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Studies on electric-discharge machining of non-contact seal face grooves

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Abstract

In this paper, the electric-discharge machining (EDM) of non-contact seal grooves was studied. Two types of material, namely: tungsten carbide and silicon carbide were tested by EDM due to their hard machining behaviors. The geometry of seal grooves is another reason why grinding or other precision machining processes cannot be applied. Four parameters of EDM processes were studied, namely: electrode material, pulse duration, discharge current, and polarity. According to experimental results, the optimal process parameters were obtained based on the specimen's qualities, such as surface roughness and depth of cut. An industrial example was also studied in the final stage of the proposed paper.

Keywords: Electric-discharge machining; Tungsten carbide; Silicon carbide; Non-contact seal; Precision engineering

1. Introduction

Seal is an important component in rotary machines, such as pump, compressor, mixer, etc. Normally, seals can be classified into two types: contact and non-contact. The mechanical seal belongs to the former type where sealing face materials are in contact with each other rotationally, and is suitable to liquid transportation status. The gas film seal belongs to the latter type where the sealing faces do not contact during services that is suitable to gas transportation status. Moreover, the service life of non-contact seals will also be elongated when compared to contact seals. Fig. 1 depicts the basic components of a film-riding gas seal: a rigidly mounted rotating seal ring and a spring-loaded (floating) stationary seal ring: the stationary face contains specially designed grooves. The depth of the etched grooves are made slightly larger than the required minimum face separation which is typically 3–5 μm [1]. The grooves actually control both hydrodynamic and hydrostatic pressure so the seal can be considered a hybrid gas seal. The operation quality therefore depends on the surface roughness and uniform depth of grooves.

Most seal ring materials are ceramic composites, for example: tungsten carbide (WC) and silicon carbide (SiC), to ensure high compressive strength. However, the brittle and hard nature of ceramic material represents poor workability. Electric-discharge machining (EDM) that belongs to non-traditional method is suitable [2,3] and therefore applied in order to manufacture the ceramic seal ring grooves [4]. In EDM, conductive material is removed by high-frequency electrical sparks generated by pulsating a high voltage between the cathode tool, shaped in the form of the desired grooves, and a conductive workpiece anode. The workpiece and the tool are submerged in a dielectric fluid. With a gap between the tool and workpiece and a high voltage, intense sparking occurs across the gap, melting and vaporizing material from both pieces. Resolidified small hollow spheres are washed away by the recirculating dielectric oil.

In this paper, four parameters of EDM processes are studied, namely: electrode material, pulse duration, discharge current, and polarity. According to experimental results, the optimal process parameters were obtained based on the specimen's qualities, such as surface roughness and depth of cut. An industrial example is also studied in the final of the proposed paper.

2. Experimental methods

Fig. 2 depicts the experimental flow chart. A simple triangle groove on both seal ring materials (WC, SiC) was EDM first by two types of tooling materials, i.e. copper

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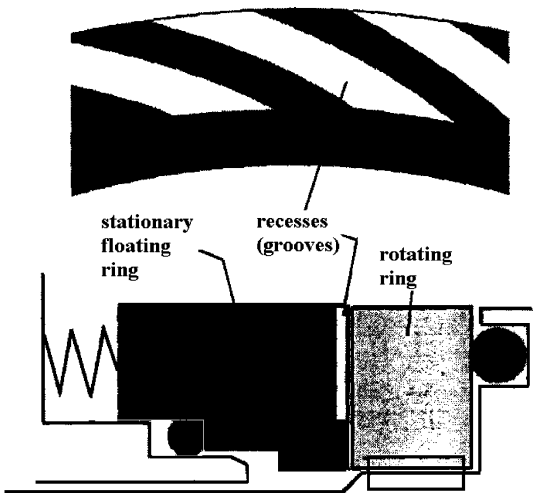

Fig. 1. Basic components of a film-riding gas seal [1].

