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Multi-Field Coupling Mechanism of Electrolytic In-process Dressing-Ultrasonic Honing System

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Abstract

This paper proposes the ELID (Electrolytic in Process Dressing) ultrasonic honing system, and conducts simulation for the solution - acoustic coupling mechanism of electrolyte between the anion and cathode of ELID ultrasonic honing system. Meanwhile, a comparative experiment is carried out for the ultrasonic honing and ordinary honing. The simulation results show that there is no obvious increase of the coupling speed of the system's electrolyte, but the rapid change of local speed, which will accelerate the electrolyte renewal around the electrode, thereby intensifying the mass transfer of reactive ion of the electrochemical double layer, increasing the updating speed of ion concentration and speeding up the electrode reaction process; the intense variations of coupling pressure further enhances the updating speed of the electrolyte; Then the electrolytic parameters, ultrasound parameters and honing parameters obtained by simulation are respectively used to conduct experiments of ELID-ultrasound honing, ultrasound honing and traditional honing for ZrO2 ceramic. The comparative experiment results show that the machining accuracy of ELID-ultrasonic honing is 10 times of the traditional honing and twice of the ultrasonic honing; the new acoustic system adopted in ELID-ultrasound honing system reduces the amplitude, so the processing efficiency increase is not significant. This ELID-ultrasonic honing system is more suitable for the ultra-precision honing of certain difficult-to-cut materials.

Keywords*: electrolytic in-process dressing, ultrasonic honing, multi-field coupling, numerical simulation*

1. Introduction

The honing machining belongs to the traditional process methods for cylinder and bushing parts; however, the traditional honing inefficiency is low, coupled with the unsatisfied accuracy. The main reasons are shown as follows: 1) In the honing process, the oilstone is apt to be passivated, so it is necessary to stop and remove the honing tool frequently, and complete shaping, dressing or replacement on the professional edge grinder. The renewal of oilstone is an extremely complex process. The first step is to heat it and melt its brazing, then remove the passivation oilstone brazed on the oilstone pedestal and install a new one. Finally, conduct re-adjustment, tool setting and honing after the shaping and dressing on the edge grinder. The frequent offline shaping, dressing, replacement and tool setting have greatly affected the honing efficiency and accuracy; 2) the oilstone dressing is also extremely difficult, especially for the precise honing process, the professional technicians are required to conduct shaping and dressing on the professional edge grinder [1-3].

In order to solve the low efficiency and poor accuracy of the above-mentioned ordinary honing, coupled with the downtime and dressing problem of ultrasonic honing etc, this paper proposes the ELID ultrasonic honing device. There is no need to dismantle the oilstone of this system's honing head after its passivation, so the ELID system is used to achieve the Electrolytic in Process Dressing until a set of oilstones are exhausted, which can avoid the honing head frequent disassembly and tool setting of honing head, thus greatly improving the honing efficiency and honing accuracy. In this paper, the multi-field coupling theory is used to study the fluid- acoustic coupling mechanism between the honing head of ELID- ultrasonic honing system and the dressing electrode.

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2. Principle of ELID Ultrasonic Honing System

Electrolytic dressing principle of ELID-ultrasonic honing system: As is shown in Figure 1, attach ELID electrolytic dressing system on the basis of ultrasonic honing and utilize the idle stroke of honing to carry out electrolytic dressing, including: a honing tool, dressing electrode, electrolyte, dressing power, transducer, and ultrasonic power. The honing tool connects to the anode of the dressing power, while the dressing electrode connects to the cathode of the dressing power, with electrolyte pouring between the anode and cathode. The transducer connects to the ultrasonic power supply, making the honing stone conduct reciprocating vibration [4-6].

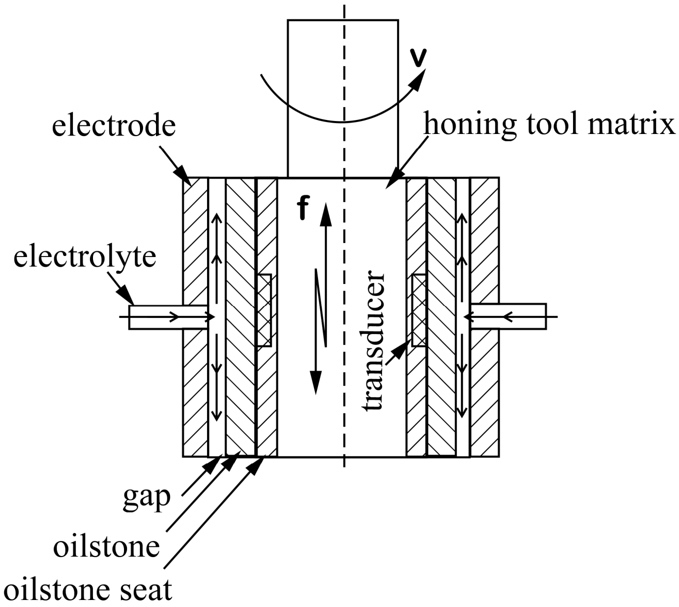


Figure 1. Effects of selecting different switching under dynamic condition

3. Research Method

Assuming electrolyte is uniform, moves in the mode of laminar flow between the electrodes and follows the Navier Stokes equation; Note that the ultrasonic vibration of any particle inside electrolyte follows the Euler equation and acoustic wave equation.

