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INFLUENCE OF ORBITAL PARAMETERS WITH TOOL ACTUATION ON RADIAL PATH IN ELECTRO DISCHARGE MACHINING PROCESS

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ABSTRACT

Tool orbiting technique can provide the solution for reducing tooling effort as well as tooling cost in electro discharge machining process. Radial tool orbiting is one of the tool orbiting techniques in which tool electrode actuates in radial direction of a circular cavity. In present paper, experimental study has been carried out to find the effect of orbital parameters viz. orbital radius (S_r), orbital speed (S_o), machining time (t_m) and flushing time (t_f) on material removal rate (*MRR*) and tool wear rate (*TWR*) during radial tool orbiting in EDM process. It is observed that MRR and TWR increases with increase in orbital speed (S_o) and machining time (t_m) whereas MRR and TWR reduces with increase in orbital radius (S_r) and flushing time (t_f).

Key words: *EDM, Radial, Orbital-EDM, Orbital radius, Orbital speed, MRR and TWR.*

1. Introduction

Electro discharge machining process is commonly used in die/mold making industries for generation of complex and intricate shape of cavity on hard to machine materials [1]. The most common application of EDM is drilling a hole. Drilling a hole with EDM process is similar to press drill with travelling quill that moves up and down. In most cases tool electrode is stationary and this is called die sinking EDM process. In die sinking EDM process cavity to be generated is replica of tool electrode. The shape and size of the tool electrode can be easily imprinted on the workpiece. However matched type of tool size with cavity size is one of the major limitations of die-sinking EDM process. Every different size of cavity requires a specific tool electrode of respective matched dimension of the cavity to be drilled; this increases the tooling effort and tooling cost. If tool electrode is allowed to orbit on X, Y and Z axis then different sizes of cavity can be generated with single tool electrode.

Orbital movement of tool electrodes is widely used in micro and macro EDM to reduce the debris concentration at discharge gap and thus avoid unstable machining and arcing. Orbital tool movement in EDM is applied for various purposes. Gu et al. [2] adopted the orbital tool motion (orbit radius 0.5mm) for bundled shaped electrode to erode the un-removed pin shaped work material. Kunieda and Muto [3] used planetary tool motion with multi spark EDM. Orbital tool motion was adopted in X-Y plane to remove the parting marks of tool. Teimouri and Baseri [4] applied planetary motion for the tool having two eccentric holes. Authors observed that planetary motion of tool electrode can improve the process stability by reducing the arc phenomenon. Orbital tool motion has also been used with assisting electrode method for generation of internal thread onto the insulating ceramics [5]. Zaida and Koshy [6] applied orbital tool movement for generation of polygons with sharp corners using RT (Reuleaux Triangle) tool. Ferreira J. C. [7] used the orbital tool movement in EDM for generation of helical threads in predrilled cavity. Orbital tool motion is very helpful during EDmachining in gas medium. The tool orbiting in gas medium helps to avoid the possibilities of shorting during machining. Kunieda and Yoshida [8] recommended the application of orbital motion in dry EDM for higher efficiency. If the movement of tool electrode is allowed to orbit on a controlled trajectory different tool paths like helical, spiral, radial etc. are possible during EDM process. El-Taweel and Hewidy [9] investigated the effect of orbital speed and orbital radius on machining performance under two different tool paths i.e. helical and spiral tool paths. It was reported that orbital tool movement on helical path gives relatively better performance than spiral tool path. Further, Dave et al. [10] carried out detailed investigation on the effect of several input parameters during helical orbital EDM process. Their notable finding was orbital radius has significant effect on material removal rate and orbital speed has negligible effect on material removal rate. But orbital radius and orbital speed was reported as less significant parameters for tool wear rate in helical orbital EDM process. This

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means, helical orbital EDM process allows use of smaller tool electrode for generation of bigger size cavities without any significant tool wear rate.

