# Feasibility of 3-D Surface Machining by Dry EDM

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**Abstract**

To study the feasibility of 3-dimensional surface machining by dry EDM, a dry EDM machine that can blow gas from a rotating pipe electrode was prototyped. Of factors thought to affect dry EDM performance, cut depth, gas pressure，pulse duration, pulse interval, and revolution of tool electrode were taken up as machining parameters to investigate their influence on machining performance. The results revealed optimum combinations of cut depth and gas pressure for realizing maximum work removal rate as well as minimum tool electrode wear ratio. It was also found that there exist optimum combinations of pulse duration and pulse interval for EDM pulse. Based on these results, micro shaped samples were machined by dry EDM. Compared to oil EDM, tool electrode wear ratio was about 1/3 smaller, and the profile accuracy was excellent. However, because not much improvement was seen for the work removal rate, methods for further enhancing work removal rate must be reviewed for realizing a practical application.

**Key Words**：Dry EDM，Gas pressure，Cut depth，pulse duration，work removal rate，Tool electrode wear ratio

## 1. Introduction

Over the recent years, numerous dry EDM researches are being reported in the area of EDM. Dry EDM is a EDM method which uses gas supplied from pipe electrode to discharge and cool machining debris existing in gaps between tool electrode and workpiece[1)]. Compared to conventional wet EDM methods, dry EDM has been reported to improve profile accuracy due to small tool electrode wear ratio, which makes electrode compensation in 3-dimensional surface machining easy[1)]. In addition, use of oxygen for the gas supplied has also been reported to be effective for enhancing work removal rate of steel workpieces by oxidative reaction[1),2)]. In this study, 3-dimensional surface machining by dry EDM was attempted to investigate the machining performance of dry EDM from the viewpoint of practical application. In machining experiments, we investigated the influence of the following parameters such as cut depth and gas pressure, pulse duration and pulse interval, Rotational speed of tool electrode, all of which are considered important in 3-dimensional surface machining by dry EDM on machining performance.

Results of sample products machined based on data obtained from these machining experiments are also discussed in the following.

## 2. Experimental Method

To investigate the machining performance of dry EDM, groove machining experiments were conducted using the electrode spindle shown in Figure 1 to blow oxygen from the rotating pipe electrode, and the machining path shown in Figure 2. The EDM machine used in the experiments was the Sodick 3-axis linear motor drive machine AQ35L.

Table 1 shows the machining conditions. Figure 2 shows groove machining process. Electrode travels one stroke for every cutting depth, and makes round trips until the target depth is achieved. The actual groove depth here is not equal to the Target depth because of the tool electrode wear and the gap. The parameters used for evaluating machining performance in the experiments were work removal rate and electrode wear ratio calculated from measured values. The former was calculated by dividing the removed volume of the workpiece with the machining time, and the latter was obtained by dividing the electrode wear volume with the removed volume.

## 3. Experimental Conditions

When performing dry EDM, settings of various machining parameters need to be optimized. For this, cut depth, gas pressure, pulse duration, pulse interval, and revolution of tool electrode were selected as machining parameters, and their influence on machining performance was investigated.

### 3.1 Cut depth and air pressure

Taking into account the importance of finding the best relation between cut depth and gas pressure for achieving large work removal rate and small tool electrode wear in dry EDM, the effects of changes in cut depth and gas pressure on machining performance were studied. Figures 3 and 4 show the results.

In Figure 3, the distribution of the work removal rate forms a convex shape in respect to the gas pressure and cut depth. The work removal rate was found to be largest around the gas pressure of 2.5MPa and cut depth of 0.1mm under the machining conditions set in the present experiments. Figure 4 also indicates that electrode wear is minimum at a gas pressure of 1.5 MPa for all cut depths used in the experiments. At constant gas pressure, electrode wear was found to be large the greater was the cut depth.