Table 1
Electrical discharge machining conditions

Material	WC, SiC
Electrode	W–Cu, Cu
Pulse duration, τ_p (μs)	1, 75, 150
Discharge current, I_p (A)	0.5, 1, 2, 3
Polarity	+, −
Dielectric fluid	Kerosene

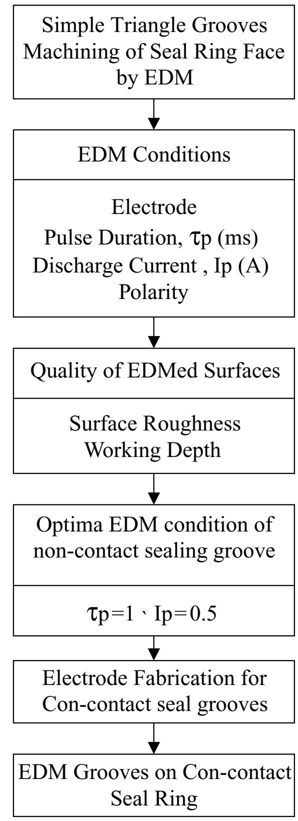

Fig. 2. Experimental flow chart.

and copper–tungsten in order to obtain the optimal process parameters. The setup of EDM is shown in Fig. 3. A servomechanism adjusts the workpiece–tool gap and a DC current pulse produces sparks at a rate of up to 10,000 Hz. Table 1 shows the process parameters adopted in this study. There were three test values on pulse duration (τ_p), namely: 1, 75, and 150 μs. Four discharge currents (I_p) were tested: 0.5, 1, 2, and 3 A. Two types of polarity were also tested, however, dielectric fluid was controlled by only one kind of kerosene. According to the experimental results, the surface roughness and depth of grooves were measured to justify which condition resulted in the best quality. Therefore, the EDM tooling for non-contact gas seal was milled and finished by the NC machine. After electrode fabrication, the grooves on gas seal ring were manufactured by EDM according to the formerly obtained optimal process parameters.

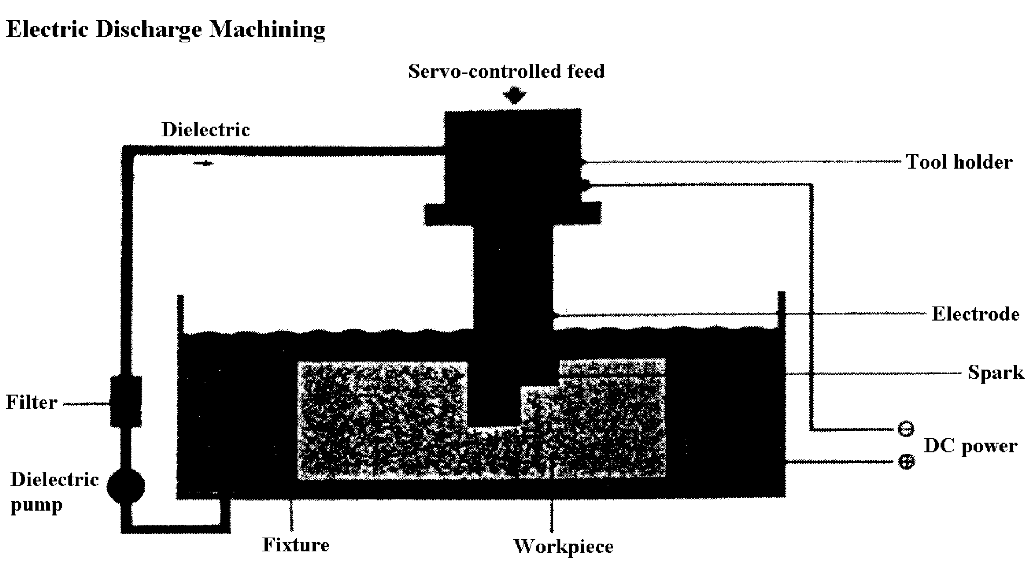

Fig. 3. Schematic diagram of the EDM process.

3. Results and discussion

3.1. Effects of electrode materials

Choosing suitable electrode materials in EDM is very important because it will influence electrode wear so as to influence workpiece surface roughness. Grooves on seal rings require uniform working depth and good surface roughness. In the present study, copper and copper–tungsten electrode materials were tested. Due to hardness, copper–tungsten electrode material shows low wear ratio, therefore, it is usually used to EDM forging die. Fig. 4 depicts the electrode surfaces after EDM: (a) copper–tungsten and (b) copper. Some dark strips on the copper–tungsten electrode surface were found because copper containments melted and wore more easily than tungsten containments. The tungsten particles therefore bulged during EDM and then became bridges between electrode and workpiece [5]. These bulged particles connected with burned carbide showing dark strips. This situation did not appear on copper electrode surface because of its uniform material containments. The copper electrode was therefore used in the following EDM of seal ring grooves.

