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Special wire guide for on-machine wire electrical discharge dressing of metal bonded grinding wheels

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To improve accuracy in wire electrical discharge dressing (WEDD), special attention should be given to wire vibration. In this work, the use of a specially designed wire guide is proposed, which is responsible for both ensuring the stability of the wire and improving the efficiency of dielectric delivery to the dressing zone. For carrying out experiments with metal bonded diamond grinding wheels, a WEDD-device was designed, manufactured and integrated into a grinding machine. High erosion material removal rates and dressing accuracy were achieved, thus demonstrating the feasibility and efficient performance of this in situ dressing process.

Keywords: Wire EDM; Dressing; Grinding.

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1. Introduction

In order to profit more from the application of metal bonded diamond wheels, attempts to improve its dressability have become an important research issue. Different truing and dressing methods have been proposed [1-3], including the application of Electrical Discharge Machining (EDM) [4-5]. Since EDM is solely applicable for the erosion of electrically conductive materials, grain protrusion can be generated in metal bonded grinding wheels, given that diamonds are generally electric insulators. Thus both wire and die-sinking EDM can be applied. The main disadvantage when using the die-sinking EDM method is related to the need to compensate electrode wear, so that the electrode must be frequently reshaped to ensure dressing accuracy [4]. Wire EDM is more flexible, as different wheel profiles can be manufactured with the same electrode and wear compensation is guaranteed by using a continuous unwinding wire supplied from a spool. However, when working with wire electrical discharge machining, special attention should be given to wire deviations [6-7]. In particular when dressing grinding wheels, small wire deflections, i.e. a few micrometers, are not acceptable, since very tight tolerances are usually required in grinding processes.

To improve the accuracy of WEDM of very thin rods (diameter of less than 50 µm), Masuzawa et al. [8] have initiated the application of a wire guide at the erosion zone, a method named wire electrical discharge grinding (WEDG). By reducing wire vibrations and deflections, the WEDG method provides better machining accuracy, and therefore has been mainly used in micro-EDM applications [9].

In wire electrical discharge dressing (WEDD), problems related to wire deviations and micro vibrations also exist, and must be minimized to ensure proper dressing results. For this reason, this work proposes the use of a special wire guide, aiming to meet requirements such as high erosion removal rates and dressing accuracy. Both requirements are crucial for making this on-machine dressing process feasible.

Below, the design of a WEDD-device is first presented, followed by discussions about wire position instability, the design of a wire guide and the results obtained with this on-machine dressing method.

2. Design of a wire electrical discharge dressing device

To enable the wire electrical discharge dressing (WEDD) to be carried out inside a grinding machine, a dressing device was designed and integrated into a CNC universal cylindrical grinding machine Studer type S31. Carrying out the dressing process inside the grinding machine is particularly important to minimize non-productive times and to eliminate grinding wheel clamping errors, since metal bonded grinding wheels are frequently conditioned on independent dressing machines and need to be carefully reassembled to avoid concentricity errors.

The designed WEDD-device is composed basically of a two axes feed system, a wire drive system and the wire guide. **Fig. 1** illustrates the WEDD-device, which was mounted on the support of the internal grinding spindle.

The feed system is equipped with roller guideways on both horizontal and vertical directions, which allows for relative displacement from wire electrode to grinding wheel in axial and radial directions respectively, making possible the erosion of different profiles. Servo feed control on both axes uses the gap voltage as sensing parameter, enabling the achievement of a stable electric discharge dressing condition. Actual positions of the axes are measured by two absolute linear encoders model LC 483 (Heidenhain). The axes are controlled by an Adaptive Control System “AC Progress VP4” - GF AgieCharmilles, which allows high dynamic erosion gap regulation.

The wire drive system adjusts and maintains a constant wire feed speed, provides constant wire tension and is responsible for supplying and disposing the wire electrode. It is located on the vertical stage of the two axis NC-controlled positioning device and is basically composed of one DC servo motor and a permanent magnetic hysteresis clutch. Different torques can be precisely adjusted and constant wire tension can be generated by keeping the clutch torque constant.

The wire guide, a key part of the device, is also located on the vertical stage. It is responsible for reducing wire vibrations and deflections by guiding the wire directly at the erosion zone, as well as for delivering dielectric to the erosion gap.