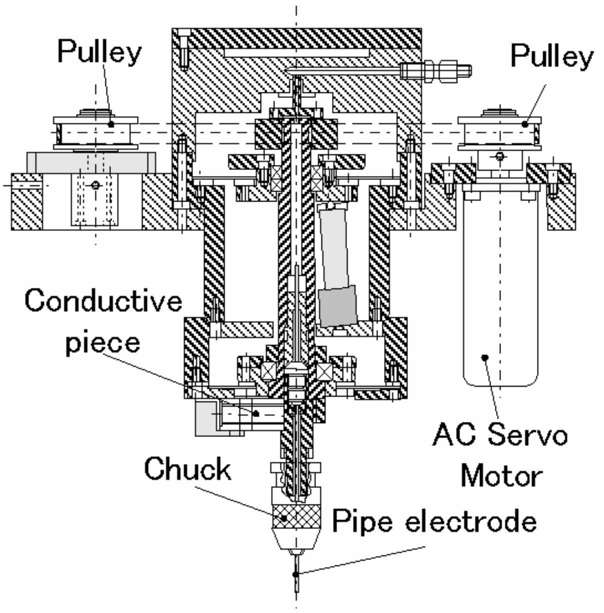


**Figure 1. Tool electrode spindle**

**Table 1. Machining conditions**

| | |
|---|---|
| Open voltage | 280 V |
| Discharge current | 110 A |
| Pulse duration | 10μs |
| Pulse interval | 15μs |
| Supplied gas | Oxygen |
| Tool electrode | CuW pipe<br>External ϕ1.0mm<br>Internal ϕ0.41mm |
| Workpiece | S45C |
| Revolution of tool electrode | 500rpm |

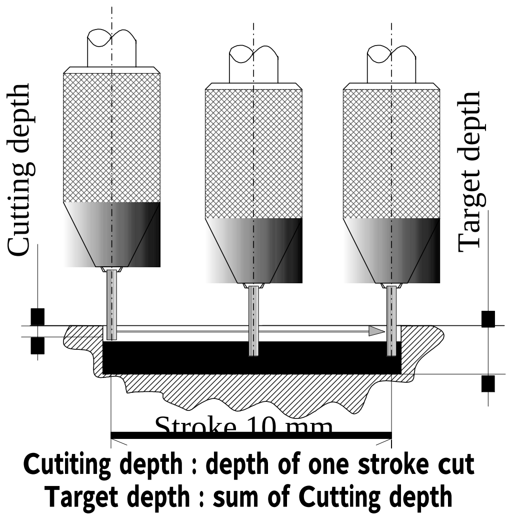


**Figure 2. Tool path**

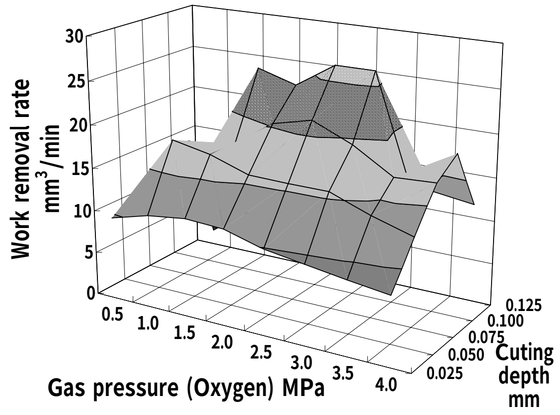


**Figure 3. Cut depth, gas pressure, and work removal rate**

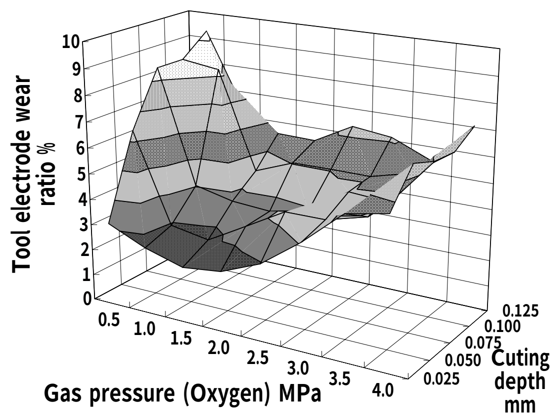


**Figure 4. Cut depth, gas pressure, and tool electrode wear ratio**

### 3.2 Pulse duration and pulse interval

Considering that pulse duration and pulse interval are important parameters in dry EDM, their influence on machining performance was investigated. The experiments were carried out at the following conditions, cutting depth of 0.1mm, oxygen gas with pressure of 2.0 MPa, and varying the pulse duration between 5 and 40μs, and the pulse interval between 5 and 20μs. Machining conditions other than pulse duration and pulse interval were set the same as Table 1.

Figures 5 and 6 show the results of measuring the work removal rate and tool electrode wear ratio when pulse duration and pulse interval are varied. It can be seen that around the pulse duration of 25μs, work removal rate is maximum and tool electrode wear ratio is minimum. The results also confirm that differences in the pulse interval do not have a major influence on work removal ratio and tool electrode wear ratio.

