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Pulsed ultrasonic assisted electrical discharge machining for finishing operations

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ABSTRACT

Electrical Discharge Machining (EDM) is a non-conventional machining process specially suitable for manufacturing hard-to-machine materials or geometrically complex parts. Many investigations have been presented combining EDM with ultrasonic (US) vibration of the electrode, but most of them have been intended to enhance the material removal rate of the process. In this paper US assisted EDM process has been used in order to improve the surface roughness in a finishing operation. For that purpose a copper rod tool electrode and a 1.2344 tempered alloy steel workpiece have been used. A pulsed US assisted EDM mode (PUEDM) has been developed and compared with the current EDM process and EDM assisted with continuous US vibration (UEDM). The results show that PUEDM process can improve the surface roughness and homogeneity of the machined surfaces in finishing EDM operations.

1. Introduction

The Electrical Discharge Machining (EDM) is a non-conventional material removal process used for manufacturing hard-to-machine materials or geometrically complex parts. The EDM process transforms the electrical energy into thermal energy by a succession of electrical discharges occurring between the electrode (tool) and the workpiece [1].

There is no contact between the electrode and the workpiece, which allows machining any kind of material, as long as it is electrically conductive, regardless of its hardness [2].

Many research works have been done to enhance the machining performance of the EDM process. These investigations are focused on three different aspects: improving the material removal rate (MRR), reducing the tool wear rate (TWR) and optimising the surface quality (SQ) [3].

Introducing vibrations to the EDM process has been widely studied since Kremer et al. [4] proved that an ultrasonic (US) vibration of the electrode could greatly improve the removal rate [5]. Murthy et al. [6] demonstrated that assisting the EDM process with US vibrations significantly reduced inactive pulses in a steel workpiece. Abdullah et al. [7] concluded that employing US vibration in the electrode increased the MRR when machining cemented tungsten carbide (WC-Co), and observed that arcing was reduced and the stability of the process was improved. Srivastava et al. [8,9] combined US vibration and EDM with cryogenically cooled electrode (CEDM) and noticed that the implementation of US vibration helped improving the MRR and maintaining the TWR and surface roughness (SR). Iwai et al. [10] tested three types of ultrasonic vibration modes and achieved an improvement of the MRR when machining polycrystalline composite diamond (PCD). Shervani-Tabar et al. [11,12] developed numerical studies to analyse the effect of the gap and the dynamic pressure on the small bubbles produced in the dielectric fluid between the tool and the workpiece in ultrasonic assisted EDM.

With regard to micro-EDM, many studies cope with ultrasonic vibration of electrodes in order to improve the machining performance [13–17].

Nowadays graphite and copper are the most common electrode materials in the EDM process. However, the difference in the sound speed between graphite and titanium alloy (material in which the US transducer is manufactured) makes the graphite material incompatible with US vibrations. So, in order to achieve the benefits of applying the US vibration in the EDM process, many researchers introduced the US vibration either in the workpiece or in the dielectric liquid.

Shabgard et al. [18] reduced the inactive pulses during the discharge and improved the process stability by applying the US vibration in the workpiece. In addition, high MRR was observed in finishing regime. Gao et al. [19] noticed that holes with higher aspect ratios could be machined in micro-EDM by applying US vibrations in the steel workpiece. Ichikawa et al. [20] investigated and discussed the effects of US vibrations applied to the dielectric fluid on hole drilling and showed that the machining time was

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greatly shortened. Liew et al. [21] achieved a significant improvement of the micro-EDM performance regarding MRR, maximum machining depth, surface topography, hole geometry and process stability by transmitting the US vibration to the dielectric fluid using a probe-type vibrator.

Although most studies have been focused on the introduction of high-frequency vibrations (especially US vibration to the tool electrode) in the EDM process, low frequency vibrations have also been used in several investigations. Prihandana et al. [22] noticed a higher MRR when applying low frequency vibration to the workpiece. Uhlmann et al. [23] progressed on the die-sinking EDM machining of high aspect ratio seal slots by using low frequency vibration to improve the flushing during the process.

In contrast, few studies have been published about the investigation of the pulsed vibration assisted EDM process. Although in most research works vibration has been applied continuously, Singh et al. [24] demonstrated that higher MRR was achieved if the US vibration was applied discontinuously. Besides, Singh et al. [25] developed a statistical model using Response Surface Methodology (RMS) for de estimation of the Surface Roughness (SR) as a function of some process parameters (Amplitude of vibration, Peak Current, Pulse-on Time, Machining Time and Flushing Pressure) in discontinuous US vibration assisted EDM. Nonetheless, is this case the US vibration was applied to the workpiece, and the research work was not focused on the finishing regime, as the obtained R_a values were above 6.5 μm (equivalent to N9 according DIN ISO 1302).