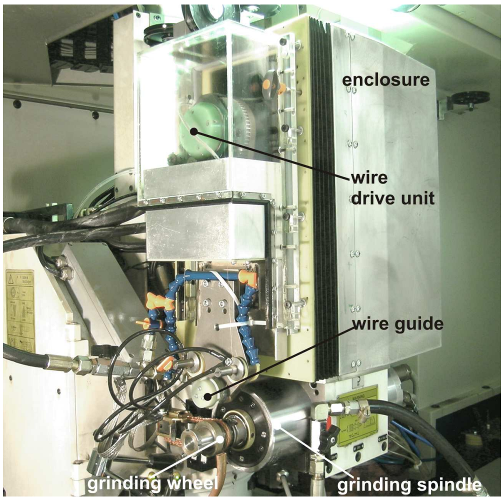

Fig. 1. WEDD-device integrated into the grinding machine.

3. Wire deviations in WEDD with a free stretched wire

In wire electrical discharge machining (WEDM), wire deviations, wire wear and micro vibrations are major causes of cutting inaccuracy. Different forces acting in the erosion gap, such as hydraulic, electro static and electro dynamic forces can deflect the wire and cause geometrical errors on machined workpieces [6-7].

In on-machine wire electrical discharge dressing (WEDD) this problem is even more critical. Inside the grinding machine, the grinding wheel can not be submerged in dielectric fluid (grinding oil). In this case, free jet nozzles must be applied during dressing to supply dielectric to the erosion gap. This fluid application method influences directly the position stability of a free stretched wire. Furthermore, the boundary layer of air which forms around the rotating grinding wheel, and normally deflects the grinding fluid away from the grinding zone [10], can also cause wire vibration and deflection.

To demonstrate the above mentioned issues, an experiment was carried out to evaluate the influence of the dielectric fluid application on wire deviation. A jet of grinding oil was applied perpendicular to the wire and its position was measured using a contactless capacitive sensor. **Fig. 2** shows, for two different lengths of free stretched wire, the measured wire deviations as a function of dielectric flow rate. A constant wire pulling force of 25 N was applied to the wire electrode type Cobracut V with diameter of 0.33 mm. The free jet nozzle with diameter of 4 mm was placed at a distance of 2 mm from the wire.

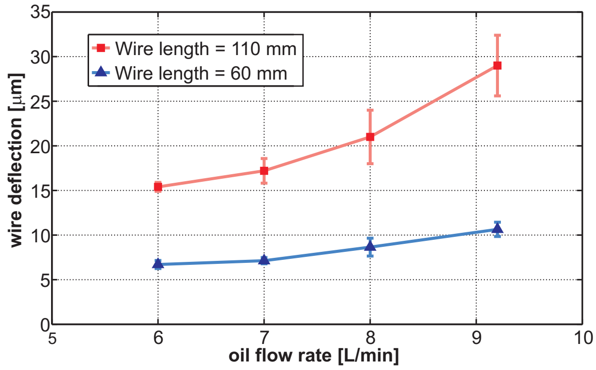

Fig. 2. Free stretched wire deflection by increasing oil flow rate.

The results indicate relatively large deviations for both wire lengths. By using a free stretched wire of length l_w=110 mm, deviations greater than 30 µm were measured. As expected, the wire position stability increases by decreasing the free stretched wire length. However, in order to truing and dressing grinding wheels of large diameter, even longer free stretched wire lengths would be required, which worsens the wire stability.

In a second experiment, the influence of the grinding wheel boundary layer of air on wire deviation was investigated. After WEDM-dressing a grinding wheel with diamond grain size D46, the wire was kept at the same depth of dressing cut, and the grinding wheel was driven at different rotational speeds up to v_s=40 m/s. The wire position was measured again using a contactless capacitive sensor. **Fig. 3** shows the wire deviation for a grinding wheel speed of v_s=40 m/s. A free stretched wire of length l_w=110 mm deflects up to 15 micrometers and vibrates with amplitudes ranging up to 3 micrometers.