Literature indicates that working capability of EDM process can be enhanced using orbital tool movement technique. As per author's knowledge, research studies mainly focused on helical, spiral and cylindrical tool path movement in orbital EDM process. Tool motion on radial path has not been reported with detailed analysis in literature. In the present study, an attempt has been made to explore the idea of tool orbiting on radial path during EDM process. Further, effect of orbital parameters namely, orbital speed (S_o), orbital radius (S_r), flushing time (t_f) and machining time (t_m) has been experimentally investigated on material removal rate (*MRR*) and tool wear rate (*TWR*).

Next section, 2, describes the tool motion on radial path in orbital EDM process, after that, brief description of input and output parameters have been given. Experimental details have been explained in section 4. The results have been discussed in section 5 and final conclusive summary followed by references has been given in last section.

2. Radial Tool Orbiting in EDM Process

During radial tool orbiting in EDM process, tool electrode actuates along radius of the circle. Initially tool electrode plunges into the workpiece at the required depth of cavity on path 1 (as shown in figure 1) and then its movement is confined to horizontal plane only.

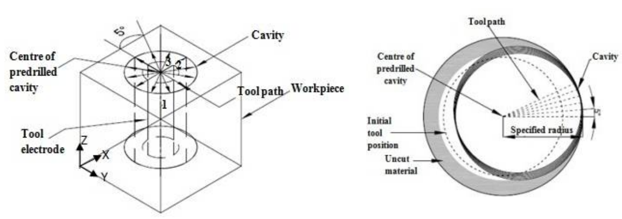

Fig. 1 (a) Isometric view of radial tool orbiting (b) Top view of radial tool orbiting in EDM process

After achieving the required depth, tool electrode actuates on path 2 and its direction is radially outward from centre of cavity. Tool electrode returns to its initial position (on path 2) after achieving specified dimension of cut i.e. orbit radius. Next movement of tool electrode is defined at 5 degree increment with the preceding tool path, follows path 3. In such a way, a complete circle is traced in 72 movement of tool in a cavity. Major portion of material is removed by sparking occurs on the cylindrical face of the tool electrode. Tool movement is guided by two stepped motors (axis are perpendicular to each other) attached with the tool holder and these motors are controlled with an orbit controller where dimension of cut and speed of tool movement is specified.

3. Process Parameters of Radial Tool Orbiting in EDM Process

Radial tool orbiting in EDM process includes the movement of tool electrode as well as sparking during machining. Hence, process parameters require controlling of orbiting property of tool electrode and the sparking phenomenon in radial orbital EDM process. Sparking between the electrodes is controlled by electrical parameters like peak current, pulse duration, duty factor, open circuit voltage etc. Orbiting property in EDM is controlled by orbital parameters like orbital radius, orbital speed, machining time and flushing time, which are mainly non electric controlling parameters. In the present investigation, effect of orbital parameters has been studied over machining responses.

3.1 Orbital radius (S_r)

It is the measure of the distance through which the tool electrode travels during orbiting. In radial orbital movement, tool electrode travels radially up to the specified radius. The amount of radius (in machine JM322) can be set up to a maximum of 9.999 mm, however the movement of the work head from the centre is a maximum of 4.999 mm.

3.2 Orbital speed (S_o)

Orbital speed is the speed of tool electrode during the orbit machining. It is measured in mm/sec. Speed of the tool electrode is varied through a controller that controls the speed of motors attached with EDM head. The range of the orbital speed is 0.04 to 0.36 mm/sec.

3.3 Machining time (t_m)

In radial tool orbital EDM process, tool electrode moves towards the cutting zone with to and fro movement on horizontal path along radial direction of a circular cavity. The time taken in a forward step during tool travel is defined as machining time (t_m). Machining time (t_m) decides the length of the forward step of tool electrode in EDM process. If machining time (t_m) is longer than tool electrode achieves the specified radius of cut in fewer forward movements and this reduces the time taken of travel during machining.