3.2. Effects of electrode polarity on surface roughness

EDM process can be classified into positive-polarity machining (electrode is cathode, workpiece is anode) and negative-polarity machining (electrode is anode, workpiece is cathode) by their polarities of electrode and workpiece. The electrons were emitted from cathode and struck the neutral molecules to cause the electrolytic dissociation, and finally bombarded the anode surface. The cations resulted from electrolytic dissociation striking the cathode. The whole circulation around the cathode mainly comprised the output of electrons and input of cations, and that around the anode is the impact of electrons. Therefore, the energy dissipations of two kinds of electrical discharge machining are different [6]. The surface roughness of WC and SiC electric-discharged machined by different polarity arrangements are shown in Fig. 5, it is obvious that the WC and SiC have better surface roughness by using negative-polarity and positive-polarity, respectively.

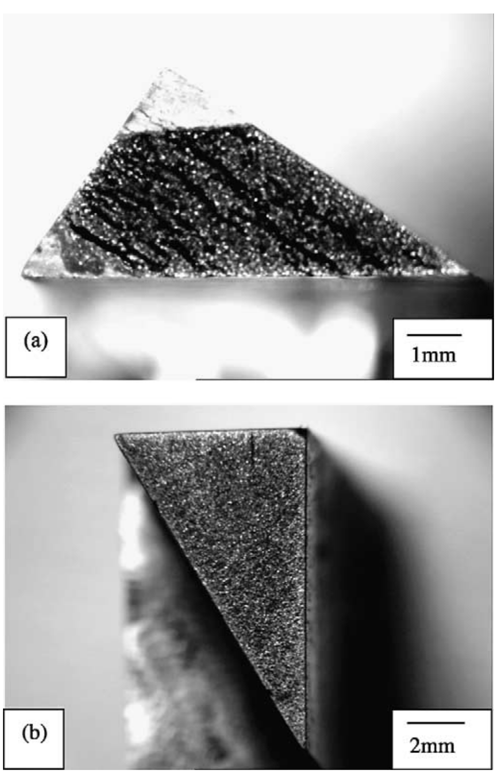

Fig. 4. The electrode surfaces after EDM: (a) copper–tungsten and (b) copper.

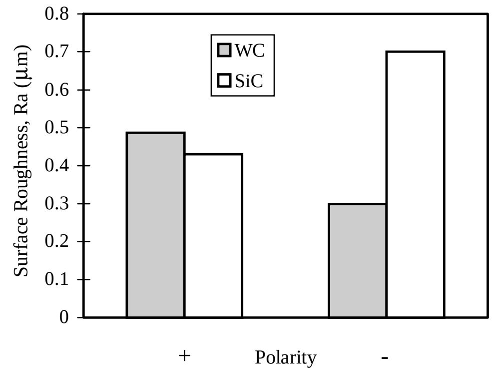

Fig. 5. Effects on surface roughness by electrode polarity with two different materials (WC and SiC).

3.3. Effects on surface roughness and working depth by pulse duration

The comparison of surface roughness between WC and SiC electric-discharged machine is shown in Fig. 6; it is apparent that the surface roughness may be worse as pulse duration increases. The increase of pulse duration may cause the rise of input energy between electrodes and workpiece; inducing a larger amount of evaporation and fusion

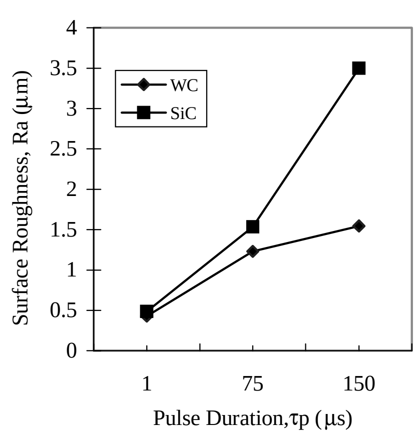

Fig. 6. Effects of pulse duration on surface roughness for WC and SiC.

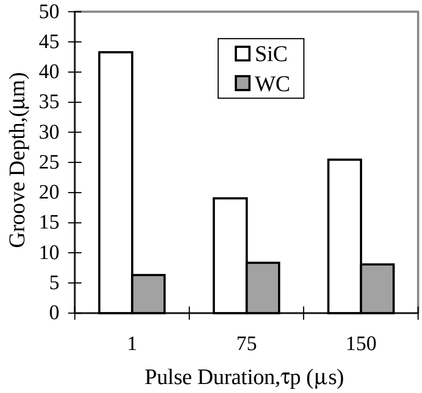

Fig. 7. Effects of pulse duration on groove depth for WC and SiC.

of material followed by the rougher surface with the larger sizes of discharge crater [7]. The fast heat removal of material with high thermal conductivity may cause the less cracks with the result that SiC electric-discharged machined may have more cracks and worse surface roughness while the pulse duration increases due to the thermal conductivity [8]. The detailed examinations of depth grooves of seals made of WC and SiC machined with 3–7 μm working depth shows that the electric-discharged machined WC may meet the requirements of design specification while the electric-discharged SiC seems not to be within the design tolerance. Accordingly, the EDM depth of groove is related to the mechanism of material removal. In addition to the evaporation and fusion for the removal of two kinds of material while electrical discharge machining, SiC generally have another removing mechanisms to induce the irregularities of machined grooves depth (Fig. 7).