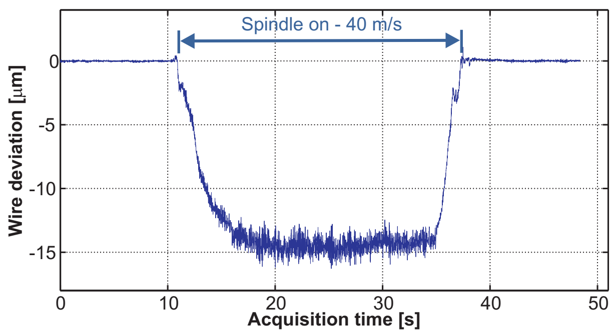

Fig. 3. Wire deviation due to grinding wheel boundary layer of air.

The results shown in **Figs. 2** and **3** indicate that both, the dielectric supply and the grinding wheel boundary layer of air can easily affect the wire position accuracy. However, a free stretched wire of length l_w=0 mm can be theoretically used by guiding the wire at the erosion zone. On this basis, a special wire guide system for the on-machine wire electrical discharge dressing is proposed, as described below.

4. Design of a special wire guide for on-machine WEDD

To minimize the negative effects of wire deviations on dressing results, a special wire guide system was developed. This system is responsible for both guiding the wire at the erosion zone and delivering dielectric fluid to the erosion gap. **Fig. 4** shows a schematic representation of the wire guide and one possible example of its application for dressing a grinding wheel. The wire guide system consists basically of a thin ceramic ring (A) clamped between two flanges (B). The flanges have radial passageways (C) extending from the central bore to its periphery, which allows the dielectric to be delivered to the erosion gap. The dielectric flows from both sides of the ceramic ring. This ceramic ring has a ground groove (D) along its periphery for holding and guiding the wire (E) at the erosion zone (F).

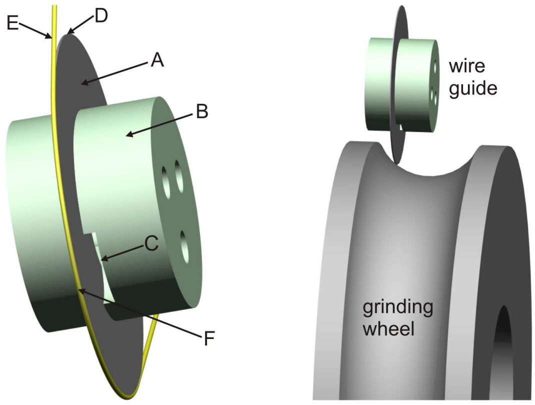

Fig. 4. Schematic representation of a wire guide system for WEDD.

For dressing deep straight edges on grinding wheels and avoiding contact between the wire guide and the diamonds grains, the ceramic ring should not exceed a maximal thickness, which depends on the wire diameter, the erosion gap and the diamonds grain size. For a D46 diamond grinding wheel and wire diameter of 0.33 mm, a ceramic ring with thickness of 0.4 mm can be used (the ceramic ring can be wider than the wire diameter due to the lateral erosion gap).

5. Experimental setup and results

To evaluate the feasibility of the on-machine WEDD with a special wire guide, both the erosion material removal rate and the dressing accuracy were investigated. All dressing experiments were carried out using the designed WEDD-device inside the grinding machine Studer S31. Standard grinding oil type Blasogrind HC5 was used for all the erosion and grinding experiments. This grinding oil has a high flashpoint of 165^{o} C, which is very important for carrying out the no-submerged wire electrical discharge dressing experiments.

5.1 Material removal rate in on-machine WEDD

In order to make the on-machine WEDD efficient, high erosion material removal rates must be achieved, keeping non-productive dressing time at small levels. In this sense, the dielectric application method plays a decisive role. The erosion gap should be completely filled with dielectric for helping the erosion to be carried out efficiently. Furthermore, the dielectric must penetrate the boundary layer of air which forms around the rotating grinding wheel, to prevent air reaching the erosion gap.

Fig. 5 shows the achieved material removal rates by increasing erosion energies for three different dressing methods: *special wire guide*, with internal dielectric supply as proposed in **Fig. 4**; *normal wire guide*, which consists of a ceramic wire guide without internal dielectric supply, and free jet nozzles for delivering the dielectric; *free stretched wire*, without using the wire guide, and supplying the dielectric via free jet nozzles. **Table 1** shows the applied erosion parameters, and specifications of the grinding wheel and the wire electrode.

