Sweeping Jet Flushing Method for EDM

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***Abstract*-Jet flushing is the most popular type of flushing for EDM (Electro Discharge Machining). However, it is usually applied with the nozzles fixed at positions which are decided on the basis of the operator's experience. In this paper we propose a dynamic jet flushing method with knowing nozzles that sweep along the outline of the EDM gap. Experimental results clarify the effectiveness of this method on the precision of machining. A method for calculating the debris distribution in the gap is proposed as well. The result of calculations successful displays the debris status with various types of jet flushing, showing the superiority of the sweeping jet method.**

Keywords—EDM, Jet Flushing, Debris, Simulation.

I. FOREWORD

Page Layout Flushing is as important as design in optimizing the process of EDM. One important role of flushing is to stabilize the repetition of discharge. It is well known that too much debris in the discharge gap often causes continues arc or short circuit & makes the process unstable. Another less popular but important fact is that to clean a dielectric fluid is another reason for short circuits and the consequent unstableness. There for, the dielectric fluid must always contain an appropriate concentration of debris.

Another important role of flushing is to realize an accurate copy of the electrode shape into the work piece. Since the breakdown distance of dielectric liquid is greatly influenced by the contamination of the liquid, the gap distance between an electrode and the work piece changes from place to place according to the change in debris concentration[1][2][3][7]. This change directly causes dimensional error in the copying process. If flushing is properly applied, making the concentration uniform everywhere over the working area the gap distance becomes uniform and an accurate copy is ensured.

To perform these important roles, ideal flushing must maintain constant and uniform debris concentration. (In this paper, the concentration discussed is two dimensional along the facing surfaces of the electrode and the work piece.)

In this paper a new flushing method, the sweeping jet, based on the popular jet flushing is proposed. The flow of the dielectric fluid in the discharge gap is calculated. Considering the flow, debris generation & debris diffusion, a simulation method for debris distribution in the discharge gap is developed. The possibility of better design of jet flushing, including the sweeping jet is given through experiments & the simulation.

II. CONVENTIONAL FLUSHING FOR EDM

Various types of flushing methods have been proposed & used. They are summarized in Table 1. They are commonly effective for removing debris from the discharge gap, as this was the main purpose when they were developed. However, most of them do not guarantee uniformity of debris concentration.

Table 1. Flushing methods for EDM.

FLUSHING METHODS		
DIRECT	INDIRECT	
	JET FLUSHING	PUMPING
1.Injection 2.Suction	3.Jet flushing	4.Electrode jump 5.Self-flushing 6.US vibration 7.2D vibration
PROBLEMS Flushing holes (1,2), Navel (1,2) Nozzle arrangement (3), Loss time (4,5) Driving mechanism (5,6,7), Size limitation (6)		

The effect of these flushing methods on the dimensional machining accuracy is an indirect result of reduced average debris concentration. There for, method with more direct homogenization of debris are requested for precision EDM. Among the methods in Table 1, ultrasonic vibration of the electrode (6) as such an effect to a certain extent [4], but the application is this method is limited to cases of small size electrodes. The self-flushing method (5) [5] & 2D vibration of the electrode (7) [6] can be modified to compensate the uneven distribution by attaching the certain motion in the direction of the third axis. However, this modification requires further sophistication of equipment which is already more complicated than for other methods.

III. REVISION OF JET FLUSHING

Jet flushing is the simplest & oldest flushing method for EDM. A dielectric fluid jet is ejected from a nozzle (or several nozzles) towards the machining area. The pressure of the jet causes certain flow in the discharge gap & the debris is carried by the flow out of the gap. This method is very widely used in factory because of its simplicity and rather good debris removal capability. However, it is not easy to determine the most appropriate position of the nozzles. The position is usually decided by operators based on their experience, often without confidence.

On the other hand, this method basically does not ensure debris uniformity because the flow in the gap is almost fixed since the nozzle is fixed at a certain position. This fixed flow causes a concentration change dependent on the flow field.

Regardless the above problems, the simplicity of this method is attractive, & if the position of the nozzle is free & can be controlled during machining, a new direction in the progress of flushing may be opened up.

