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Machining characteristics and removal mechanisms of moving electric arcs in high-speed EDM milling

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ABSTRACT

Low machining efficiency is the major challenges of conventional electrical discharge machining (EDM). To resolve this problem, a novel machining method of high-speed EDM milling with moving electric arcs was developed, which can remove material continuously without discharge intervals of pulse power supply and achieve extremely low tool-electrode wear for the direct-current power supply employed. An EDM milling equipment was devised to explore machining characteristics and removal mechanisms of moving electric arcs in high-speed EDM milling process. Firstly of all, the motion characteristics of moving electric arcs were investigated. The theoretical analysis shows that the arcs maintain an independent movement relative to the tool-electrode and workpiece. Then, the plasma channels were captured by high-speed video camera, which contributed to develop the model of removal mechanisms of moving electric arcs. Finally, the machining experiments were carried out based on titanium alloy, which verified that a much higher material removal rate could be easily achieved by moving electric arc. Moreover, the tool-electrode wear in high-speed EDM milling is much lower than conventional EDM due to the protective layer formation.

1. Introduction

As a non-traditional material removal process, electrical discharge machining (EDM) can remove conductive materials by thermal effect regardless of their hardness, and is employed to fabricate dies and molds, as well as in automotive, aerospace and medical implant components [1–3]. However, it is seriously restricted by the low material removal rate (MRR) for application, especially compared with some high-speed and efficient processing methods, such as high-speed and ultra-high-speed milling [4,5], so the conventional EDM is widely applied for manufacturing intricate shapes of hard materials which are difficult to be machined by traditional machining processes [6–8]. A lot of basic research work based on machining mechanisms [9], electrodes [10,11], dielectric [12], additional auxiliary conditions [13] and optimization of EDM machining parameters [14,15] had been conducted by researchers in order to improve machining efficiency of conventional EDM. But it can not completely solve the barrier of machining efficiency from machining mechanism. A complete EDM cycle consists of four functionally different phases that take place sequentially without overlapping in time, namely discharge channel formation (ignition delay), discharge channel expansion, discharge channel extinction and discharge interval [16]. Consequently, conventional EDM machine is equipped with a pulse power supply to match the above four processes, but that will inevitably leads to discharge interval for the existence of the pulse interval. Actually, there is no material removal process in the period of discharge channel formation when plasma channel occurs between the tool-electrode and workpiece. In addition, at the stage of discharge interval, the tool-electrode should be pulled up to complete deionization and remove debris from discharge gap. Thus, it will waste lots of effective material removal time for this up-and-down movement of tool-electrodes. In a cycle repeating periodically of EDM process, workpiece materials are actually removed intermittently, with a small portion of materials eroded by each pulse period. According to the above analysis, it seems very difficult to achieve a high material removal rate in conventional EDM. If the material can be removed without the interruption of the ignition delay and discharge interval, the efficiency of EDM will be greatly improved. This means EDM must be done with continuously burning electric arcs. The discharge time of electric arc is longer than that of electric spark. Thus, the output energy should be more powerful and larger removal efficiency can be obtained, especially for increasing the output voltage or current of the power supply. However, if the electric arc continuously discharges at a certain location, it will lead to severely burned tool-electrode and sample. Some researchers have proposed different approaches to solve this

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problem in arc machining. Lin [17] and Wang [18] presented blasting erosion arc machining based on hydrodynamic arc-breaking mechanism, which contributed to constantly changing the discharge position as well as avoiding the tool-electrode and workpiece to be ablated seriously. Wang [19] used the power supply, which consists of a pulse generator and a DC power source, to control the discharge duration time of the electric arcs. Shen [20] suggested a new and efficient compound machining combined arc machining and electrical discharge machining together, Both of them were working in parallel. All the above methods could prevent electric arc continuously discharging at a certain point, but they did not fundamentally eliminate the discharge interval, so the material is eroded intermittently instead of continuously. It seems that there is still a great potential to further improve material removal efficiency with the electric arcs.

With respect to the low machining efficiency of conventional EDM process, a novel and fast processing method of high-speed EDM milling with moving electric arcs was developed in this paper. This method can remove material continuously without arc extinction, and a higher material removal rate can be obtained. The machining characteristics of moving electric arcs were investigated. Then the removal mechanisms of moving electrical arcs were analyzed based on the images captured by a high-speed camera. Finally, the machining experiments were carried out to machine titanium alloy, which revalidates the above mechanism model and it was found that a much higher material removal rate and lower tool-electrode wear could be easily achieved by high-speed EDM milling with moving electric arcs.