3.1. Navier Stokes Equation

$$-\nabla \cdot \eta(\nabla u' + (\nabla u')^T) + \rho(u' \cdot \nabla)u' + \nabla p' = 0 \quad (1)$$

$$\nabla \cdot u' = 0 \quad (2)$$

In the above formula, ρ - density, kg/m^3; η - dynamic viscosity; P_a • s; u'- speed, m / s; p'- pressure, P_a.

3.2. Ultrasonic Vibration Equation

Motion equation (Euler equation):

$$\rho_0 \frac{\partial u}{\partial t} = -\frac{\partial p}{\partial x} \quad (3)$$

In the above formula: ρ_0 - medium density, kg/m^3; u - acoustic vibration speed, m / s; p - acoustic pressure, P_a; t - vibration time of acoustic particle, s; x - vibration position of acoustic particle, m.

Wave equation:

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \tag{4}$$

In this formula: $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$, c- the propagation velocity of the acoustic wave in the medium, m / s.

3.3. ELID-Ultrasonic Coupling Equation

The velocity and pressure of any particle are changing with time and space. The speed of any point is equal to the vector sum of fluid velocity and the vibration velocity of acoustic wave at this point:

$$U = u + u' \tag{5}$$

In the formula: U - coupling speed, m / s.

The pressure of any point is equal to the sum of the fluid pressure and the acoustic wave pressure:

$$P = p + p' \tag{6}$$

In this formula: P——coupling pressure, P_a.

