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Fabrication of Differently Shaped Tool Electrodes for Micro-EDM

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ABSTRACT
Conventional techniques used for the fabrication of tool electrodes for micro-EDM are limited to cylindrical shapes. Machining of microelectrodes with non-circular cross-section is a difficult task. Few methods were recently reported in the literature but they are very complex and expensive. This paper proposes to develop a simple technique for grinding differently shaped tool electrodes for micro-EDM. The developed system consists of an arduino based tool spindle indexing mechanism incorporated in the in-situ tool grinding attachment with piezoactuated tool feed system. The setup can be used for mechanical grinding as well as Block Electrical Discharge Grinding (BEDG).Trial experiments were carried out to fabricate square and hexagonal shaped microelectrodes on graphite rod by mechanical grinding. Experimental results obtained showed that the developed in-situ tool grinding system with indexing mechanism is suitable for fabricating polygonal shaped tool electrodes for die-sinking micro-EDM.

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Introduction

Electrical Discharge Machining (EDM) is an electro-thermal process that can be used for machining any electrically conducting material regardless of its other physical properties [1]. The pulsed application of electrical energy between the tool electrode and the workpiece results in localized melting and evaporation of small volume of material producing a small crater on the work surface. Continued application of discharges and by controlling the process parameters like voltage, current, frequency, pulse on time, duty cycle etc the required geometry can be machined on the work [2]. EDM finds application in machining hard-to-machine materials into complex shapes. When EDM principle applied at micro level for the fabrication of micro parts and features it is called micro-EDM. Micro-EDM differs from conventional EDM in terms of energy involved, size of the tool electrode used and size and complexity of the component parts machined[3-4].

Micro-EDM is one of the best alternative techniques used for the fabrication of complex 3D structures in difficult-to-machine materials at micro level which finds wide applications in Micro Electro Mechanical System (MEMS) devices. [5-7]. Depending on the different methods of tool deployment in relation to the workpiece, micro-EDM may be classified into micro-EDM drilling, micro-EDM milling or die-sinking micro-EDM [8]. In micro-EDM a simple shaped (cylindrical) rotating tool electrode is given path control to machine the workpiece material layer-by-layer [9]. The size of the tool electrode used must be much smaller than the micro cavity required. As the tool size decreases, the difficulty in fabricating the tool and also the tool wear rate etc increases. In micro-EDM die-sinking process, a non-rotating tool electrode is used to machine a cavity of the same cross-section in the workpiece. Advantage of the process is that considerably larger size tool electrode can be used simplifying the process with reduced machining time.

Fabrication of tool electrodes for micro-EDM

Size of the tool electrode used in micro-EDM is too small and hence fabrication and handling of the tool is difficult. More over to eliminate the clamping error and error due to the spindle run out, in-situ tool fabrication is adopted for micro-EDM. A tool electrode of larger diameter is held in the tool spindle and reduced to the required micro size by Electrical Discharge Grinding (EDG) technique or by mechanical grinding [3, 10].

Conventionally, micro tool electrodes are fabricated by Wire Electrical Discharge Grinding (wire-EDG) or Block Electrical Discharge Grinding (BEDG) methods [11]. Wei Han and Kunieda machined micro rods with electrostatic induction feeding [12]. H. Onikura et al. employed ultrasonic vibration assisted mechanical grinding to fabricate high aspect ratio micro tools in cemented carbide [13]. Yin Qingfeng et al. used a modified EDG with two block electrodes (EDG-TBE) to simplify the process by eliminating the need for measurement [14]. But the applications of these techniques are limited to the fabrication of cylindrical tool electrodes. When a micro tool electrode of non-circular cross-section is required, as in the case of die-sinking micro-EDM, above techniques cannot be used.