Table 1
Erosion parameters, grinding wheel and wire specifications

WEDD erosion parameters:			Grinding wheel and wire electrode	
discharge duration	t_e	1,5 µs	Grinding wheel specification:	
pause interval time	t_o	25 µs	1A1-50-5-20-D46-C125-M263	
wheel speed	v_{sd}	20 m/s	wire type	CobraCut V
depth of dressing cut	a_{ed}	20 µm	wire diameter	0.33 mm
oil flow rate	25 L/min		free wire length	110 mm

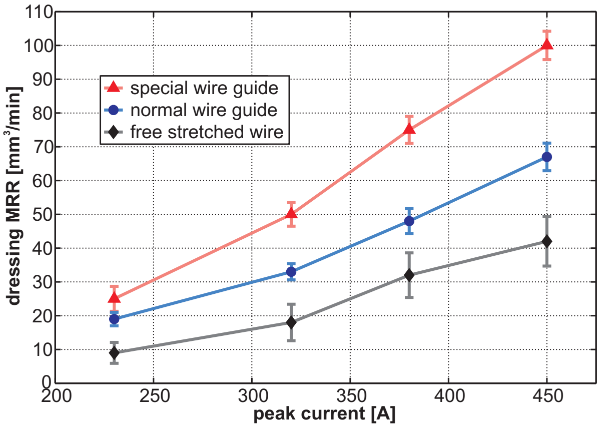

Fig. 5. MRR for different WEDD conditions.

The results indicate that lower erosion material removal rates are achieved by using a free stretched wire. This is particularly related to the gap instability, since the wire is subjected to deflections and vibration during the dressing process. Higher erosion material removal rates were achieved by using the special wire guide. This shows the importance of using the right dielectric delivering method for a non-submerged erosion process.

The achieved material removal rates guarantee short dressing times, thus minimizing non productive times and making acceptable the integration of this dressing method inside a grinding machine. For example, eroding a total depth of dressing cut

$a_{ed\ ges}$=10 µm with erosion material removal rate MRR=100 mm^3/min on a diamond grinding wheel diameter d_s=400 mm and width b_s=15 mm takes less than 2 minutes of dressing time.

5.2 Dressing accuracy in WEDD

Besides the need for high erosion material removal rates, accuracy is also crucial for making the on-machine WEDD feasible. **Fig. 6** shows measurements of surface waviness on Si_3N_4 workpieces after plunge grinding with a D46 grinding wheel (1A1-50-5-20-D46-C125-M263), dressed by WEDD. **Table 2** lists the applied dressing and grinding parameters.

With the special wire guide, lower surface waviness values were achieved in comparison to the free stretched wire. Furthermore, when using the wire guide the surface waviness is not affected by increasing the depth of dressing cut a_{ed} from 3 up to 10 µm. Its use also leads to a significant better dressing repeatability. By using a free stretched wire, very poor dressing repeatability was achieved, which is directly linked to the wire deviations during the dressing process. **Fig. 7** illustrates a 2.5 mm axial wide detail of a grinding wheel surface after WEDD with a free stretched wire. Irregular marks (waviness) are clearly visible on the grinding wheel surface, which can be directly transferred to the workpiece after plunge grinding.

Table 2
Erosion parameters, grinding wheel, dielectric and wire specifications

WEDD erosion			Plunge Grinding		
peak current	i_e	320 A	1A1-50-5-20-D46-C125-M263		
discharge duration	t_e	1,5 µs	Wheel speed	v_s	50 m/s
pause interval time	t_o	25 µs	Specif. MRR	Q'_w	5 mm^3/mms
wheel speed	v_{sd}	20 m/s	Speed ratio	q_s	100
wire CobraCut V	∅	0,33 mm	Wheel width	b_s	10 mm

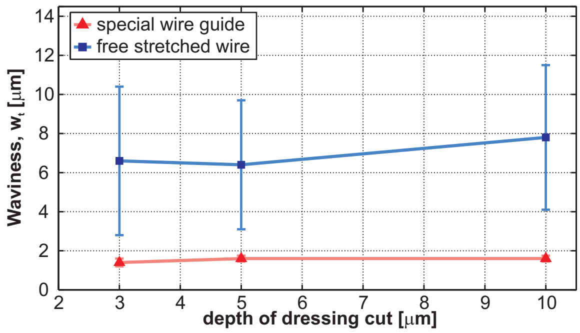

Fig. 6. Surface waviness on ground Si_3N_4 workpieces.

