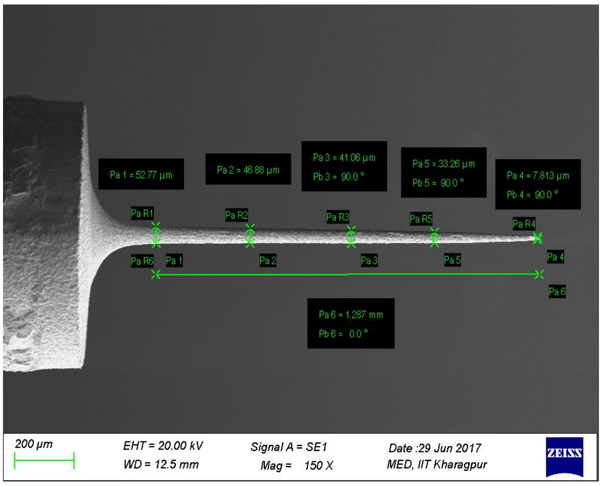
1. Debris removal mechanism plays a significant role in final tool micro-structure.




**a) Micro-tool machined using wire micro-EDG**




**b) Micro-tool machined using disk micro-EDM**




**c) Micro-tool machined using block micro-EDM**

**Fig. 3. Shape and dimensions of fabricated micro-tool**

2. Among the three techniques, tool fabricated by disk micro-EDM process yields the best result under the given conditions.
3. The lengths of the fabricated micro-tools were also found to be different in all three techniques, which indicates that tool wear rate is dissimilar for different techniques.

## References

[1] Guo, Dengji, Xiaoyu Wu, Jianguo Lei, Bin Xu, Reo Kometani, and Feng Luo. "Fabrication of micro/nanoelectrode using focused-ion-beam chemical vapor deposition, and its application to micro-ECDM." *Procedia CIRP* 42 (2016): 733-736.

[2] Liu, Yong, Huitao Cai, and Hansong Li. "Fabrication of micro spherical electrode by one pulse EDM and their application in electrochemical micromachining." *Journal of Manufacturing Processes* 17 (2015): 162-170.

[3] Wang, Minghuan, Yaobin Zhang, Zhiwei He, and Wei Peng. "Deep micro-hole fabrication in EMM on stainless steel using disk micro-tool assisted by ultrasonic vibration." *Journal of Materials Processing Technology* 229 (2016): 475-483.

[4] Jain, V. K., Subodh Kalia, Ajay Sidpara, and V. N. Kulkarni. "Fabrication of micro-features and micro-tools using electrochemical micromachining." *The International Journal of Advanced Manufacturing Technology* (2012): 1-9.

[5] Fan, Zhi-Wen, Lih-Wu Hourng, and Cheng-Yu Wang. "Fabrication of tungsten microelectrodes using pulsed electrochemical machining." *Precision Engineering* 34, no. 3 (2010): 489-496.

[6] Fan, Zhi-Wen, and Lih-Wu Hourng. "The analysis and investigation on the microelectrode fabrication by electrochemical machining." *International Journal of Machine Tools and Manufacture* 49, no. 7 (2009): 659-666.

[7] Wang, JianYuan, and Dong Yea Sheu. "Developing a Process Chain with WEDG Technology and Pulse ECM to Fabricate Ultra Micro Pins." *Procedia CIRP* 42 (2016): 815-818.

[8] Zhang, Hui, Sansan Ao, Weidong Liu, Zhen Luo, Wenjie Niu, and Ke Guo. "Electrochemical micro-machining of high aspect ratio micro-tools using quasi-solid electrolyte." *The International Journal of Advanced Manufacturing Technology* (2017): 1-9.

[9] Elsiti, Nagwa Mejid, M. Y. Noordin, and Adam Umar Alkali. "Fabrication of high aspect ratio micro electrode by using EDM." In *IOP Conference Series: Materials Science and Engineering*, vol. 114, no. 1, p. 012046. IOP Publishing, 2016.