Asma Perveen et al. (2012) used specially designed sacrificial blocks with slots for fabricating differently shaped micro-electrodes by BEDG process [15]. Bin Xu et.al proposed micro-Double-staged Laminated Object Manufacturing (micro-DLOM) technique for the fabrication of 3D micro electrodes of noncircular cross-section [16]. In the first stage 2D structures were machined by wire-EDM of thin foils and in the second stage 2D structures are laminated by thermal diffusion welding at high temperature and pressure. Jianguo et al. proposed a combined method of wire electro chemical micro machining (WECMM) and micro electric resistance slip welding to fabricate 3D micro electrodes [17]. Takayuki et. al employed a tandem EDM mechanism for simultaneous machining of micro electrodes and micro holes[18]. Dengji Guo et.al tried with focused ion-beam chemical vapour -

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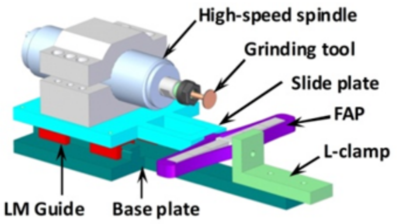

Figure 1: FAP integrated with in-situ tool grinding attachment

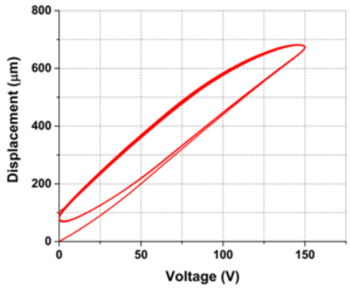

Figure 2: Hysteresis curve for feed displacement of the in-situ tool grinding attachment with FAP.

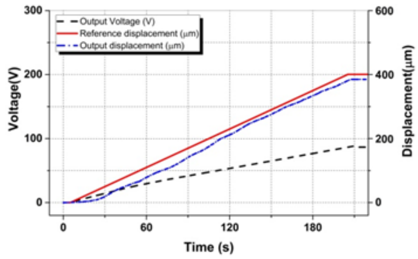

Figure 3: Experimental tool feed displacement obtained for reference input feed displacement of 400μm ramp signal

-deposition (FIB-CVD) technique for fabricating 3D micro/nano electrodes, which is used in micro-electro-chemical discharge machining (micro-ECDM)/EDM [19]. However all these methods are very complex, time consuming and highly expensive to implement. This paper discusses the development of a simple in-situ tool grinding system with indexing mechanism for the fabrication of polygonal shaped micro electrodes. Development of tool grinding system is described in section2. Experimental procedure for the fabrication of polygonal shaped tool electrode is explained in section 3. Experimental results are discussed in section 4 followed by conclusions presented in section 5.

Development of in-situ tool grinding system with indexing mechanism

The in-situ grinding system with indexing mechanism is developed mainly to fabricate polygonal shaped micro-tool electrodes for die-sinking micro-EDM. The developed system consists of (i)in-Situ tool grinding attachment with piezoactuator based feed control,(ii)tool electrode spindle with indexing mechanism,(iii)high-speed spindle with grinding wheel for mechanical grinding and(iv)in-situ measurement system/tool positioning system.

In-Situ tool grinding attachment with Piezoactuator based feed control

Piezoactuator based feed control system is incorporated in the in-situ tool grinding attachment [20, 21]. The grinding attachment consists of a base plate with a pair of linear motion (LM) guide ways on its top and an adjustable L-clamp fixed on its extended part. A slide plate is mounted on the linear guides. A Flexurally Amplified Piezoactuator (FAP) is connected between the L-clamp and the slide plate as shown in Fig.1. Since the actuator is blocked on one side and the free side is connected to the slide plate, any displacement of the actuator can provide precise movement to the slide plate. Slide plate carries high speed spindle with mounted point for mechanical tool grinding or the worktank with dielectric recirculation system for BEDG. The grinding attachment is mounted on the motorised x-y stage (8MT 175-50, Standa, Lithuania) for traverse motion. Figure 2 shows the displacement plot of the tool grinding attachment with FAP against the applied voltage. The attachment can produce a maximum feed displacement of 680μm at 150V input to the FAP and shows about 60 μm hysteresis. Maxwell model of the FAP is used to account for hysteresis and Maxwell inverse model in LabVIEW software is used for controlling the feed displacement. The feed control system is tested for reference input displacements and found to produce output feed displacements with a maximum error of 6.93 percentage for input displacements up to 600 μm [22]. Figure 3 shows the experimental tool feed of 385.6μm obtained for a reference input displacement of 400μm.