3.4 Flushing time (t_f)

The fro (backward) movement of tool electrode during machining is provided for flushing of dielectric fluid. The time duration of a single back step of tool electrode is defined as flushing time (t_f). In die-sinking EDM process, tool electrode has given some vertical lift during machining which is defined as flushing height. As described earlier, during radial tool movement the vertical movement of tool is restricted; hence tool electrode is provided retraction in horizontal path. The time taken for retraction is termed as flushing time.

4. Experimental details

Experiments were performed on Joemars (model-JM322) make die sinking EDM machine as shown in figure 2 (a). The Z movement of this machine is controlled by servo controller. The X and Y movement of table is manually controlled. An orbital attachment unit is connected with the head of the machine. This unit includes two stepped motors, one each for X and Y direction movement of tool electrode. The movement of the tool electrode can be observed on dial indicator provided with unit as shown in figure 2 (b). The movement is controlled by an orbit cut controller that has provision of changing orbital parameters like radius, speed, flushing time, machining time etc. The maximum displacement of tool under orbiting condition is 4.999 mm from its centre. Thus, it can machine up-to the 9.999 mm. The orbital cut controller can control X, Y and Z axis movement independently with 1 µm precision.

(a) **(b)**

Fig. 2 (a) EDM machine (b) orbit cut attachment

Cylindrical pure copper (99.9% Cu) was used as tool electrode of 8 mm diameters and 15 mm length. Specimens were cut from regular bar of AISI 304 materials with 15 X 15 X 10 mm dimension. The depth of the cavity was fixed to 6 mm.

To identify the effect of each orbital parameters independently, experiments were performed using One-Factor-at-A-Time (OFAT) method. Each parameter was varied at once keeping other parameters constant. Table 1 shows the various parameters and their values used in present investigation.

Table 1. Parameters and their values

Parameters	Unit	Values
Orbital radius (S_r)	mm	0.5, 1.0, 1.5, 2.0, 2.5
Orbital speed (S_o)	mm/s	0.05, 0.06, 0.09, 0.13, 0.36
Machining time (t_m)	s	0.300, 0.667, 1.034, 1.401, 2.67
Flushing time (t_f)	s	0.067, 0.167, 0.267, 0.367, 0.467
Peak current (I_p)	A	17
Spark gap (S_g)	V	40
Pulse on time (t_{on})	µs	195
Pulse off time (t_{off})	µs	86
Open voltage (O_c)	V	170
Polarity	--	+

The performance of EDM process is usually measures with respect to material removal rate (*MRR*) and tool wear rate (*TWR*). *MRR* and *TWR* are defined as the volumetric removal of material from workpiece and tool electrode respectively per unit time. It is expressed in mm^3/min. Mathematically, these can be calculated as follows.

$$MRR = \frac{\Delta W_{wp}}{t_m \times \rho_{wp}} \quad (1)$$

$$TWR = \frac{\Delta W_t}{t_m \times \rho_t} \quad (2)$$

Where, ΔW_{wp} and ΔW_t are the weight difference of workpiece and tool electrode respectively before and after machining, t_m is the total machining time, ρ_{wp} and ρ_t are densities of workpiece material and tool material respectively.

5. Results and discussions

5.1 Effect of orbital radius (S_r)

Fig. 3 shows the change in material removal rate (*MRR*) on varying orbital radius. Orbital radius was varied at five different values ranging from 0.5 to 2.5 mm. Maximum *MRR* can be obtained at smallest orbital radius i.e., 0.5 mm. Increase in orbital radius decreased the *MRR*.

Highest *MRR* was observed at lower orbital radius, this can be explained by two reasons. At smallest orbital radius, the displacement of tool electrode was minimum form the centre of cavity. Time taken for the smaller displacement (radius) was minimum for lower orbital radius in radial orbit movement of tool electrode. A greater fraction of machining time was used for cutting purpose of the workpiece material. Hence, smaller orbital radius produced higher *MR*R.