4. Results and Discussion

4.1. The Initial Conditions

Table 1. Honing parameters

Cutting speed (r/min)	Feed rate (m/s)	Diameter (m)	Depth (m)
80	0.483	0.2	0.2

Table 2. Electrolyte parameters

Density (kg/m^3)	Viscosity (Pa. s)	Electrode gap (m)
1e3	1e-3	1e-3

Table 3. Ultrasonic parameters

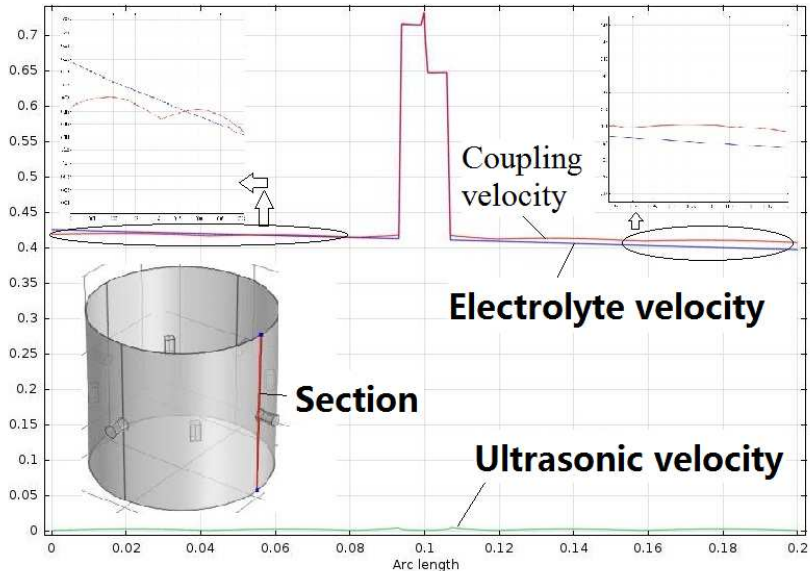
Frequency (KHz)	Voltage (V)
20	100

Table 4. Initial conditions

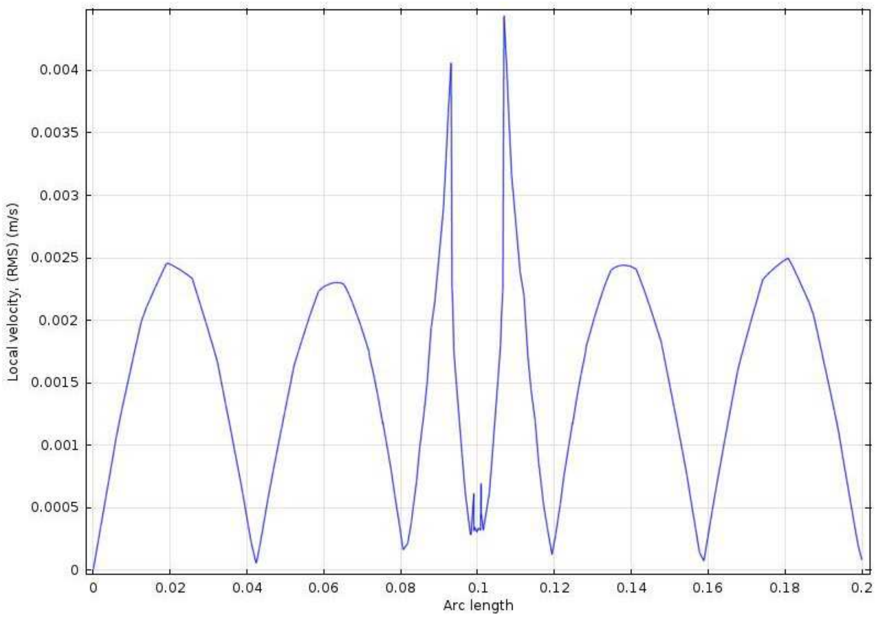
Inlet diameter (m)	Inlet velocity (m/s)	Pressure (Pa)	Temperature (K)
0.01	0.2	0	300

4.2. Velocity

The velocity simulation results show that the electrolyte rate before the coupling is 0.8631m / s, and the maximum speed of electrolyte after the ultrasonic vibration of coupling is 0.8686m / s with the speed change only of 0.005m / s thereby the effect of ultrasonic vibration on the over speed of electrolyte is relatively small; Figure 2a) shows the velocity variation of the longitudinal section along the electrolyte inlet, and Figure 2b) refers to the vibration velocity of particle under the affect of ultrasonic vibration with its maximum value of 0.005m / s, therefore, the local-regional electrolyte in the electrode gap vibrates at the velocity of 0-0.005m / s, which accelerates the updating rate of the electrolyte near the electrodes and is conducive to the discharge of electrolysis products as well as the dynamical updating of the reactive ion concentration.



a) The coupling velocity of the longitudinal section



b) Vibration velocity of particle

Figure 2. Velocity simulation results

4.3. Coupling Pressure

As shown in Figure 3 and Figure 4, Figure 3 indicates the coupling situation of the overall pressure of the ELID-ultrasound system, and Figure 4 is the pressure variation of one-dimensional section. The sectioning position is as shown in Figure 2a). The figures show that the pressure change mainly comes from the ultrasonic vibration and the alternating pressure effect causes the electrode to shock the electrode surface severely, thereby promoting the electrolyte's cycling regeneration. It is conducive for the updating of reaction ion concentration around the electrode thus accelerating the reaction rate, increasing the reaction speed, and improving the efficiency of electrolysis and dressing. Furthermore, affected by the alternating pressure, the expansion and polymerization of bubble continuously generated within the electrolyte can lead to the cavitation effect on the surface of the honing stone and the electrode [7]. Theoretically speaking, this effect can accelerate the discharge of electrolysate, thereby speeding up the shedding and update speed of oxidation film on the surface of oilstone. On the one hand, it will accelerate the electrolytic speed; on the other hand, the premature shedding may decrease the polishing quality due to the fact that the oxide film itself can be regarded as the polishing work piece [8]. However, the cavitation effect around the electrode may damage the electrode, which needs to be further studied.

