Macro & micro-feature fabrication on external cylindrical surface using perimetric electrical discharge texturing

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Abstract. Machining of thin walled lesser stiff rotationally symmetric components is quite challenging. Electric discharge texturing is one among many of the material removing texture fabrication techniques. Extensive research has been performed for wire electric discharge machining by various researchers but so far very little effort has been made for electric discharge texturing on cylindrical surface. No one has attempted for texturing on thin walled cylindrical components. In the present study, preliminary trial experiment was conducted to evaluate suitability of newly developed Electric Discharge Machining technique i.e. Perimetric Electric Discharge Texturing (PEDT). A Perimetric Work Support & Drive System (PWSDS) was developed for Die sinker EDM to perform texturing on thin walled difficult to machine circular components used in aviation, automobile and heat transfer applications. Experimental setup was prepared for ENC-35 (Die sinker EDM). Trial experiment were performed at low current on Aluminium alloy (EN AW-6082-AlSi1MgMn) tube using copper electrode. Process was investigated for the effect of current and current density on MRR, surface roughness and geometrical accuracies (circularity, concentricity). The dielectric Dearomatized hydrocarbon fluid EDM100 was applied through nozzle to flush out the material removed by melting and evaporation. It was found that very small current quickly removes a very thin layer of the surface material without much damage to the base metal and improves the surface finish. The circularity is found to be dependent upon the run out accuracy of the spinning drive wheel. PEDT proves out to be most promising method of metal removing texturing technique specially for lesser stiff typical components.

Key words: Rotationally Symmetric, Texturing, Perimetric texturing, Circularity, Run out, Spinning Drive Wheel.

1. Introduction

EDM is the earliest and most widely used non-conventional material removal process, capable of machining electrically conductive complex geometry parts with high dimensional accuracy and acceptable surface finish irrespective of hardness, strength & other mechanical properties. It finds application in die, mould, aerospace, automotive, micro-electronic and biomedical industries. Die sinking, wire cut and milling EDM are quite common and due to increasing trend for miniaturization,
micro EDM is becoming more popular. Surface texturing also termed as structuring or patterning, is defined as producing engineered surfaces with deliberately created multiple features (micro holes, micro asperities) of size ranging from millimeter to nanometer with better control of surface design for the fulfillment of specific functional requirements. Surface finish components (lay, roughness and waviness) are also covered in surface texturing [1]. 20th century scientists started manifesting their interest in surface roughness and its influence on tribological performance. Patterned surface with strips along the curved surface of cylinder liner by honing technology was applied for the first time in 1940s to improve friction behavior. Though its beneficial effects were neither recorded nor published [2,3]. Technological advancements for surface improvement using macro and micro textures continues with the development of surface structuring by chemical etching and abrasion in 1980s [4], vibro rolling in 1984 [5] and laser ablation in 1990s [6-10]. Though all these methods are used for macro or micro texturing but suffers with lack of precision and reproducibility and fabrication of fine features are still challenging. Surface textures formed as micro-pillars [11-14] or micro-pits [15-18] as per the functionality requirements and texturing methods. Textures are characterized by the sum of principal geometric features like shape and dimension, density and asperity distribution on the surface. Texturing finds their application mainly in the fields like tribology, electronics, metrology, optics, biomedicines and physics. Thin walled structures find their application in vehicles as energy absorber to increase passenger safety. Other applications of texturing include tribology (to reduce friction), to increase bond strength control of press fit component assemblies, heat transfer for micro devices and cylinder liners for automotive engines.

1.1 Texture Fabrication Technologies (TFT’s)

TFT’s are distinguished on the basis of the material manipulation to create surface texture and are classified as following:

- Material removal technologies
- Material displacement technologies
- Material adding technologies
- Self-forming methods

Material removal technologies are further divided into (i) chemical etching, (ii) high temperature texturing (laser texturing, electrical discharge texturing, ion beam or electron beam methods), (iii) mechanical processes (ultrasonic machining, blasting, grinding and honing). In laser surface texturing (LST) the material is removed due to excessive localized heating and melting of substrate material in contact with laser beam and is used to produce dimples (semi spherical textures). LST requires costly equipment and process suffers from the drawbacks such as high operating energy, surface finish deterioration, metallurgical alteration of the surface, larger heat affected zone (HAZ 300-450 µm [19]), requires post finishing process (to remove burr or bulge of height 3.5 -4.5 µm [20-21]). Electric discharge texturing (EDT) is another high temperature texturing used for electrically conductive material and has the advantages of (i) producing complex geometries with sharp corners, (ii) creating features with smaller dimensions (< 100 µm) (iii) achieving low surface roughness of finished parts (< 100 nm with high precision (~ 1 µm) and (iv) mechanical stress free machining.