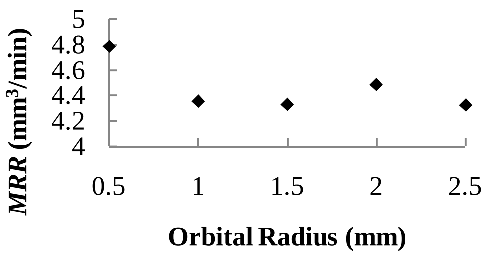

Fig. 3 MRR vs. Orbital radius

With increase in orbital radius, tool electrode has to displace more; this added some extra time in total machining time and thus lowers the *MRR*. Other reason for lower *MRR* with higher orbital radius was reduction in spark contact area between tool electrode and cavity wall. Increase in orbital radius, increases the cavity size. As the cavity size increases, the spark contact area or area covered by spark decreases because tool diameter was same. This can be understood with the help of figure 4.

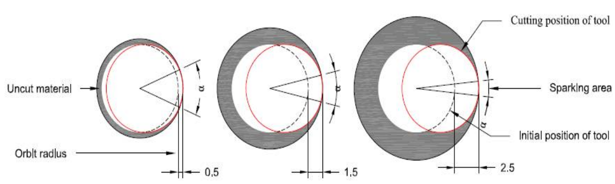

Fig. 4 Relation between spark contact area and orbital radius

In figure 4, symbol "α" represents the probable spark contact area of the cavity and gray shaded area is uncut material (material to be removed). "α" is decreasing with increase in orbital radius. At smallest orbital radius i.e. 0.5 mm, spark contact area (α) is maximum, it means larger volume of material was removed in one travel of tool electrode. In next travel of tool electrode, relatively smaller volume of material was left to be removed (for achieving 0.5 mm radius) that will take very less time. Thus in the 4th quadrant of cavity, major portion of material were removed by previous tool travel and therefore tool achieve the specified radius of cut in less time. With increase of orbital radius larger volume of material to be removed in each travel of tool which increased the total machining time and resulted lower *MRR*.

Figure 5 clearly shows the reduction in *TWR* with increment in orbital radius during radial tool orbiting in EDM process. At minimum orbital radius i.e. 0.5mm, *TWR* is highest and maximum orbital radius shows the smallest *TWR*.

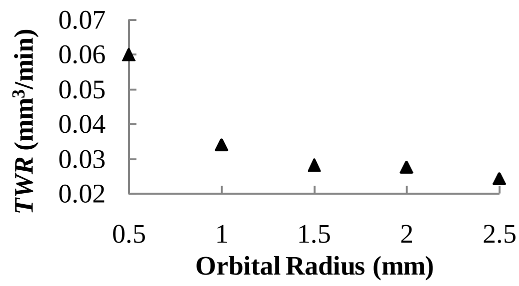

Fig. 5 TWR vs. Orbital radius

At smaller orbital radius, tool electrode quickly came into the vicinity of surfaces where sparks generated. Due to frequent sparking, higher *TWR* is resulted, because heat generated during sparking did not get sufficient time for conduction through tool electrode. Higher heat leads faster removal of materials from both workpiece and tool electrode and resulted maximum *TWR*. When the orbital radius increases, tool electrode has to travel more distance during which dielectric fluid cools the electrode material and prevents it from excessive wear.

5.2 Effect of orbital speed (S_o)

The effect of variation in orbital speed on material removal rate (*MRR*) is shown in figure 6. It can be observed that *MRR* was increasing with increase in orbital speed. Minimum *MR*R was found with 0.05 mm/s orbital speed and was significantly increasing with increase in orbital speed. When orbital speed is (0.36 mm/s) maximum, highest *MRR* was resulted.