Tool electrode spindle with indexing mechanism

Nema17 stepper motor (1.8deg.per step, voltage 3-6V, current 1.7A, holding torque 4.4Kg-cm, number of wires 4 and shaft diameter 5mm) is used as the tool spindle. A micro stepping drive (RMCS-1158, input voltage 12-40v dc, peak current 0.25-2.0A) which subdivides 200 steps into 6400 micro-steps (step angle 0.05625deg) through an arduino based control (Arduino Mega 2560) is employed for the indexing drive of the spindle. Arduino is a programmable controller with software through which a software code can be uploaded to a physical model. Arduino Mega2560 has 54 digital input/output pins of which 14 can be used as PWM outputs and 16 for analog inputs. It has one USB port, one power jack and a reset button. ER11 collet (0.5mm-4mm clamping range) is used on the spindle to hold the tool electrode. The spindle unit is mounted on a bracket for rigid support and the bracket is attached to the heavy duty vertical post with lead screw as shown in Fig.4 and Fig.7.

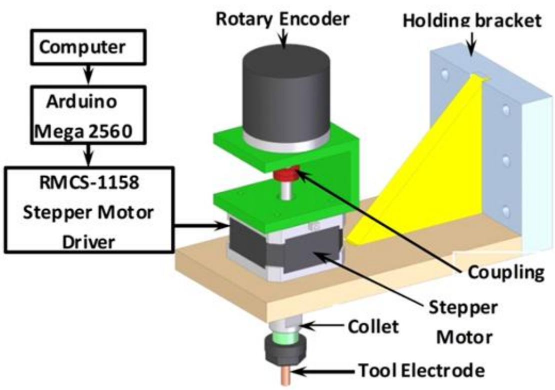

Figure 4: Block diagram of the tool spindle with indexing mechanism

A regulated power supply (0-32V dc) is used to power the micro stepping driver and the stepper motor. Arduino board is powered and interfaced with computer through the USB cable. For rotary indexing of the tool spindle, input the parameter values in the computer and upload the programme to the Arduino board. Arduino generates the control signal and sends it to the micro stepping driver which in turn rotates the spindle to the required angle. The indexing movement of the spindle is calibrated by coupling it with a rotary encoder which can measure 8000 counts per rotation or correct to 0.045degree. Encoder output is acquired by NIUSB6251 data acquisition system and LabVIEW software. Block diagram of the test setup and the plot of the encoder output for 60degree input angle are shown in Fig.5 and Fig.6 respectively. Test result showed that angular indexing of the spindle achieved is in good agreement with input angle.

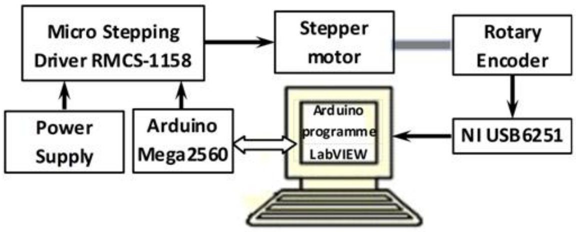

Figure 5: Block diagram of the experimental setup for calibrating spindle indexing