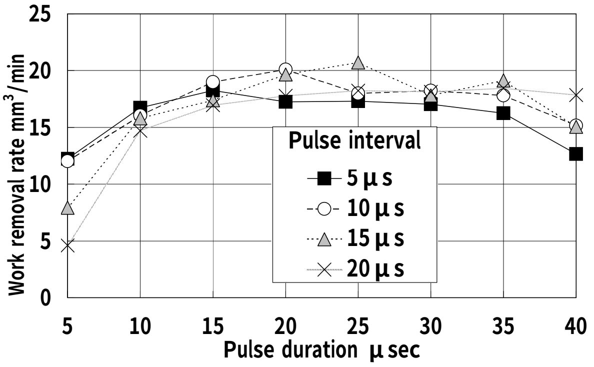


**Figure 5. Pulse duration and work removal rate**

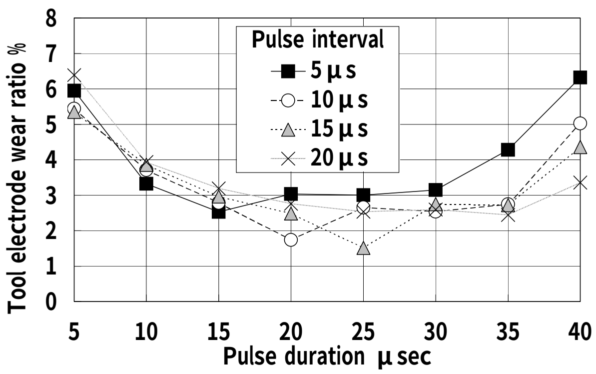


**Figure 6. Pulse duration and tool electrode wear ratio**

### 3.3 Effects of rotational speed of tool electrode

To investigate the influence of rotational speed of tool electrode on machining performance, experiments were conducted varying the rotational speed of the tool electrode from 0 to 4000rpm. The cut depth was set at 0.1mm and the 2.5MPa oxygen was used. Figures 7 and 8 show that when the rotational speed of the tool electrode increases, the tool electrode wear ratio increases moderately, and

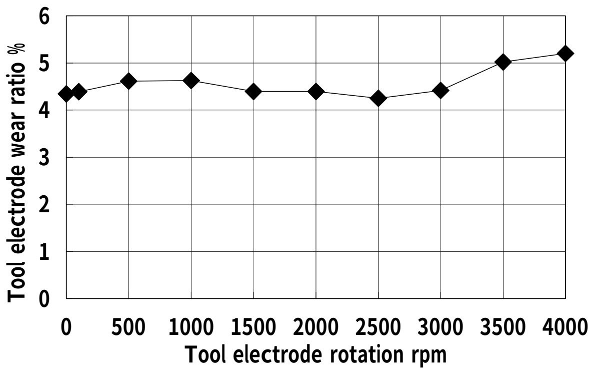


**Figure 7. Relation between revolution of tool electrode and tool electrode wear ratio**

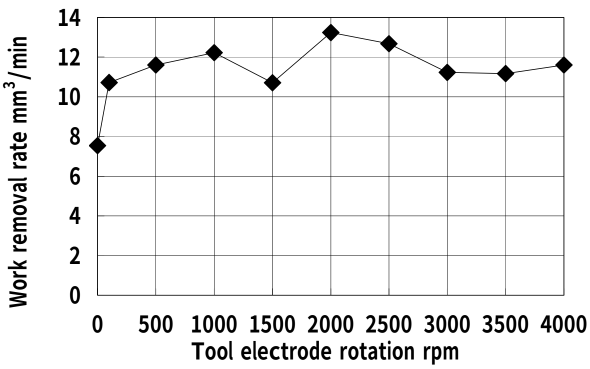


**Figure 8. Relation between revolution of tool electrode and work removal rate**

the work removal rate becomes more or less constant when above 500rpm.

### 3.4 Discussion

When gas pressure increases, the speed of the gas flowing from the pipe electrodes increases, producing cooling effects between the electrodes. As a result, plasma generated by discharge is extinguished sufficiently during pulse interval, and machining debris between the tool electrode and workpiece can be discharged out more readily. These phenomena are considered as the reasons of high work removal rate and small tool electrode wear ratio. The oxidation reaction which becomes active when gas pressure increases is also thought to be related to this tendency. However, when gas pressure is very high, most debris are removed from the clearance so that the gap between the electrode and workpiece decreases[3)]. It results in frequent short-circuiting, which increases mechanical friction, causing the tool electrode wear ratio to become high and the work removal rate to become small. These findings suggest the presence of an optimum gas pressure for the work removal rate and tool electrode wear ratio.

