Alex. Eng. J., Alex. Univ., Volume 29 No.1 , pp A 83 - A 100 (1990)

CHARACTERISTICS OF PULSED-ELECTROCHEMICAL SUPERFINISHING

H.El-Hofy
Production Engineering Department
Faculty of Engineering, Alexandria University
Alexandria, Egypt

Abstract

Electrochemical superfinishing (ECS) is a fine machining process which has been well aknowledged as a method of producing excellent surface quality in difficult-to-machine alloys.

The combination of electrolytic dissolution and mechanical scrubbing (MS) improves the conventional superfinishing process. As a result of such a mechanism, the small stock removal, due to chipping is assisted by the dissolution action.

The application of pulsed electrolytic dissolution, besides chipping, is introduced. Effects of open gap voltage, duty cycle and scrubbing speed are investigated.

The percentage contribution of each machining phase, surface quality and out-of-roundness are also evaluated.

1. Introduction

Superfinishing by vibration grinding is a surface microfinishing operation in which the micro-surface irregularities are removed by effect of the continuous and slow reciprocation of grained abrasive sticks that move along the workpiece length. The sticks oscillate concurrently at short and rapid strokes with a coninuously revolving workpiece as shown in Fig. 1. This process is however known to sustain some of the surface macro-irreqularities such as waviness and out of roundness.

By introducing an electrolytic dissolution action to mechanical chipping Fig. 2, high stock of removal rates become achievable. In electrolytic honing, it has been reported that the machining speed is 10 times faster than the conventional honing and 4 times faster than internal grinding [1].

It is therefore the high stock removal capabilities combined with the ability to generate close dimensions that gave the process high merits in all fields of industry. The need for initial grinding, that is necessary used in conventional superfinishing is also avoided.

The process can also be used when other processes fail to yield production or generate the required size in the so called difficult-to-machine alloys as well as tool steel.

Applying ECS to parts that are sucsceptible to heat and distortion is advantageous because the bulk of the metal is removed electrochemically in an electrolyte cooled atmosphere. The problem of thermal distortion is therefore eliminated.

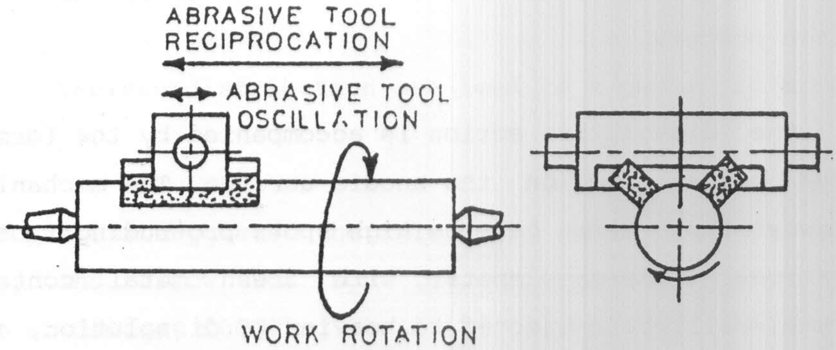


Fig. 1 Superfinishing external cylinderical surfaces for rotating workpieces.

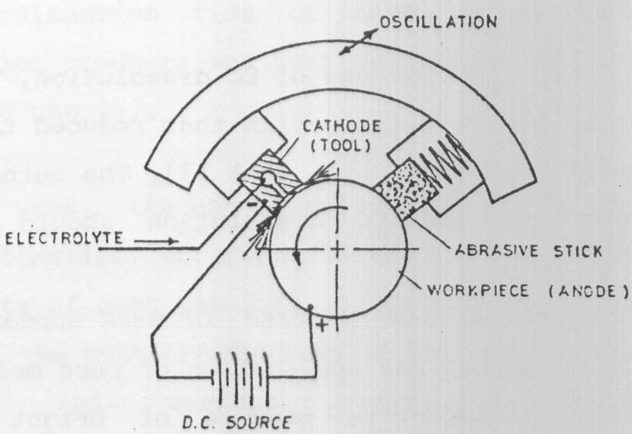


Fig. 2 Electrolytic superfinishing process

Burr-free components can also be obtained as a result of the dissolution process.

In ECS, the dissolution action is accompanied by the formation of a protective oxide film on the anodic surface. The mechanical action scrubb away that flim on the high spots protruding from the ideal configuration. These spots, with fresh metal contacting the electrolyte, will be subjected to heavier EC dissolution, compared to areas still covered with the protective film. Under such circumstances, the protective film can be used to correct the geometric inaccuracy [3].

It has been reported that the power of the film depends on the electrolyte used. In this regard some electrolytes possess fairly strong power to reduce the ECD with their protective film. Other types have strong protective film too, but the electric charge needed to build up the film is too small.

Inspection of the process of EC dissolution, without mechanical chipping, showed a dark visible film that reduced the current 10-20 % while the metal removal rate 50 % [3]. The authers suggested that mechanical scrubbing and EC dissolution should act alternatively.

In order to overcome the problem of dark appearance, during ECS, El-Lawendy [2] suggested the application of pure mechanical scrubbing for 15 seconds in order to produce of bright surface finish .

Towards improving the efficiency of electrolytic grinding Kupfuswamy et al [4] introduced a magnetic field of 50-100 Gauss when machining tungesten carbide (K20) in 15 % $NaNO_3$. Such a technique enhanced the mobility of the ions, caused a stirring action and, improved the electrolyte conductivity.