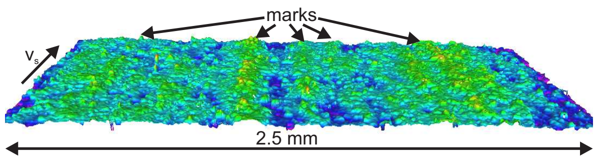

Fig. 7. Grinding wheel surface after WEDD with a free stretched wire.

Fig. 8 shows the results of roundness RONt, the peak-to-valley deviation (Gaussian filter, 1-50 upr), measured on eroded steel workpieces with diameter d=40 mm. The erosion parameters are the same presented on **Table 2**. Lower roundness and better repeatability were achieved by using the special wire guide. In this case, smaller depth of dressing cuts leads to better roundness results, indicating that after profiling a grinding wheel, dressing finishing steps help to ensure better dressing accuracy.

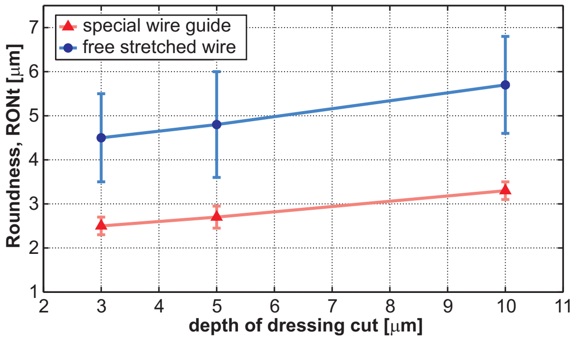

Fig. 8. Surface roundness on eroded steel wheels after WEDD.

To further illustrate the on-machine WEDD method, two D46 grinding wheels were profiled with particular shapes (**Fig. 9)**. The wheel profile 1 has two diameters differing by a radial depth of Δr1=1000 µm, and connected by a tapered transition with angle α=45°. The profile was measured on ground Si_3N_4 workpieces after plunge grinding specific material removals of V'_w=300 and 3000 mm^3/mm. The average values after three measurements were Δr1=999.7 and 998.9 µm, and α=45.1° and 44.9°, respectively. The wheel profile 2 has two outer radii, differing intentionally by a radial depth Δr2 greater than twice the wire electrode diameter, to show that it is possible to use the wire guide for dressing deep straight edges.

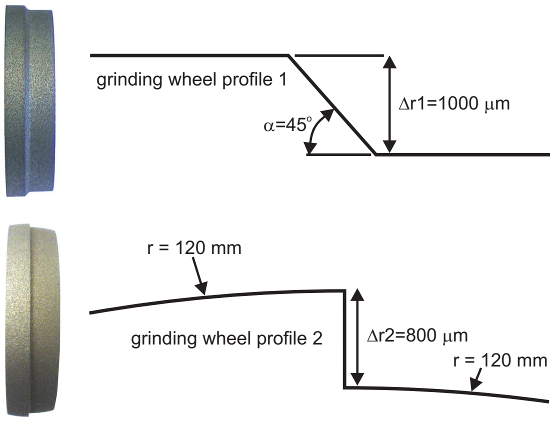

Fig. 9. Grinding wheel profiles after WEDD with the special wire guide.

7. Conclusions

In this paper the on-machine wire electrical discharge dressing (WEDD) method using a special wire guide is presented. A WEDD-device was designed and integrated into a grinding machine for carrying out dressing experiments with metal bonded grinding wheels. Experimental work indicated that the use of a free stretched wire for the on-machine WEDD is not suitable for achieving high material removal rates and tolerable dressing accuracy. Inside the grinding machine the free stretched wire is subjected to various excitation sources, and therefore can easily vibrate and deflect. By using the designed wire guide system higher material removal rates and better dressing accuracy were achieved. Altogether, the proposed on-machine dressing method ensures a significant improvement on the dressability of metal bonded diamond wheels.

Acknowledgments

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FIGURE CAPTIONS

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