IV. SURFACE PRODUCED USING CONVENSIONAL JET FLUSHING

For the first step, we must know how the jet influences the dimensional accuracy. We choose the flatness of the machined surface as the most basic characteristic to be

checked. The change of flatness in accordance with the nozzle setting was investigated when machining a flat 50mm x 50mm square surface. Discharge pulse selected such that it is difficult to continue machining without flushing. Machining conditions are as follows.

Work piece: EN31 with 58 HRC
Electrode: copper
Polarity: electrode= (+)
I0=6A, t0=68µ s
Ignition voltage: 305V
Dielectric fluid: EDM oil
Nozzle diameter: 3mm
Jet angle: 150
Flow rate: 31/min (total)

The surface profile after 8 hours of machining was measured for three types of nozzle setting.

1. Two nozzles on one side.
2. Two nozzles on one side & another nozzle on the opposite side. (the maximum available number of nozzles was 3 in this experiment.)
3. Three nozzles on one side. The sides are alternated every 5 minutes.

The profiles measured are shown in the figures 1 to 3. Figures 1 & 2 clearly indicate that the nozzle position influences the flatness of the machined surface. Nozzle setting 3 was tested to check whether the or not a simple compensation of the flow direction is effective in making the debris distribution uniform. Figure 3 clearly shows that the distribution of debris is not so simple as to be made uniform merely by applying in alternate flow.

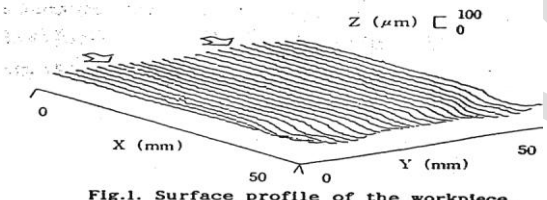


Fig.1. Surface profile of the workpiece. (Flushing from one side.)

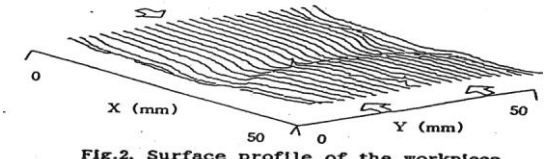


Fig.2. Surface profile of the workpiece. (Flushing from both sides.)

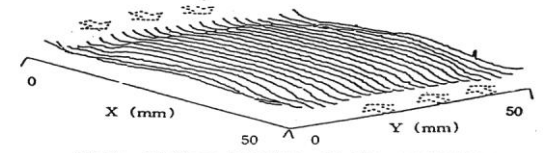


Fig.3. Surface profile of the workpiece. (Alternate flushing.)

V. SWEEPING JET FLUSHING

From the experiment above it was confirmed that the position of the nozzle is an important factor in determining debris distribution and, consequently, copying accuracy. It suggests that dynamic position change of nozzles may be effective for compensating the uneven distribution of debris and ensuring the precise copy. To confirm this idea, dynamic jet flushing was tested.

Figure 4 illustrates the principle of this method. Jets are supplied from nozzles which move along the outline of the machine area.

Machining tests were carried out for a typical nozzle movement as shown Figure 5. Phase shift of 90 degrees was given for avoiding the continues confliction of the two jets. In practice, a jet is supplied from two parallel nozzles set with 10mm of separation.

The surface obtained is in Figure 6 flatness was obviously improved in comparison with the results in Figures 1 to 3.

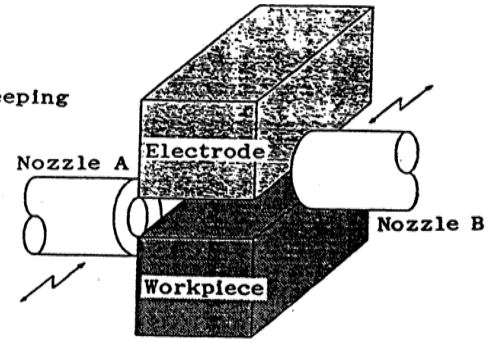


Fig.4. Principle of 'sweeping jet' flushing.