The reason why tool electrode wear ratio minimizes and work removal rate maximizes when the pulse duration is around 25μs is ; a long reaction time is required for the oxidation reaction to become active, thus the longer the pulse duration, the more active is oxidation reaction, and the work removal rate tends to increase. On the other hand, if the pulse duration is too long, removal efficiency reduces in respect to pulse energy in terms of heat conduction, and at the same time, because discharge frequency drops, the work removal rate drops. When the pulse interval is short, plasma generated by discharge is not deionized sufficiently during pulse interval, the tool electrode wear ratio increases, and the work removal rate decreases. On the contrary, when it becomes long, discharge frequency drops and mechanical wear increases. As a result, the work removal rate is small and the tool electrode wear ratio high.

Though the rotational speed of the tool electrode is not directly related to machining, discharge of machining chips becomes difficult when too low or stationary. In this case, short-circuit rate increases and the work removal rate drops. At the rotational speed increases, as mechanical wear increases, the tool electrode wear ratio also increases moderately.

## 4. Machining Samples by Dry EDM

The following discusses the results of machining samples by dry EDM using oxygen gas to investigate the feasibility of the method proposed. The machined shapes were V-shaped die shape, Y-shaped punch shape, and hole.

### 4.1 Dry EDM milling samples

Dry EDM milling was carried out using pipe electrodes. Figure 9 shows the results. CuW pipe electrodes with an external diameter of ϕ0.15mm and internal diameter of ϕ0.07mm were used. The workpiece was SKD-61 plate with a hardness of HRC50. The gas was oxygen with a pressure of 2.0MPa, and the machining depth was set at 0.10mm. Machining was also carried out in oil for comparison. Table 2 shows the machining results. To compare the bottom accuracy of machining in gas and machining in oil, the swelling at the base was measured. Figures 10 and 11 show the measured results. Measurement was carried out using a Mitutoyo non-contact sensor unit SV-3000. The results indicate that the machining time required is the same for oxygen and oil, but tool electrode wear ratio is about 1/3 less when machined in gas. The figures also show that bottom accuracy is better when machined in gas.