Up to now, although vibration-assisted EDM machining has been widely studied, most of the investigations were focused on improving the MRR. The objective of this study is to use US vibration in order to obtain a better surface roughness in a finishing EDM process. Three different processes will be compared and discussed in this paper: EDM without vibration, EDM with continuous US vibration (UEDM) and EDM with pulsed US vibration (PUEDM).

2. Experimental setup

2.1. EDM process

For this study, a NX3 EDM machine from ONA was used. The tests were performed using a copper rod electrode with a diameter of 15 mm. Each electrode was polished with a Mecatech 334 polisher from Presi until obtaining mirror finish in the front face, in order to improve the surface roughness in finishing EDM operations. The schematic diagram of the machining equipment used in this study is shown in Fig. 1.

Quenched and tempered 1.2344 (X40CrMoSiV5-1) tool steel (50 HRc) samples were used for the EDM machining tests. The surface to be machined was grinded before the EDM machining, in order to assure the same surface roughness and the same parallelism between the electrode and the workpiece in the different tests. The physical properties of the workpiece material are shown in Table 1.

The objective roughness value (R_a) in these tests was around 0.30 μm, which was the best obtainable roughness value taking into account the workpiece material and machining conditions mentioned in this section. The combination of the tool electrode material, workpiece material and machined area prevented from achieving 0.10 μm surface roughness, which is the best roughness value that the cited NX3 EDM machine can obtain.

A special machining programme was prepared for these tests. This particular programme starts with a high intensity regime, and it is progressively lowered until finishing with the lowest intensity regime that the EDM machine can provide. In order to achieve a

Table 1
Physical properties of 1.2344 tool steel.

Density, ρ [kg/m^3]	7800
Melting temperature, T_m [°C]	1427
Thermal conductivity, κ [W/mK] at 215 °C	24.3
Specific heat, C_p [J/kg °C]	460

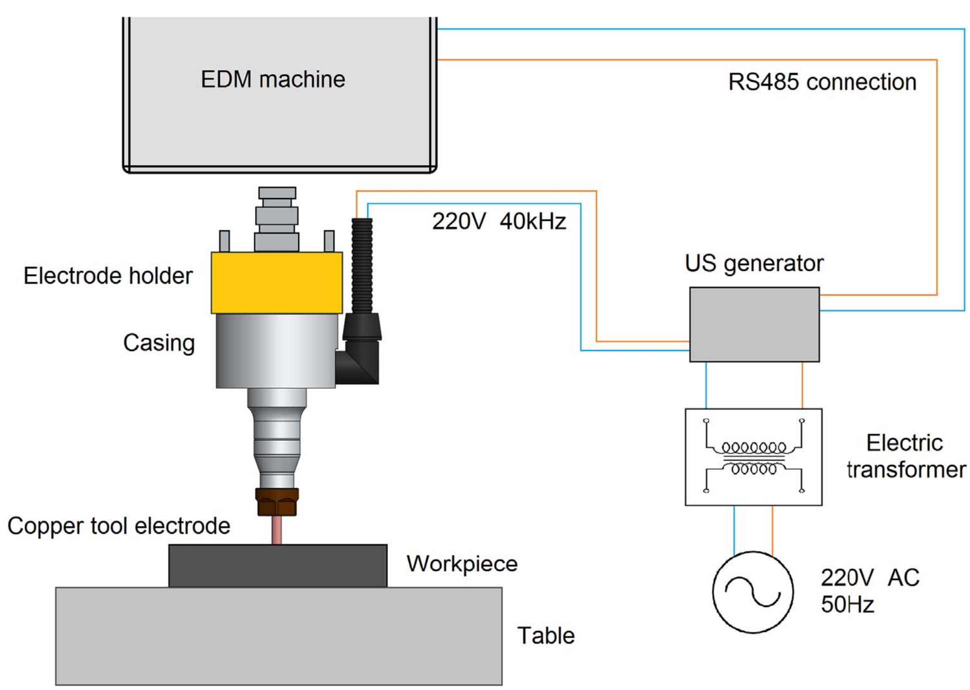

Fig. 1. Schematic diagram of the machining equipment.