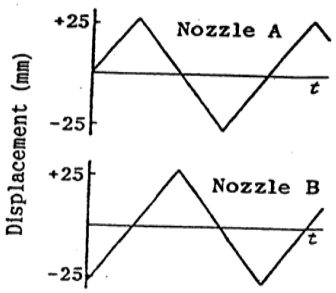
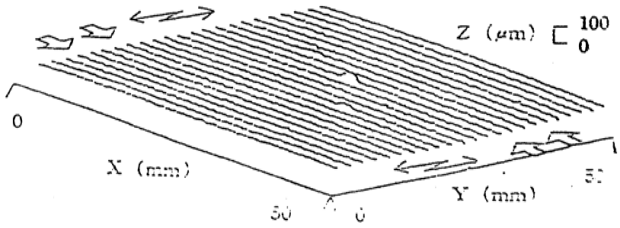


Fig.5. The movement of nozzles in the experiment of sweeping jet flushing.



VI. SIMULATION OF JET FLUSHING

Although a good result of the sweeping jet was obtained in the above mentioned, several parameters, such as sweeping speed, machining area and strength of the jet, may influence the process. Development of a computational method to simulate the process will help to optimize these parameters.

a. Simulation of the fluid flow in the gap

The first step is to simulate the fluid flow in the gap because the fluid flow is one of the main motive forces of debris distribution. Koenig mathematically calculated the flow for injection flushing [7]. The method is available for limited applications but is not suitable for in combination with the calculation of debris distribution. We applied a numerical method to satisfy the purpose of the simulation.

Since the pressure applied is not high & the influence of gravity is negligible in such a narrow gap, the

equation of continuity &Navier stokes' equations are presented as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

$$\frac{Du}{Dt}=-\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}+\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \quad (2)$$

$$\frac{Dv}{Dt}=-\frac{1}{\rho}\cdot\frac{\partial p}{\partial y}+\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad (3)$$

$$\frac{Dw}{Dt}=-\frac{1}{\rho}\cdot\frac{\partial p}{\partial z}+\nu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right), \quad (4)$$

where

$$\frac{D}{Dt}=\frac{\partial}{\partial t}+u\frac{\partial}{\partial x}+v\frac{\partial}{\partial y}+w\frac{\partial}{\partial z}. \quad (5)$$

u, v, w are flow velocity corresponding to the directions x, y, z. ρ: density, p: pressure, v: dynamic viscosity.

Since the gap is narrow the flow in z direction may be ignored, i.e. w=0.

The gradients of u and v are estimated to be much larger in the z direction than in the x & y directions. This leads to the following relation for average velocities u and v.

$$\frac{\partial^2 u}{\partial z^2}=-\frac{12}{H^2}\bar{u}\ ,\quad \frac{\partial^2 v}{\partial z^2}=-\frac{12}{H^2}\bar{V}, \quad (6)$$

where H is the gap distance.

Redefining u and v as average velocities or former u and v, basic equations for the EDM gap are obtained as,

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}-\frac{12\nu}{H^2}u \quad (7)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=\nu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{1}{\rho}\cdot\frac{\partial p}{\partial y}-\frac{12\nu}{H^2}v. \quad (8)$$

Calculation was carried out by applying the control-volume method, which is one of the finite-difference methods. The hybrid method was applied for the approximation to calculate plane flux. To avoid unnecessary oscillation solution, a method using the staggered grid was employed.

The main algorithm applied was SIMPLE (semi-implicit method for pressure-linked equation). The calculation procedure is as follows.

1. Assume the pressure, p.
2. Calculate u and v using equation (7) and (8).
3. Revise p, u and v in order to satisfy the equation of continuity.
4. repeat from stage 1 using the new pressure valve until the solution converges.

The line-by-line method derived from the TDMA (tridiagonal-matrix algorithm) method and the Gauss-Zeidel method was used for calculating matrix coefficients.

The machining area 50mm x50mm is divided into a mesh with 33 x 33 grids. The given constants, boundary condition and the initial condition are as follows, assuming that the fluid is EDM oil:

ρ=0.78 g/cm2, v=2.71mm2/s, H=0.17mm;

Gradients of u and v are zero at the edge of the machining area;

p is 7200Pa(at the grid where a nozzle is set) or zero (other grids);

u=v=0 at t=0.