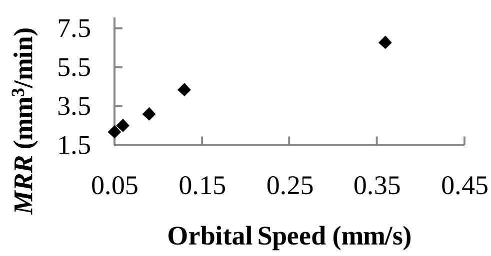

Fig. 6 MRR vs. Orbital speed

The increasing trend of *MRR* was due to the increase in speed of tool electrode during radial tool orbit machining. With increase in speed of tool movement, time consumed in travelling of tool from centre of cavity to the machined area decreased and that improved the material removal rate at lower orbital speed. Increase in orbital speed of tool electrode leads to increase in tool wear rate. From figure 7, it can be observed that *TWR* is minimum at the lowest orbital speed of tool movement and is increasing with increase in orbital speed. Maximum *TWR* was obtained with highest orbital speed.

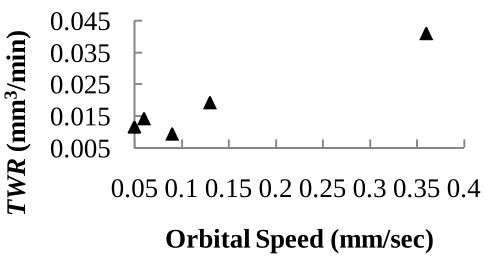

Fig. 7 TWR vs. Orbital speed

More tool wear rate at higher orbital speed may due to rapid heating of tool electrode. Higher orbital speed in radial orbital EDM process reduces the travelling time of tool electrode due to which tool electrode comes quickly in vicinity of cavity wall where sparking occurs. Due to frequent sparking, tool electrode got less time for heat conduction generated during sparking. This increases the tool wear rate. At lower speed of tool movement, tool electrode has given sufficient time to conduct the heat through it. This decreases the *TWR*.

5.3 Effect of flushing time (t_f)

Flushing time in radial tool orbital EDM process is time duration given to tool electrode for providing space to enter dielectric fluid into the working zone. During this time tool electrode retracts back, so that dielectric fluid get time for flushing of eroded particles. Figure 8 shows the effect of flushing time on MRR. From Fig. 8, it can be observed that *MRR* continuously decreases with increases in flushing time (t_f). Maximum *MRR* was observed at lowest flushing time

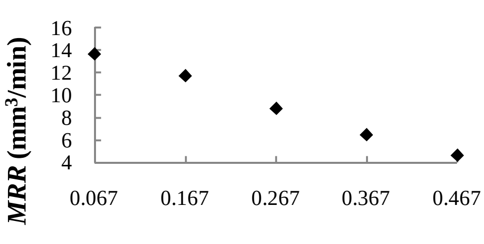

Fig. 8 MRR vs. Flushing time

Effect of variation of flushing time on *TWR* was observed and plotted in figure 9. (0.067 sec.) while minimum *MRR* was observed at highest flushing time (0.467 sec.). Lower flushing time implies lower retraction time of tool electrode during machining. This means after short time of flushing, tool electrode again engaged in sparking that results more *MRR*. Increase in flushing time, increases the tool retractions time that is non machining time. Non-machining time increases the total machining time and reduces the *MRR*. Therefore, *MRR* is found reducing with increase in flushing time (t_f).

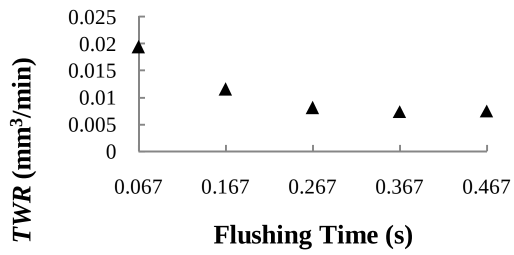

Fig. 9 TWR vs. Flushing time

As shown in Fig. 9, it can be observed that *TWR* decreases with increases in flushing time (t_f). Further increment in flushing time (t_f) did not affect the *TWR*. At the lower flushing time (t_f) setting, tool electrode engaged in machining for larger fraction of machining time. So, tool electrode frequently engaged in sparking without proper cooling this might cause excessive wear of tool electrode at lower flushing time (t_f). As flushing time increases, better flushing condition prevailed results into lesser tool wear. However, increasing flushing time beyond a certain limit does not increase flushing.