2. Basic principles

2.1. Equipment design

Fig. 1 schematically shows the mechanisms of self-devised machining equipment used to generate moving electric arcs. The motion system is composed of a spindle motor and XYZ-axis liner stages AC servo motors controlled by a motion control card. The flushing system pumps dielectric fluid into a high speed rotary joint. Then the dielectric fluid is transferred through the hollow spindle, which could rotate up to 5000 rpm, and eventually pours into the discharge gap. The tool-electrode is designed as a tubular body to ensure the high-speed motion of any point on the tool-electrode relative to the workpiece surface. The tubular tool-electrode mounts on the main hollow spindle and a workpiece is fixed on the worktable comprised the electrode pair for discharging. The negative pole of the DC power supply is connected to the tubular tool-electrode through a transmission slip ring. Similarly, the positive pole is connected to the workpiece through a protective resistance.

2.2. Formation mechanism of moving electric arcs

When the DC power supply and flushing pump are switched on, the rotating tubular tool-electrode moves toward the workpiece surface. If the discharge gap between two poles is small enough, ignition occurs at one point, where the distance between the poles is considered as the smallest. The plasma channel forms after the ignition, and the energy from DC power source is continuously transported to it. Thus, the electric arc appears and immediately moves around tool-electrode axis due to the high-speed rotation of tool-electrode, then the moving electric arc forms. The energy of moving electric arc, which primarily comes from the DC power supply, leading to an extremely high temperature and pressure inside the plasma channel, distributes the energy uniformly along the trace and results in the workpiece material melting and evaporating rapidly. The molten material injects into the dielectric fluid and forms plenty of debris which are removed by flushing dielectric. Furthermore, the flushing dielectric and constant tool-electrode rotation are beneficial for deionization in the discharge gap, even the position where the plasma channel previously stays. Consequently, the electric arc keeps burning without extinction, which travels quickly and constantly changes positions relative to the tool-electrode and workpiece, avoiding burning tool-electrode and workpiece within a small area.

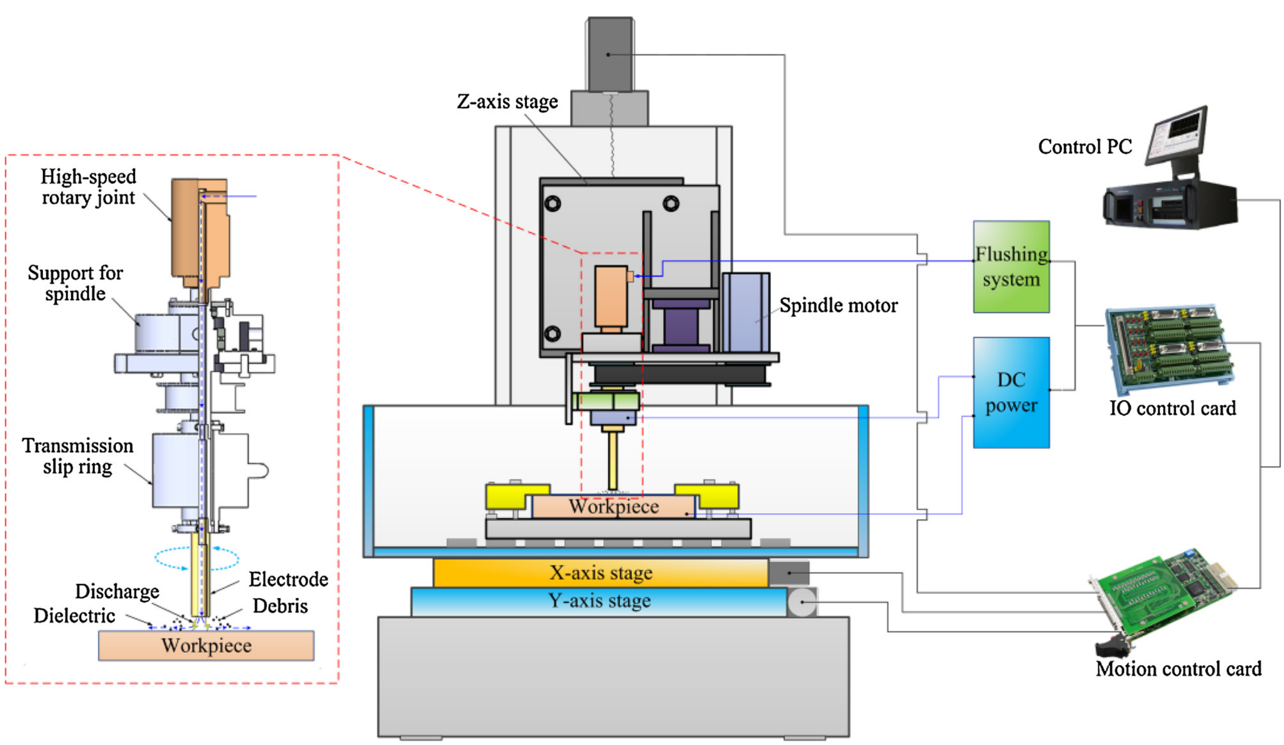

Fig. 1. Schematic of machining equipment used to generate moving electric arcs.