The flow field was calculated every 0.01ms.

The result of the calculations is as follows.

For fixed nozzle, u and v converged within 1ms(in the time scale of EDM) .

The stationary-state flow fields calculated are shown in Figure 7 and 8. the straight line starting at each grid center indicates the direction and the speed of the flow there. These figures suggest uneven debris distribution and consequently, poor flatness of the surface with such a nozzle setting, to a certain content.

For a sweeping jet, the flow changes according to the nozzle movement. An example of the calculation result is shown in Figure 9. The position and the moving direction of the nozzles are indicated in the figure. Flow simulation of the sweeping jet, however, gives little indication of the flatness of the work piece.

b. Simulation of debris distribution in the gap

Debris distribution was simulated for obtaining a more direct indication of the machining accuracy, or, in other words, the location change of the gap distance.

Debris is carried mainly by the fluid flow. However, there must be other motive forces because there are cases of stable machining without intentional flushing. In the EDM process, the slight up-and-down movement of the electrode & the pulsed pressure of discharge locally disturb the debris distribution. The disturbance is likely to carry the debris I the direction from high to low concentration. Following this argument, we applied diffusion theory together with the result of the flow calculation.

In a small square, dx X dy, the change of debris concentration, c (x, y, t) (m-2), due to diffusion in the x direction is described as

$$-\kappa\frac{\partial^2 c}{\partial x^2}dxdydt, \quad (9)$$

x : diffusion coefficient. On the other hand, the change due to liquid flow is

$$\frac{\partial(cu)}{\partial x}dxdydt. \quad (10)$$

similar equations are also obtained for the y direction. Debris generation is given as r(x, y, t) (m-2s-1) depending on the local discharge frequency. In total, the differential equation for debris distributions derived as

$$\frac{\partial c}{\partial t}+\frac{\partial(cu)}{\partial x}+\frac{\partial(cv)}{\partial y}=\kappa\left(\frac{\partial^2 c}{\partial x^2}+\frac{\partial^2 c}{\partial y^2}\right)+r. \quad (11)$$

Using the same numerical methods as in flow simulation, debris distribution can be calculated. In practical calculation the debris generation functions & the diffusion coefficient must be given.

Debris generation r at grid (I, j)was assumed to be determined by

$$\frac{r_{ij}}{r_0}=1+\beta\left(\frac{c_{ij}}{C_{av}}-1\right), \quad (12)$$

where ro: average debris generation (s-1) per grid. Ro=2500/1089(but the value has no practical meaning); cij: debris concentration at grid (I, j);

Cav: average debris concentration;

β: contribution coefficient of debris concentration on discharge frequency.

The diffusion coefficient was decided after several simulations in order that the concentration distribution would fit the ups & downs of the surface machined by one side, fixed-jet flushing (cf. Figure 1). Although this coefficient may change for every grid, a constant value was used for simplification. For the grids at the edges of the machining area, a 10-times-larger coefficient was given.

The results of the calculation for the fixed jet are shown in Figures 10 and 11.they correspond to the case with two nozzles on the side and with two nozzles on both sides, respectively.

For the sweeping jet, the distribution changes with time, as shown in Figure 12, corresponding to the position and the movement direction of the nozzles shown.

Since the geometry of the machined surface is thought to be related to the concentration is one cycle of nozzle movement is shown in Figure 13. this clearly demonstrates the advantage of the sweeping jet over conventional fixed jets such as shown in Figures 10 and 11. Figures 11 and 13 correspond well with the actual ups and downs of the machined surfaces shown in Figures 2 and 6.

The correspondence between the results of the simulation and experiment was also confirmed when sweeping speed was changed.