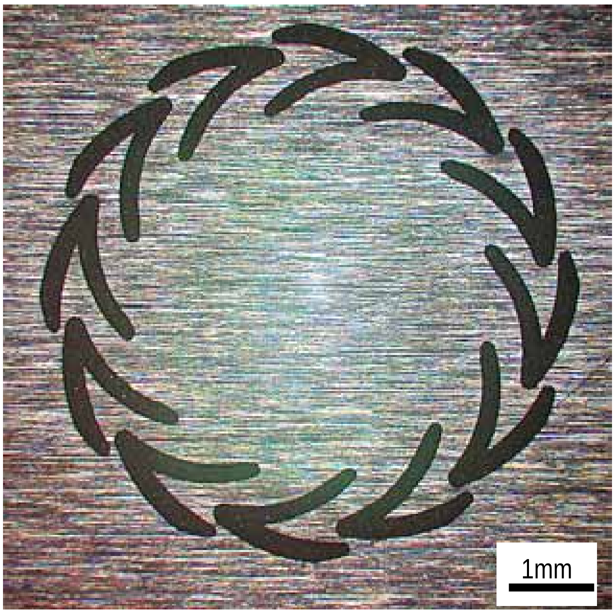


**Figure 9. Dry EDM milling sample**

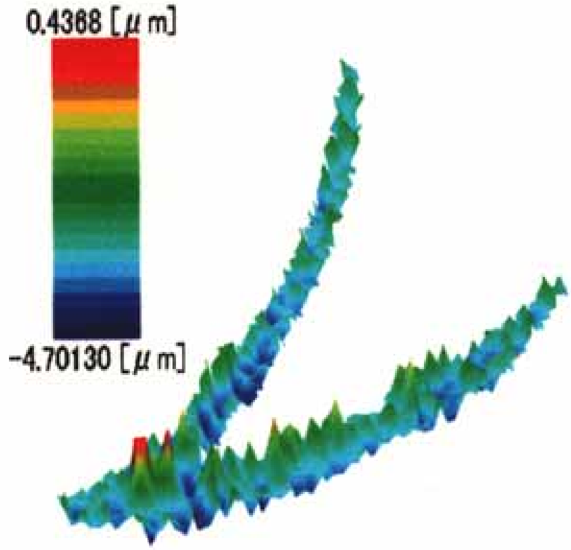


**Figure 10. Dry EDM milling**

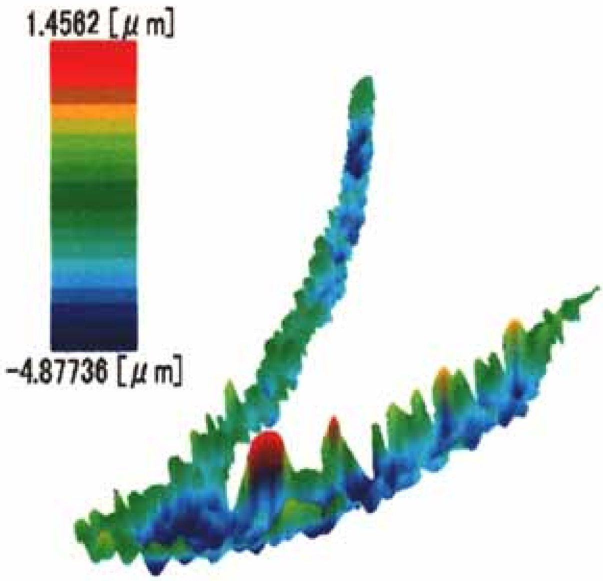


**Figure 11.Oil EDM milling**

**Table 2. Results of dry EDM**

| Machining fluid | Oxygen | Oil |
|---|---|---|
| Machining time h:m | 5:27 | 5:30 |
| *Tool electrode wear length* / *Machining depth* | 38% | 132% |

### 4.2 Contouring samples

Figure 12 shows the results of dry EDM contouring using a pipe electrode. The machining conditions are the same the above dry EDM milling. However, SKD-11 rods with a diameter of 1.0 mm was used as the workpiece. The machining depth was set at 0.7mm. As a result, Y-shaped contouring samples could be obtained at a machining time of 90 hours, tool electrode wear ratio of about 28%, and thickness of 0.075mm.


**Figure 12. Dry EDM contouring sample**

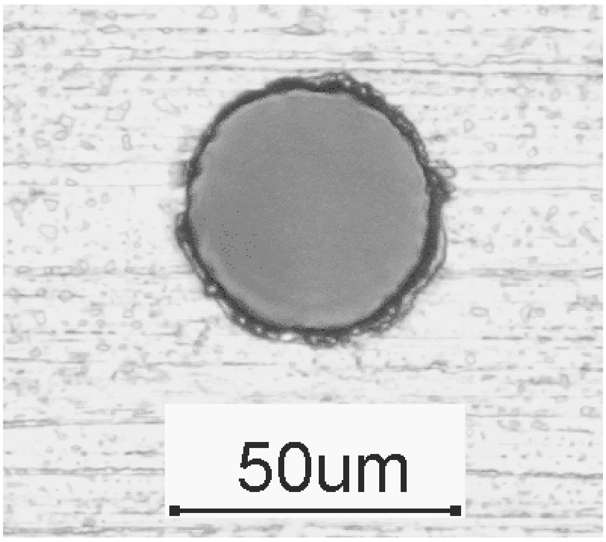


**Figure 13. Dry EDM drilling sample**

**4.3 Drilling samples**

Figure 13 shows the results of drilling using a tungsten rod of 0.030mm in diameter for the tool electrode. The workpiece was made of stainless steel with a thickness of 0.050mm, and oxygen was used. As a result, holes with a diameter of 0.041mm could be drilled at a machining time of eight minutes. Tool electrode wear was 0.001mm.

**5. Conclusion**

The results of performing 3-dimensional surface machining using dry EDM revealed the following;

a. There exist optimum combinations of gas pressure and cut depth for achieving maximum work removal rate and minimum tool electrode wear ratio in dry EDM. There also exist optimum combinations of pulse duration and stationary time.

b. Micro machining was realized by dry EDM using gas. The tool electrode wear ratio was smaller with gas than oil, while the work removal rate did not change.

The results also suggest the need to review methods for further enhancing the work removal rate to realize practical applications of dry EDM in the future.

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