Breakout detection in fast hole electrical discharge machining

P. Koshy *, M. Boroumand, Y. Ziada
Department of Mechanical Engineering, McMaster University, Hamilton, Canada

---

Abstract

Real time tracking of the working end of the tool in fast hole electrical discharge drilling process is not straightforward due to extensive relative erosion of the tool, which manifests as severe longitudinal and shape wear. This poses a problem in terms of sensing hole breakout as well as hole completion, with adverse implications on process productivity and component quality. To this end, this paper presents a scheme that concurrently monitors the back pressure of the dielectric fluid injected through the tool and the displacement of the machine tool ram, to detect hole breakout and completion, respectively. Implementation of such a system has the scope for significantly enhancing process output, particularly in applications that entail the drilling of a large number of holes.

Key words: back strike prevention, breakthrough detection, microdrilling

---

`Int. J. Mach. Tools & Manuf. 50 (2010) 922--925`

1 Introduction

Fast hole electrical discharge machining (EDM) is a non-contact thermal process that is widely used for rapid drilling of sub-millimeter diameter holes with aspect ratios as high as 150. Typical applications involve machining of cooling holes in components such as turbine blades that are made from difficult-to-cut materials such as nickel alloys, in the aerospace and power generation industries.

Material removal in this process is through melting and vaporization brought about by utilizing the heat generated from a train of high frequency (50–

---

* Corresponding author
Email address: `koshy@mcmaster.ca` (P. Koshy).

100 kHz) electrical spark discharges between the tool and the workpiece, in the presence of deionized water used as a dielectric medium. The process employs rotating tubular tools generally of either brass or copper, through which the dielectric fluid is injected at high pressure. This effectively flushes machining debris off the interelectrode gap, maintains a stable process and facilitates rapid drilling rates. Tool feed relative to the workpiece is realized under servo control, so as to maintain a frontal gap of several μm between them.

A characteristic feature of the fast hole drilling process is that it is not uncommon to incur volumetric tool wear in excess of the volume of material removed from the workpiece, which corresponds to considerable longitudinal wear of the tool. Unlike in mechanical drilling, real time location of the tool end face that is engaged in material removal is therefore rather complicated. This affects both the productivity of the process and the quality of the components machined.

Firstly, unless it is a blind hole, it is essential to ensure that the drill does indeed break through. Secondly, the time that corresponds to any extraneous axial feed of the tool following completion of the hole is non-productive, and in applications that involve the drilling of a large number of holes, can add up to be a significant proportion of the total cycle time. Furthermore, in some cases it may be required to drill through one feature (say feature 1 in Fig. 1) but stop machining before the tool starts drilling into an adjacent feature that is only several mm away (feature 2 in Fig. 1), an occurrence known as back strike. It is therefore not just desirable but in many instances critical to have a capability for detecting hole breakout.

The problem of sensing the completion of a hole in fast hole EDM is rendered intricate by the extensive wear of the tool electrode that induces significant shape degeneration of the working end of the tool, in addition to the longitu-

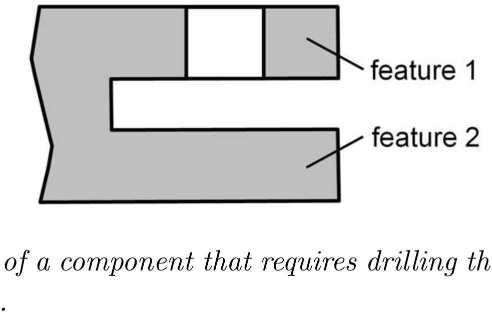

Fig. 1. *Sectional view of a component that requires drilling through feature 1 without drilling into feature 2.*

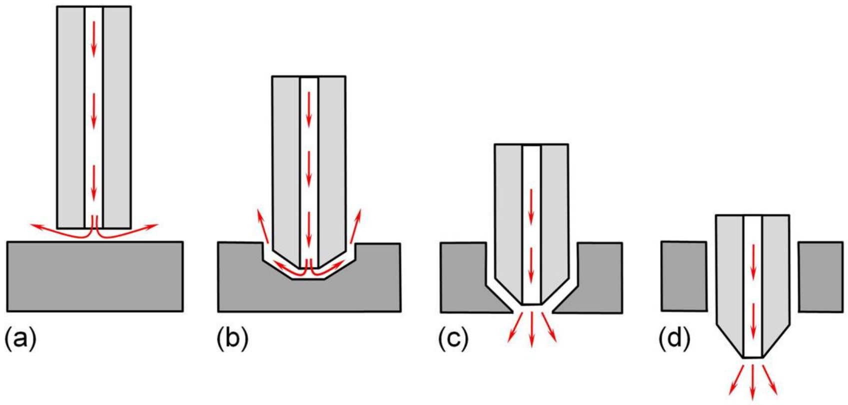

Fig. 2. *Stages in fast hole electrical discharge drilling: (a) approach, (b) intermediate, (c) breakout, and (d) completion; arrows denote the flow of dielectric fluid.*