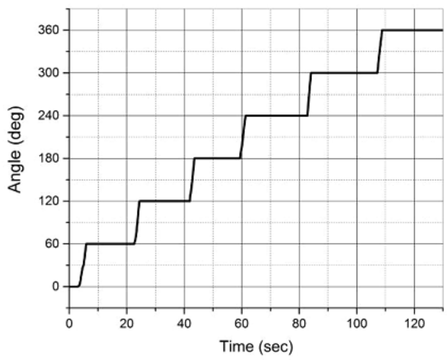

Figure 6: Indexing motion of the spindle for 60 deg step angle

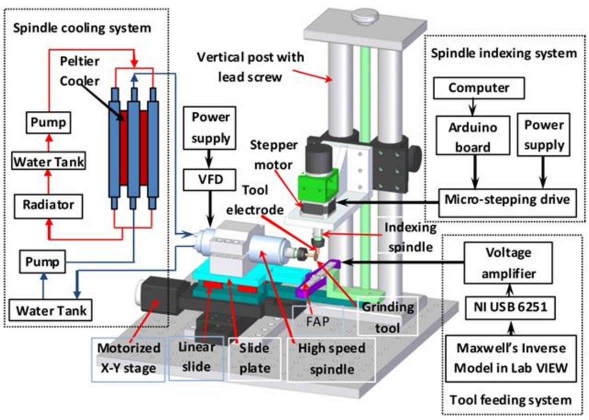

Figure 7: Block diagram of the experimental setup for mechanical grinding of differently shaped microelectrodes

High-speed spindle with grinding wheel for mechanical grinding

Block diagram of the developed setup for mechanically grinding tool electrodes for micro-EDM is shown in Fig.7. The tool grinding setup consists of (i) tool spindle with indexing mechanism, (ii) Piezoactuator based tool (grinding wheel) feeding unit and (iii) the high speed spindle unit for driving the grinding wheel. The high speed spindle (GDZ-12, 75V, 2-5A,) having speed range of 12000 to 60000rpm is powered through Variable Frequency Drive (VFD) for speed control. A peltier based water cooling system is used for maintaining the temperature of the spindle below 30^{o}C during operation [23]. Cooling water is passed between the cold sides of the peltier plates and circulated through the cooling jackets of the spindle using a variable speed pump. A secondary re-circulating system with separate water tank and radiator is used for removing heat from the hot side of the peltier plates as shown in Fig.7.

Fabrication of polygonal shaped tool electrodes

Mechanical grinding experiments were carried out on the developed setup to fabricate square and hexagonal shaped tool electrodes for die-sinking micro-EDM.

Fabrication of square shaped micro tool on graphite electrode

A graphite rod of 2mm diameter is held on the indexing spindle. A SiC mounted point of 20mm diameter with 4mm shank is mounted on the high speed spindle. Initial positioning of the grinding wheel with respect to tool electrode is achieved by the motorized x-y stage and using the USB digital microscope (Supereyes, Model B008 with measurement software). Spindle cooling system is switched on and the spindle temperature is maintained at about 25^{o}C. Micro electrode with square shape is machined in two stages. In the first stage grinding, diameter of the electrode is reduced with continuous rotation of the tool electrode. This first cut will eliminate the clamping error and run out of the indexing spindle. For the first stage grinding, micro stepping drive and arduino are powered. Arduino programme for continuous rotation is chosen and uploaded to arduino. VFD is powered and frequency is set for 12000rpm and the high speed spindle is switched on. In order to give feed motion to the grinding wheel, Maxwell inverse model of the FAP in LabVIEW is used in the feed control. The required feed displacement of 300µm at 2µm per second feed rate and 10 µm/s retraction rate as a ramp signal is the input to the model. The model generates the drive voltage corresponding to the input displacement and feeds it to the linear amplifier (LA75, amplification factor 20). Amplified voltage is supplied to the actuator which in turn moves the slide plate carrying the high speed spindle and hence the grinding tool. On completion of the first stage grinding in which electrode diameter is reduced, the grinding tool is brought to contact position with the reduced portion of the electrode by moving the y-stage and using the USB digital microscope.