2. Experimental Set-up for EDT

Micro feature fabrication such as creating grooves, steps and taper along rotationally symmetric hollow component with low stiffness value puts a big challenge. Proposed experimental setup makes use of Perimetric Work Support and Drive System (PWSDS) developed in-house for stress free support and drive of the thin walled tubular components of circular cross section to perform efficient EDT. PWSDS as shown in Fig. 2 consists of spin drive wheel to impart rotary motion to the component whereas tension roller along with guide plate ensure its correct positioning and slip free rotation during EDT processing.
2.1 Perimetric Electric Discharge Texturing (PEDT)
To carry out the present research work, ENC-35 EDM was employed. The existing abrasive electro discharge diamond grinding (AEDDG) set up modified into Perimetric Electrical Discharge Texturing (PEDT) set up as shown in ‘figure 1’ (schematic). The Perimetric Work Support and Drive System (PWSDS) adopted on ENC-35 EDM as shown in ‘figure 2’, to support and drive rotationally symmetrical component at desired speed. In-feed motion is imparted to the electrode through servo controlled Z-axis to maintain desired inter electrode gap. For this investigation, high strength structural Aluminium alloy EN AW-6082 (AlSi1MgMn) was selected as work material for texturing (to produce stepped dia.). MRR is determined for different current values. The results of PEDT for the test specimen in terms of geometrical accuracies and surface finish in correlation with the applied current were also studied.

2.2. Experimentation
Microtechnica® ENC-35 EDM machine mounted with PWSDS was used for experimentation. As shown in the ‘figure 2-a’, the PWSDS is mounted on the table of ENC-35 EDM. Provision is made for dielectric supply through nozzle. Machining parameters are provided in the table 1.

Figure 1. Schematic of experimental setup for perimetric EDT

(a) Perimetric work support and drive system  (b) Perimetric electric discharge texturing in Progress

Figure 2. Experimental setup for Perimetric EDT
1. Vertical Slide of EDM carrying Tool electrode,
2. PWSDS mounted on the table of EDM
3. Dielectric supply nozzles
4. Copper electrode
5. Component (specimen)
Table 1. Machining parameters

| Machining parameter       | Setting condition |
|---------------------------|-------------------|
| Workpiece polarity       | Positive          |
| Electrode polarity       | Negative          |
| Voltage (V)              | 110               |
| Peak current (A)         | 3, 4.5, 6, 9, 12  |
| Pulse on time (µsec.)    | 60                |
| Pulse off time (µsec.)   | 5                 |
| Drive wheel speed (rpm)  | 25                |
| Servo speed for tool movement | Q<sub>up</sub> 5µsec. |
|                          | Q<sub>down</sub> 5µsec. |

In the present experiment texturing was performed on Aluminium workpiece as shown in ‘figure 3-a’. The work piece was produced by rough turning (cutting speed-100 m/min., longitudinal feed-0.3 mm/revolution and depth of cut-1 mm) with HSS turning tool to achieve surface roughness in the range of 10 µm Ra. Copper electrode (size Dia. 10 mm) is used for texturing on Aluminium work piece to study the effect of current on MRR, surface roughness and geometrical accuracies. Vernier calipers, micro meter was used for linear measurements viz. diameter and length, CMM used for circularity and concentricity measurements and portable surface roughness Tester Surtronic S108(Taylor Hobson make) was used for measuring the surface roughness.

(a) Component pre-condition  (b) Component after Electric discharge texturing

Figure 3. Work piece (Specimen)

3. Results and Discussion
The experiment results as shown in tables 2 and 3 are divided into two groups. First group is concerned with the influence of current on MRR. Graphs as shown in ‘figure 4’ represent the effects of current on MRR. The second one is pertaining to the analysis of the accuracies and surface roughness as obtained from perimetric electro discharge machining.