dinal wear mentioned previously. The tool end that is initially of a shape as shown in Fig. 2a sustains a taper along the feed direction during the course of machining the hole (Fig. 2b). This implies that as the tool breaks out, the machined hole involves a taper that is complementary to that on the tool (Fig. 2c). In order that the hole is completed with the taper corrected, the tool would therefore need be fed past the hole end by a distance somewhat greater than the axial length over which the tool end is tapered (Fig. 2d).

Approaches to addressing the issue of tool wear in EDM have included tool wear sensing and compensation techniques [1,2] that have been applied primarily in electrical discharge milling operations, and geometric simulation of the process [3]. When operating in the micro EDM regime, factors such as machining depth that influences the flushing efficacy, and subtle variations in such variables as spark energy can influence the relative electrode wear [4]. This discounts the adoption of compensation or simulation strategies that invoke constant relative wear.

In light of aspects presented thus far, this paper presents two simple techniques for the real time detection of hole breakout and completion. Breakout is detected by monitoring the back pressure of the dielectric fluid, and hole completion is assessed by consideration of the ram displacement of the machine tool.

2 Principle and Proof-of-Concept

The scheme proposed for detecting the instance of hole breakout is based on the concept of pneumatic gauging, which is widely applied in industry for

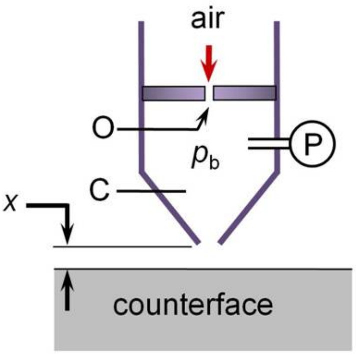

Fig. 3. *Principle of pneumatic gauging.*

precision measurement of fine displacement. The method involves the supply of air at a regulated pressure through a control orifice O (see Fig. 3) to the atmosphere through a nozzle, past a variable pressure chamber C so as to impinge on a counterface. Any change in the stand-off distance x between the nozzle tip and the surface alters the flow of air as it leaves the nozzle. This is reflected as a highly sensitive change in the back pressure p_b measured using a pressure transducer P. Alternatively, the corresponding change in the flow rate could be considered. The effect of nozzle geometric parameters and operating variables on the performance of such a sensor can be found in reference [5].

Pneumatic measurement of displacement has been largely employed in static or quasi-static applications to do with dimensional measurement, assessment of geometric form attributes such as flatness and circularity [6], and characterization of surface roughness [7]. The technique has also been utilized in applications as diverse as in-process detection of surface porosity in machined castings [8], metrology of biological matter [9] and foodstuff [10], and in the determination of mass transfer coefficients [11].

The concept of pneumatic gauging was adapted by Hayakawa et al. [12] for application in EDM by using the dielectric liquid injected through a tube electrode as the working fluid for the assessment of the interelectrode gap width (Fig. 4a). The variation in back pressure p_b in terms of the stand-off distance x (as shown schematically in Fig. 4b) was observed to exhibit a linear segment for x less than ~ 50 μm, which is a range typical of gap-width in EDM. In this region the back pressure was found to be especially sensitive to the stand-off distance, while being independent of the external diameter of the tool for a constant internal diameter. The back pressure could hence be statically calibrated for various known values of distance x, and thereafter used for the in-process estimation of gap-width. The time lag and bandwidth of the sensor were further found to be on the order of 1 ms and 100 Hz, respectively, which rendered it applicable for the control of gap-width in EDM machine tools. The application envelope of this innovative technique has been further extended in the present work to detect hole breakout, as discussed in the following.

During the course of machining, the dielectric fluid has to flow past the interelectrode gap, on to and through the annular space around the tool of a thickness roughly equal to the gap width (Fig. 2b), which results in the buildup of an appreciable back pressure. At the instant of hole breakout, however, there is an abrupt and significant decrease in the resistance to the flow of the dielectric fluid (Fig. 2c), which would register a rapid drop in the back pressure signal. This can be captured using a sensitive pressure transducer with a piezoelectric sensing element, as demonstrated later.