5.4 Effect of machining time (t_m)

The duration of machining time decides the length of a forward step during tool orbiting in radial path in EDM process. Longer the machining time, larger will be the forward step. This means tool electrode has to finish the cut of larger thickness of material before retracting back for flushing of dielectric fluid. The relation between *MRR* and machining time is shown in figure 10.

From Fig. 10, it can be observed that material removal rate (*MRR*) is increasing with increase in machining time (t_m). For longer machining time i.e., at 1.401 seconds, maximum *MRR* was observed.

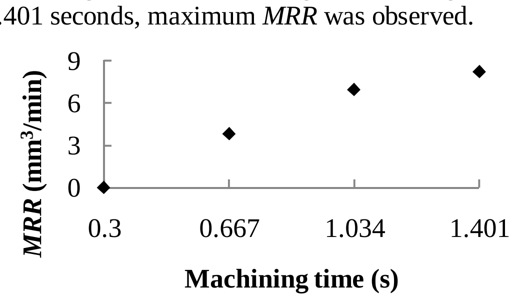

Fig. 10 MRR vs. Machining time

This is because increase in machining time (t_m) increases the stroke length during forward movement of tool electrode in radial tool orbiting. With longer stroke length, tool electrode covers the intermediate distance (from centre to cutting zone) in minimum time. This reduces the travelling time of tool and hence improves the *MRR*. Machining time decreases, *MRR* was also found to be decreased. When machining time (0.300 seconds) was very low, machining was not performed because the machining time was not sufficient for establishing spark between electrodes.

Effect of machining time (t_m) was observed on *TWR* and shown in figure 11. *TWR* was increasing with increase in machining time. The heat generated in working zone was responsible for erosion of material from tool electrode and workpiece but due to having higher thermal conductivity of tool material, heat was conducted through the tool. Beside the conduction of heat through tool material, fresh dielectric fluid was also carrying away heat from the tool material. Due to these reasons, tool electrode experienced less wear than that of workpiece in EDM. When machining time was increased, tool electrode had to remains engaged with sparks for longer time due to which more material got eroded from tool surface. Maximum TWR was found at 1.034 s, further increase in machining time decreased the TWR.

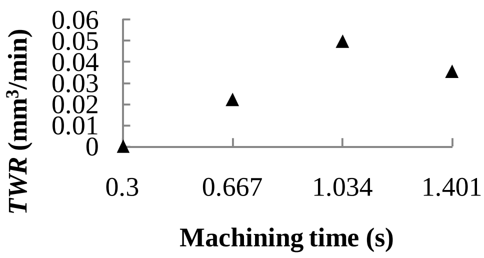

Fig. 11 TWR vs. Machining time

6. Conclusions

This paper presented an experimental investigation on radial tool orbiting in electro discharge machining process. Some of the important findings are written below.

a) MRR and TWR were observed decreasing with increase in orbital radius (S_r). 0.5 mm orbital radius resulted to maximum MRR and TWR. Variation in TWR after 1.5 mm orbital radius became minimal.

b) Considerable effect of orbital speed (S_o) on MRR and TWR was observed during radial tool orbiting in EDM process. MRR and TWR ware increased with increase in orbital speed.

c) Increase in flushing time (t_f) reduced the *MRR* and *TWR*.

d) MRR and TWR were increasing with increase in machining time. If machining time (t_m) was set quite low (0.300 s), machining was not performed.

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Nomenclature

Symbol	Meaning	Unit
S_r	Orbital radius	mm
S_o	Orbital speed	mm/s
t_m	Machining time	s
t_f	Flushing time	s