Now indexing spindle is stopped and first side of the square electrode is ground by setting a feed displacement of 450µm to the grinding tool at the same feed rate and retraction rate. Then select the arduino programme for stepping motion and input the step value for 90degree and upload the programme to the arduino. Arduino generates and sends the control signal to the micro stepping driver to move the tool spindle through 90degree. Thus the tool electrode is indexed to bring the second side in position for grinding. Grinding tool is fed through 450µm to grind the second side of the square tool. On completion of the second

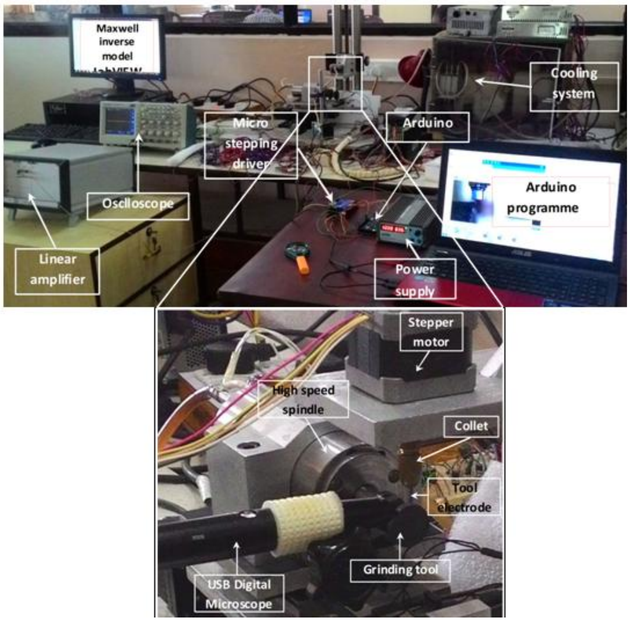

Figure 8: Photograph of the experimental setup for mechanical grinding of differently shaped microelectrodes

side, the same procedure is repeated two more times to finish the square tool for the set length. Same procedure is followed to grind hexagonal shaped tool on graphite electrode of 2mm diameter. In the first stage electrode diameter is reduced by giving 250μm feed displacement for the grinding tool and driving the tool electrode at 200rpm. In the second stage, tool electrode spindle is kept stationary and grinding tool is fed through 300μm for grinding the first face of the hexagonal microelectrode. Then arduino programme for stepping motion is selected and step value for 60degree is input to index the tool electrode through 60degree. Procedure is repeated to complete the remaining sides of the hexagonal tool. Figure 8 shows the photograph of the experimental setup for grinding polygonal shaped micro tool electrodes.

Results and Discussion

Figure 9 shows the plot of progress of 300μm tool feed and the corresponding drive voltage against time for reducing the diameter of the graphite electrode from 2000μm to 1400μm. Figure10 shows the feed displacement of 450μm of the grinding tool and the corresponding drive voltage for grinding one face of the square tool.

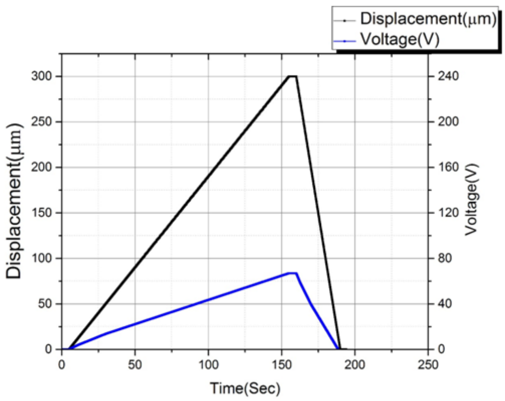

Figure 9: Tool feed at 2 μm/s for 300μm and the variation of corresponding drive voltage

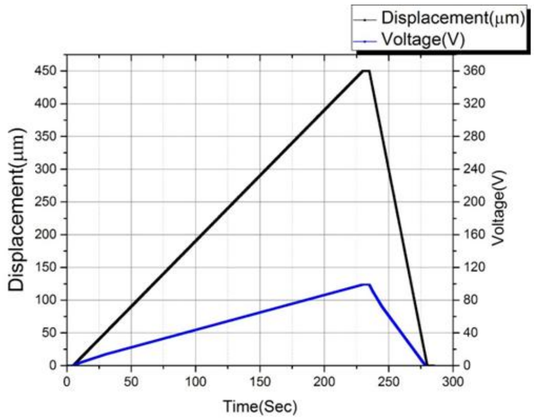

Figure10: Tool feed at 2 μm/s for 450μm and the variation of corresponding drive voltage