Subsequent to hole breakout, the next issue is sensing the completion of the hole, which can be realized by tracking the relative average speeds that are characteristic of the different stages (Fig. 2) in the machining of a hole. This is a consequence of the servo control considering the difference between a set voltage and the average gap voltage to feed the tool. In the approach stage (Fig. 2a) the tool moves towards the workpiece at a constant feed rate set on the controller. During the intermediate stage (Fig. 2b), the rate at which the tool advances into the workpiece is limited by the linear rate of material removal, and is lower than the feed rate in the approach stage. Once machining of the hole is complete (Fig. 2d) the tool would advance further at the same

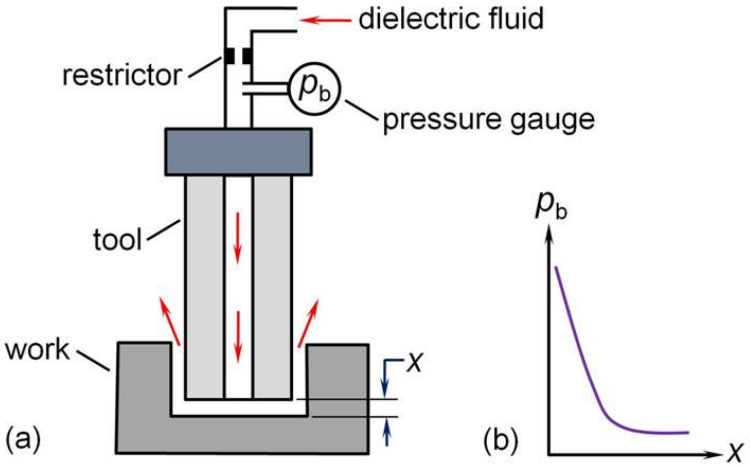

Fig. 4. *In-process measurement of gap width in EDM [12]: (a) schematic of experimental setup, (b) qualitative variation of back pressure with gap-width.*

feed rate as in the approach stage, as it no longer entails any material removal.

The change in average tool speeds as the process progresses through various stages of a single drilling cycle as above implies that the ram displacement versus time plot would exhibit distinct changes in slope on initiation of machining and on completion of the hole. Following hole breakout, which can be detected by monitoring the back pressure signal, completion of the hole can therefore be sensed by identifying the time at which the average slope of the displacement characteristic assumes a value consistent with that in the approach stage.

The proof-of-concept of the two ideas above that pertain to detection of breakout and hole completion is shown in Fig. 5. The test referred to drilling of a tool steel workpiece of thickness 3.2 mm with a brass electrode of 0.3 mm diameter at a flushing pressure of 1.7 MPa. The back pressure was monitored using a piezoelectric pressure transducer (PCB Piezotronics, Model 111A26) with a sensitivity of 150 mV/bar and a rise time of less than 1.5 μs. The displacement of the ram of the machine tool was measured using a linear variable differential transformer.

The initial change in the slope of the displacement characteristic (Fig. 5b)

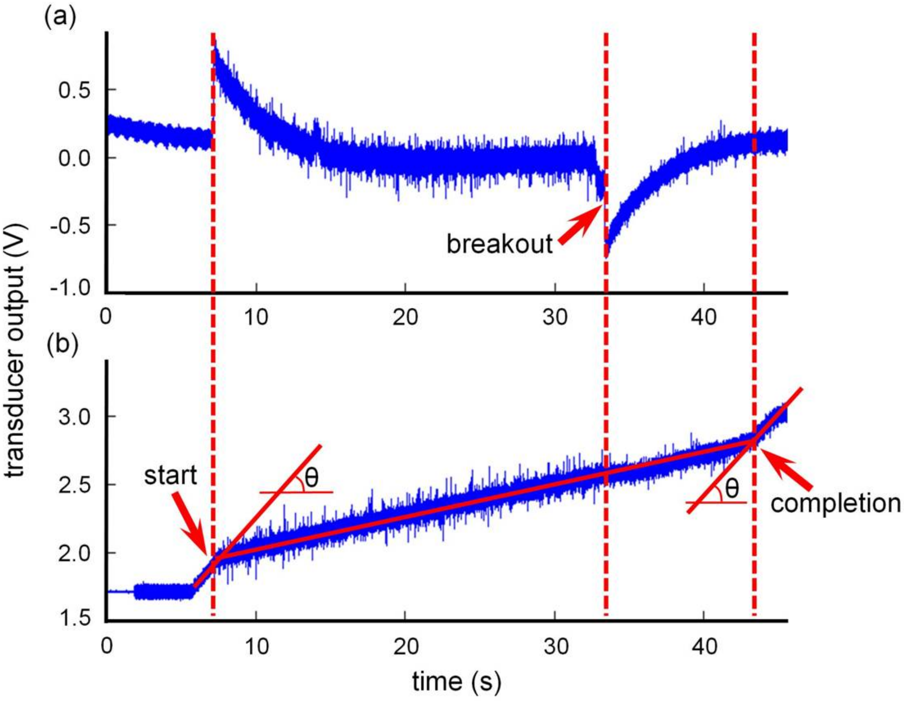

Fig. 5. *Time evolution of: (a) back pressure signal, and (b) displacement signal, in fast hole EDM.*