3.4. Effects on surface roughness and working depth by discharge current

The surface roughness increases when discharge current increases as shown in Fig. 8. When discharge current occurs between tool and workpiece, both surfaces melt and vapor. At the same time, the dielectric fluid (kerosene) also vapors and inflates resulting in high gas pressure and impacts the workpiece surface. When some materials on the surface

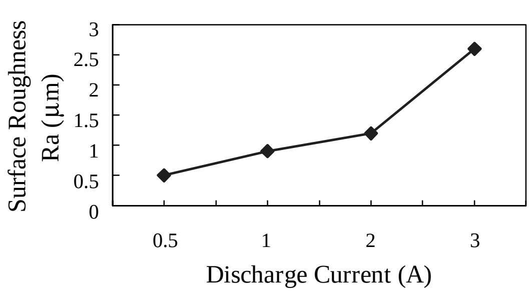

Fig. 8. Effects of discharge current on surface roughness when EDM WC.

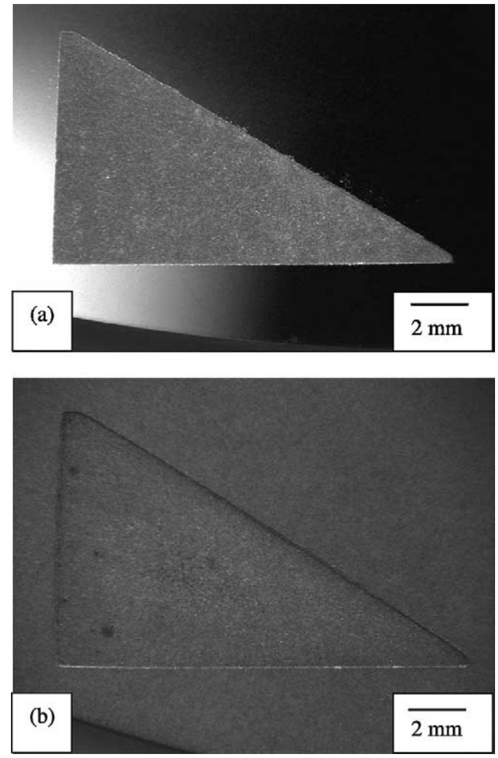

Fig. 9. The best workpiece surfaces after EDM: (a) WC and (b) SiC.

of the workpiece were removed by discharge spark, craters occur [9,10]. If discharge current increases, the material remove ratio also increases, but it produces large craters and obtains large surface roughness.

3.5. EDM of gas seal ring grooves as an industrial example

According to previous experiments, the best surface roughness of WC was better than that of SiC after EDM. The polarity of electrode was positive when EDM WC workpiece, however, the polarity of electrode was negative when EDM SiC workpiece if best workpiece surfaces are intended. On these conditions, the best surface accuracy can be obtained. The optimal process parameters are as follows: pulse duration being 1 μs and discharge current being 0.5 A. Fig. 9 depicts the best workpiece surfaces after EDM: (a) tungsten carbide, and (b) silicon carbide.

Fig. 10 depicts the drawing of a gas seal ring face from industrial specification. In order to obtain uniform depth of each groove, an integrated electrode was manufactured by a computer numerical control milling machine. The CAD model of EDM electrode for this gas seal ring face is shown in Fig. 11. By using this electrode with copper material, a WC seal ring face was tested by EDM process. It took less than 2 h to obtain average 3 μm in depth of grooves. The surface roughness is less than 0.35 μm. Fig. 12 depicts the photograph of the WC gas seal ring face after EDM.