Ground micro tool electrode is observed under optical microscope (LEICA DM 750M, magnification 100X) and the image is acquired and measured using Leica Application suit V4.2 measurement software. From the acquired image shown in Fig. 11, face width of the square tool is observed as 502.5515 μm. Figure 12 shows the photograph of the square tool of side502.5515μm ground on graphite electrode. Figure 13 shows photograph of the hexagonal micro tool ground on graphite electrode and its acquired microscope image showing face width of 575.5555μm in Fig 14. Figure 15 and Fig. 16 shows the microscope image and the photograph respectively of the square tool with sides 1005.1003 μm ground on graphite.

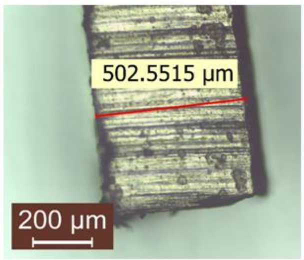

Figure11: Microscope image of the square tool of face width 502.5515 μm (Magnification 100X)

Figure12: Photograph of the square tool of sides 502.5515 μm

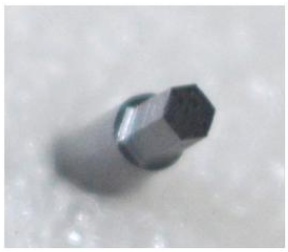

Figure13: Photograph of the hexagonal tool of sides 575.5555 μm

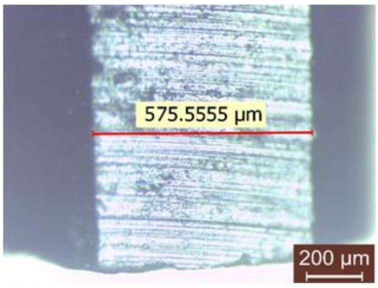

Figure14: Microscope image of the hexagonal tool of face width 575.5555 µm(Magnification 100X)

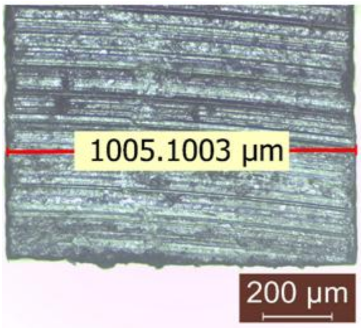

Figure15: Microscope image of the square tool of face width 1005.1003 µm(Magnification 100X)

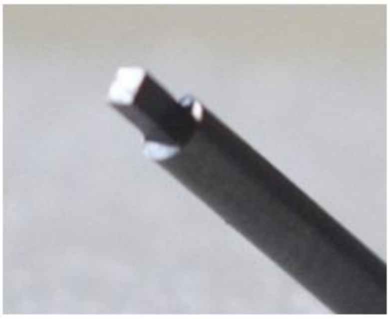

Figure16: Photograph of the square tool of sides 1005.1003 µm

Conclusions

An in-situ tool grinding system with indexing mechanism is developed and integrated with a prototype micro-EDM setup with piezoactuator based tool feed control. Arduino based control is used for rotary indexing of the tool spindle. A USB digital microscope with measurement software is used for initial positioning of the grinding tool. Mechanical grinding experiments were carried out to fabricate square and hexagonal shaped micro tool electrodes on graphite electrode. Experimental results obtained showed that developed tool grinding system with indexing mechanism is capable of grinding polygonal shaped micro tools with good geometrical accuracy. Therefore, with proper selection of grinding tool, the proposed technique can be used for the fabrication of differently shaped micro tool electrodes on different materials.

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