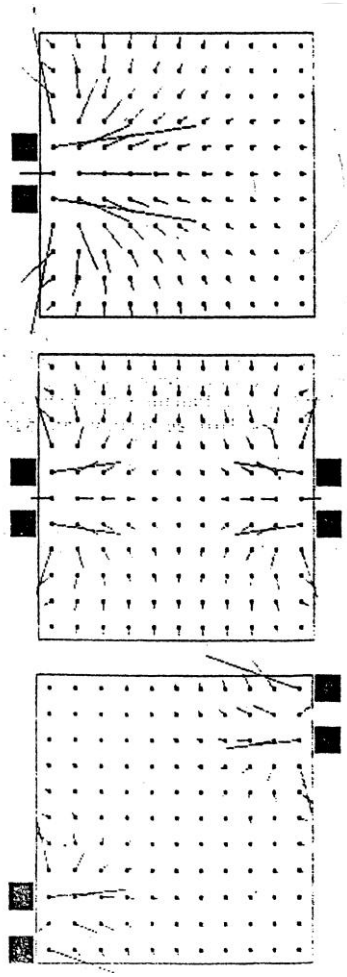


Fig.7. Calculated flow velocity. (Flushing from one side.)

Fig.8. Calculated flow velocity. (Flushing from both sides.)

Fig.9. Calculated instantaneous flow velocity. (Sweeping jet flushing.)

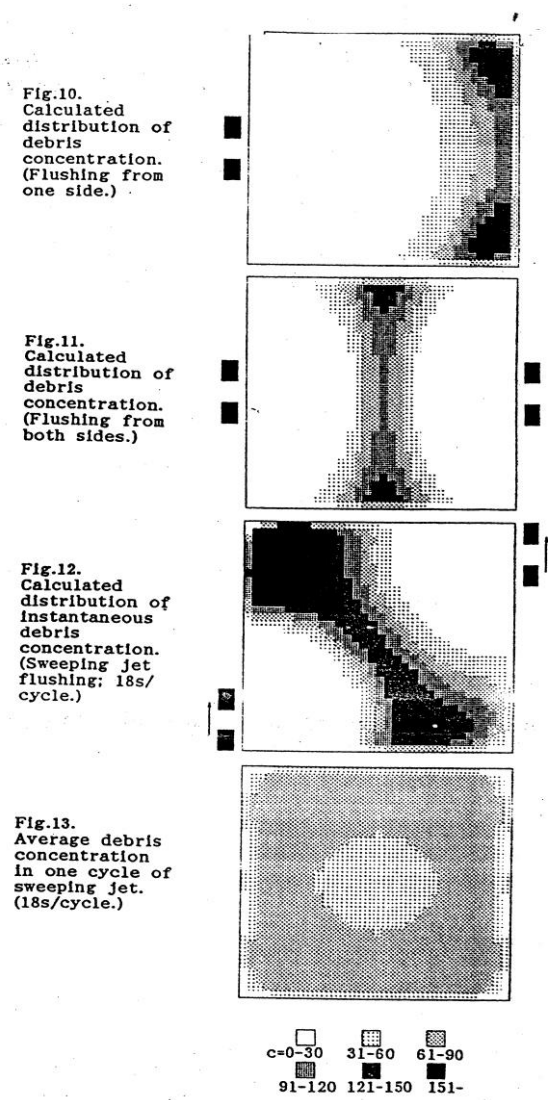


Fig.10. Calculated distribution of debris concentration. (Flushing from one side.)

Fig.11. Calculated distribution of debris concentration. (Flushing from both sides.)

Fig.12. Calculated distribution of instantaneous debris concentration. (Sweeping jet flushing; 18s/ cycle.)

Fig.13. Average debris concentration in one cycle of sweeping jet. (18s/cycle.)

VII. CONCLUSIONS

An improved jet flushing method, the sweeping jet, was proposed, and experiments supported the superiority of this method over conventional fixed jet flushing.

Simulation calculation was carried out to determine the flow pattern in the EDM gap. A simulation combining this flow analysis with the idea of debris diffusion gave debris distribution for various types of jet flushing, including the sweeping jet. It was confirmed that this simulation algorithm can represent the distribution phenomenon of debris with good correlation with the geometry of the work piece surface produced.

Although given data and assumptions in the simulation should be refined in further steps, a rough estimation of debris distribution in jet flushing has become possible. It will help to determine the nozzle setting in practical operation and ensure better accuracy.

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