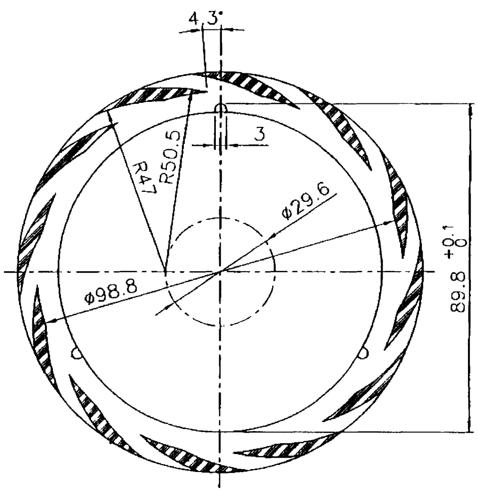

Fig. 10. Drawing of gas seal ring face.

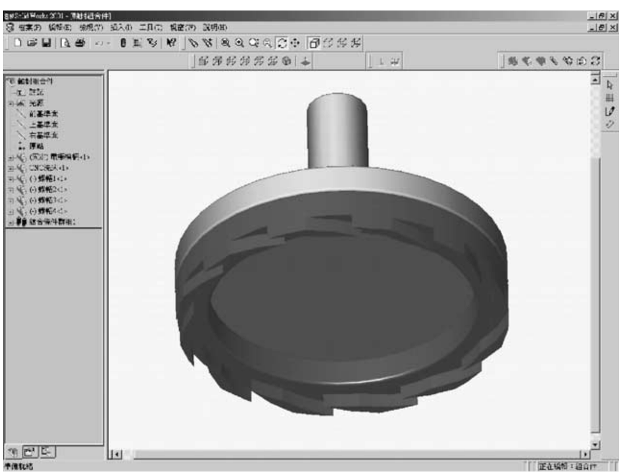

Fig. 11. CAD model of EDM electrode for gas seal ring face.

Fig. 12. Photograph gas seal ring face after EDM.

4. Conclusions

In this paper, the electric-discharge machining (EDM) of non-contact seal grooves was studied. Two types of material, namely: tungsten carbide and silicon carbide were tested by EDM. Four parameters of EDM processes were studied, namely: electrode material, pulse duration, discharge current, and polarity. According to experimental results, the optimal process parameters were obtained based on the specimen's qualities, such as surface roughness and working depth. An industrial example of gas seal ring grooves by EDM process was also studied. The surface roughness R_a is less than 0.35 μm and depth of grooves is less than or equal to 3 μm. Copper is better than copper–tungsten as an electrode material due to homogeneous wear ratio. The optimal process parameters are as follows: pulse duration being 1 μs and discharge current being 0.5 A. The best combinations considering polarity of electrode and workpiece material during EDM are as follows: using positive electrode in the case of tungsten carbide workpiece and using negative electrode in the case of silicon carbide.

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References

[1] H.K. Muller, B.S. Nau, Fluid Sealing Technology—Principles and Application, Marcel Dekker, New York, 1998.
[2] L.C. Lim, L.C. Lee, Y.S. Wong, H.H. Lu, Solidification microstructure of tool steels, J. Mater. Sci. Technol. 7 (1991) 239–248.
[3] M. Ramulu, M.G. Jenkins, J.A. Daigneault, Spark-erosion process effects on the properties and performance of a TiB_2 particulate-reinforced/SiC matrix ceramic composite, Ceram. Eng. Sci. Process. 18 (3) (1997) 227–238.
[4] T. Schaller, L. Bohn, J. Mayer, K. Schubeft, Microstructure grooves with a width of less than 50 μm cut with ground hard metal micro end mills, J. Jpn. Soc. Precis. Eng. 23 (1999) 229–235.
[5] M.P. Samuel, P.K. Philip, Powder metallurgy tool electrode for electrical discharge machining, Int. J. Mach. Tools Manuf. 37 (11) (1997) 1625–1633.
[6] D.D. Dibitonto, P.T. Eubank, M.A. Barrufet, Theoretical models of the electrical discharge machining process. I. A simple cathode erosion model, J. Appl. Phys. 66 (9) (1989) 4095–4103.
[7] A.M. Gadalla, B. Bozkurt, Expanding heat source model for thermal spelling of TiB_2 in electrical discharge machining, J. Mater. Res. Soc. 7 (10) (1992) 2853–2858.
[8] L.C. Lee, L.C. Lim, Y.S. Wong, Crack susceptibility of electro-discharge machined surface, J. Mater. Process. Technol. 29 (1992) 213–221.
[9] R. Bormann, Getting Those Better EDMD Surface, Modern Machine Shop, 1991, pp. 56–66.
[10] B. Bozkurt, A.M. Gadalla, P.T. Eubank, Simulation of erosion in a single discharge EDM process, J. Mater. Process. Manuf. Sci. 11 (4) (1996) 555–563.