3.1. Current vs. MRR
In line with the previous researches, the MRR as shown in the table 2 is proportional to the current. This effect is due to more thermal energy in the spark at higher current, resulting in more amount of molten material created per spark as the temperature at the time of machining is nearly equal to or more than the melting temperature of the material. As shown in ‘figure 4’, the trend of increase in MRR with an increase in current is almost linear.
### Table 2. Current vs MRR

| Specimen no. | Machined dia. $D_m$ (mm) | A     | B     | C     | D     | E     |
|--------------|--------------------------|-------|-------|-------|-------|-------|
| 1            | 39.27                    | 38.24 | 36.81 | 36.34 | 35.65 |
| 2            | 39.28                    | 38.25 | 36.81 | 36.34 | 35.65 |
| 3            | 39.27                    | 38.24 | 36.82 | 36.36 | 35.66 |
| 4            | 39.26                    | 38.26 | 36.82 | 36.38 | 35.66 |
| 5            | 39.28                    | 38.25 | 36.82 | 36.40 | 35.64 |
| Mean $D_m$ (mm) | 39.27                  | 38.25 | 36.82 | 36.36 | 35.65 |
| Av. current (A) | 3                        | 4.5   | 6.0   | 9.0   | 12.0  |
| Machining Time (min.) | 60                      | 60    | 60    | 30    | 30    |
| MRR (mm$^3$/min) | 29.04                   | 39.39 | 53.44 | 115.7 | 129   |

![Figure 4. Current vs MRR](image)

### 3.2. Analysis of accuracies and surface roughness

Geometrical accuracies i.e. circularity is shown in table 3. Circularity error to a great extent depends on running accuracy of the drive wheel and forces involved during perimetric electrical discharging texturing. Running accuracy of drive wheel is less than 8 µm in the current set up. Perimetric Work Support and Drive System ensures stress free support and effective drive to the workpiece. Also process forces involved in EDM are negligibly small. All these favorable conditions put together result in circularity improvement from initial value 30-40 µm to final value 10-15 µm. Low current range selected for current study is associated with a little evaporation of dielectric helps in uniform cooling and flushing of the machined metal and results into insignificant thermal distortion hence concentricity is preserved to its initial value viz. 80µm. With the increase of current, energy of spark increases, resulting in greater melting, evaporation and damage to the work piece surface. Surface roughness along the EDM textured surfaces was improved from initial value of 10 µm Ra to final value of 1.2 µm Ra due to (i) tiny material removal at low peak current-3 Ampere, (ii) precise fine servo speed tool movement i.e. $Q_{up} = Q_{down} = 5$ µsec, (iii) efficient dielectric supply and (iv) force free machining characteristic of the process.
Table 3. Geometrical accuracies

| Machining zone | Circularity Accuracies (µm) along EDT surfaces |
|----------------|---------------------------------------------|
| Specimen no.   | A    | B    | C    | D    | E |
| 1              | 11   | 12   | 11   | 14   | 13|
| 2              | 13   | 14   | 12   | 11   | 10|
| 3              | 10   | 12   | 11   | 13   | 10|
| 4              | 12   | 11   | 13   | 11   | 11|
| 5              | 14   | 12   | 11   | 10   | 10|
| Mean D_m (mm)  | 39.27| 38.25| 36.82| 36.36| 35.65|
| Average current (A) | 3   | 4.5  | 6    | 9    | 12 |
| Concentricity (µm) | ≈ 80 | ≈ 80 | ≈ 80 | ≈ 80 | ≈ 80 |

4. Conclusions
The perimetric electric discharge texturing along external surface of aluminium tube was performed and the effect of current was observed on the MRR, geometrical accuracies viz. concentricity and circularity and surface roughness. Results of the experiment are encouraging and validates the perimetric work support and drive system (PWSDS) as a superior method to support and rotate the circular components while performing electric discharge texturing. It was concluded that achievable surface roughness can be controlled through adjustment of current value and in the present study the minimum surface roughness of value 1.2 µm Ra could be achieved with current value of 3 Amperes since very small current quickly removes a thin layer of the surface material causing little melting and or damage to the base metal. Further to this, circularity is improved from initial value 30-40 µm to final value 10-15µm and maximum MRR of 129 mm3 per min is achieved. No effect on concentricity was observed in the experiment. Electrical discharge texturing using newly developed perimetric work support and drive system (PWSDS) is simple, economic and efficient technique of surface texturing in comparison to other techniques like laser texturing and is especially suitable for thin walled lesser stiff cylindrical components. Current research outcome opens up the scope for further research in the field of PEDT on thin walled tubular structures and patterning along curved surfaces of difficult to machine materials.

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