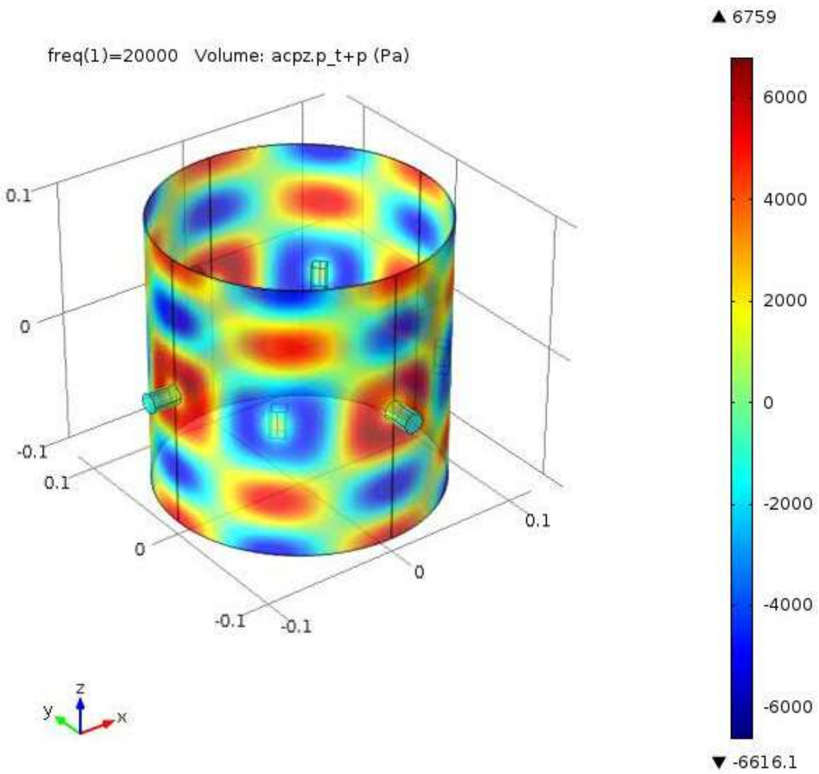


Figure 3. The total pressure of the ELID-ultrasound system

4.4. Experiments

The theoretical analysis and simulation experiments can be used to determine the parameters, as shown in Table 2. The comparable experiments about ordinary honing, ultrasonic honing and ELID-ultrasonic honing are conducted with the same process parameters. The oilstone in the experiments is metal binding agent with the granularity of W10-W1 and the experimental material is the ZrO2 ceramics. Experiments are carried out on the homemade edge grinder.

As shown in Table 2, the machining accuracy of ELID-ultrasonic honing is 10 times of the traditional honing, and twice of the ultrasonic honing. As the ELID-ultrasonic honing system abandons the amplitude transformer, the bending vibration disc and other institutions, the oilstone vibration is directly driven by the transducer [9], so the amplitude of this system is relatively smaller, which causes the unconspicuous honing efficiency of single piece. However, in the case of mass production, the working hours of replacement, shaping, dressing and tool setting have been reduced, which greatly improves the production efficiency. As the machining precision is paid more attention in the ultra-precision honing, the production efficiency is not the main indicator, so the system is suitable to be used in the field of ultra-precision honing.

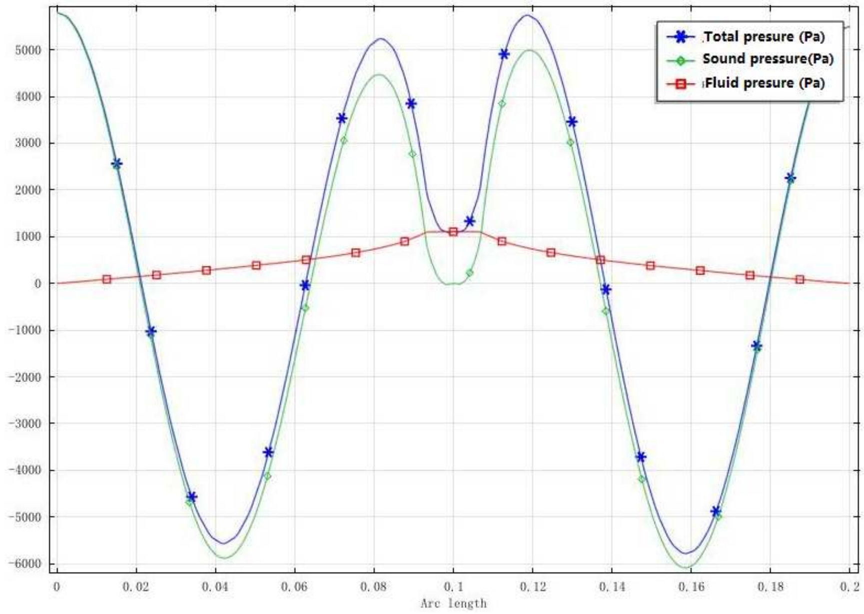


Figure 4. Pressure variation of the one-dimensional section

Table 2. Comparison between the experimental parameters and the experimental results

	Honing parameters		Ultrasonic parameters		Electrolytic parameters			results		
	speed (rpm)	Feed rate (St/min)	Power (W)	Frequency (KHz)	Current (A)	Voltage (V)	Pulse on (µs)	Ra (µm)	Accuracy (µm)	Removal Rate (g/min)
Honing	80	30						0.4	5	2.2
Ultrasonic honing	80	30	250	19-21				0.2	1	4.5
ELID-ultrasonic honing	80	30	250	19-21	20	0-20	20	0.1-0.01	0.5	4.9

5. Conclusion

Simulation results show that after coupled ultrasonic vibration, the increase of flow field speed and pressure accelerates the dynamic update of electrolyte and the update of the reaction ion concentration near the electrode. Besides, the electrode reaction is more rapid and the rate of electrolytic dressing increases, which is favorable for efficient grinding; simulation parameters are further used to carry out comparative experiments of ordinary honing, ultrasonic honing and the ELID-ultrasound honing. The precision of ELID-ultrasound honing has been increased 9 folds compared with ordinary honing and 1 fold compared with the ultrasonic honing.

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