from zero to $\tan\theta$ signifies the approach of the tool towards the workpiece. Subsequent start of drilling can be seen to have induced a rapid rise in the back pressure signal (Fig. 5a), which corresponds to a change in the slope of the displacement signal (Fig. 5b) to a value less than $\tan\theta$. The instance of hole breakout is characterized by the conspicuous drop in the back pressure. The completion of the hole is evident in the ram displacement signal and refers to the time at which the average slope reverts back to $\tan\theta$ (Fig. 5b).

Although, it is not strictly necessary to monitor the back pressure if it is just the sensing of hole completion that is important, simultaneous monitoring of both pressure and displacement signals would enhance the robustness of the monitoring system. The time to hole completion after breakout is indicative of the extent of tool shape wear and may therefore be used for determining appropriate tool redressing intervals, especially if back strike is of concern. Furthermore, once the hole breaks out, the tool may feed at a somewhat lower rate on account of machining not progressing as effectively due to the machining gap starved of dielectric fluid; to this end, the breakout detection scheme can also be used to selectively activate auxiliary external jet flushing into the gap, to enhance machining performance through to the completion of the hole.

3 Conclusions

The proof-of-concept of a simple monitoring system to rapidly and robustly detect hole breakout and completion by considering the time evolution of back pressure and ram displacement signals in the fast hole EDM process has been established. The concept is readily extended to multi-axis fast hole machining applications. It is envisaged that the application of such a system would significantly enhance process productivity, especially in applications that entail the drilling of a large number of holes. The system is further capable of improving the quality of machined components in terms of generating taper-free holes, and precluding the incidence of back strike.

Acknowledgments

Authors thank the team comprising Kyle Buckle, Martin Malinski, Michael D'Amico, Andrew Riddle and Chris Hopkins that designed and manufactured a fast hole EDM attachment as part of their undergraduate capstone project. Funding for this work from Liburdi Engineering and the Ontario Center of Excellence for Materials and Manufacturing is gratefully acknowledged.

References

[1] Y.F. Chang, Z.H. Chiu, Electrode wear compensation of electric discharge scanning process using a robust gap-control, *Mechatronics* 14 (2004) 1121–1139.

[2] P. Bleys, J.P. Kruth, B. Lauwers, A. Zryd, R. Delpretti, C. Tricarico, Real-time tool wear compensation in milling EDM, *CIRP Annals* 51 (2002) 157–160.

[3] Y.H. Jeong, B.K. Min, Geometry prediction of EDM-drilled holes and tool electrode shapes of micro-EDM process using simulation, *International Journal of Machine Tools and Manufacture* 47 (2007) 1817–1826.

[4] D.T. Pham, A. Ivanov, S. Bigot, K. Popov, S. Dimov, An investigation of tube and rod electrode wear in micro EDM drilling, *International Journal of Advanced Manufacturing Technology* 33 (2007) 103–109.

[5] E.O. Doeblin, 2003, *Measurement Systems: Applications and Design*, McGraw Hill, New York.

[6] M. Curtis, F. Farago, 2007, *Handbook of Dimensional Measurement*, Industrial Press, New York.

[7] D. Grandy, P. Koshy, F. Klocke, Pneumatic non-contact roughness assessment of moving surfaces, *CIRP Annals* 58 (2009) 515–518.

[8] I. Menzies, P. Koshy, In-process detection of surface porosity in machined castings, *International Journal of Machine Tools and Manufacture* 49 (2009) 530–535.

[9] G.E. Gale, A thickness measuring device using pneumatic gauging to detect the sample, *Measurement Science and Technology* 6 (1995) 1566–1571.

[10] S.P. Bridge, P.T. Robbins, W.R. Paterson, D.I. Wilson, A pneumatic gauging sensor for measuring the thickness of soft films, *Journal of Process Mechanical Engineering* 215 (2001) 19–27.

[11] G.F. Jackson, An assessment of the application of pneumatic gauging to the measurement of mass transfer coefficients, *Journal of Physics E: Scientific Instruments* 11 (1978) 569–575.

[12] S. Hayakawa, W. Wang, F. Itoigawa, T. Nakamura, T. Matsubara, In-process measurement and control of gap distance in EDM process, *International Journal of Electrical Machining* 8 (2003) 39–43.