Improper electrolyte distribution can lead to a geometric error in the workpiece [2,3].

While Randlett [1] suggested the release of stone pressure, at the end of honing, and allow for ECD to achieve if order to avoid the metallurgical damage, Guoqiang et al [3] claimed that the use of light stone pressure, after the EC process, produce tolerances of about 0.0005 inch on the diameter while roundness and straightness are held to less than 0.0003 inch.

It has shown recently that, the use of pulsating current, allows for the application of high instantaneous current densities, to the workpiece, without the need of an elaborate electrolyte pumping system and rigid machine. This is possible because each current pulse is followed by a relaxation time of zero current which allowes for removal of reaction products and heat generation by Joule effect from the interelectrode gap [5].

In the present work, the use of pulsed voltage in the mechanical - electrolytic combination occurring in electrolytic superfinishing is presented. Effects of open gap voltage, duty cycle and the mechanical chipping speed on the metal removal mechanism are discussed. Workpiece out-of-roundness and surface roughness are also measured.

2. Experimental procedure and conditions

Fig. 3 shows the equipment used in the present experimental work.

Accordingly, the workpiece rotates at N rpm, while the machine head, incorporating both the cathodic-tool and abrasive stick oscillates at a frequency f which is affected by the workpiece rotation (f = 3.7 N).

It follows that the average scrubbing speed [6] is given by

$$V_{av} = [(\pi DN)^2 + (2.f.k)^2]^{0.5}$$

where,

K : The oscillation amplitude, mm

D : The average workpiece diameter mm

During each test a fine turned workpiece is clamped, in position, between two centers. The cathodic-tool is then set at an initial gap 0.5 mm using a filler gauge. The scrubbing pressure is also kept at a predetermined value using a spring pressure which was kept constant during the whole tests.

The electrolyte is then allowed to flow. On reaching the steady state, the workpiece is rotated when the electrolysing current is actuated. The average voltage and current were measured, Fig. 3.

At the end of machining, which elapsed for 2 minitues, the mechanical abrasion and electrolytic dissolution are stopped. The workpiece is then cleaned dried and reweighted using a sensitive balance.

For some workpieces, the surface roughness, before and after machining were measured in four, marked, positions along its circumference.

Similarly out of roundness profiles were also obtained. Changing the on-time, for the voltage wave forms of Fig. 4 duty cycles of 0.47, 0.66, 0.73 and 1.0 were experimented at two open gap voltages (19 and 29) and, three levels of workpiece rotational speeds (80,120, 121 rpm) with a corresponding average chipping-speed of 12.36 18.55 and 32.78 m/min.

Working Conditions

All the experiments are carried out under the following conditions:

1. Workpice: stainless steel 304

   Specifications:

Element	Cr	Ni	C	Mn	Si
Composition %	18.58	8.2	0.1	0.23	0.021

   Surface hardness: 80 BHN

   Outside diameter: 49 mm

   Average out-of-roundness: 24 μm

   Average surface roughness : 2.25 μm

   Average length : 46 mm

   Density : 0.0079 gm/mm^3

2. Electrolyte : $NaNO_3$, 20 % w/v [7].

   Flow rate : 7.5 g/l

3. Cathodic-tool : material : brass

   width : 10 mm

   length: 60 mm

   shape : see Fig. 5.

4. Scrubbing-tool : Silicon carbide, resin bond

   Pressure : 250 gm/cm^2

   width : 10 mm

   length : 60 mm

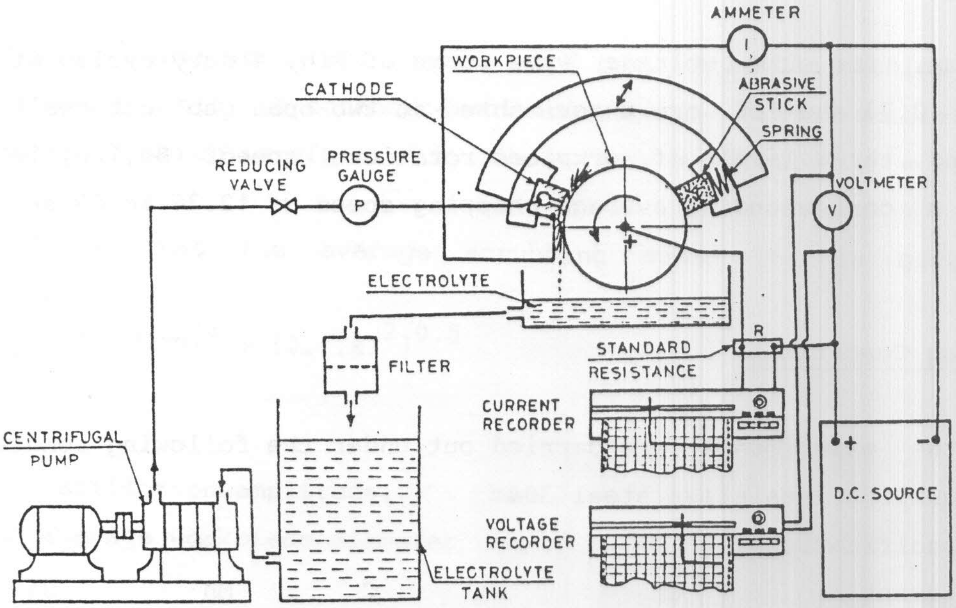


Fig. 3 Experimental set up for electrolytic superfinishing [2].

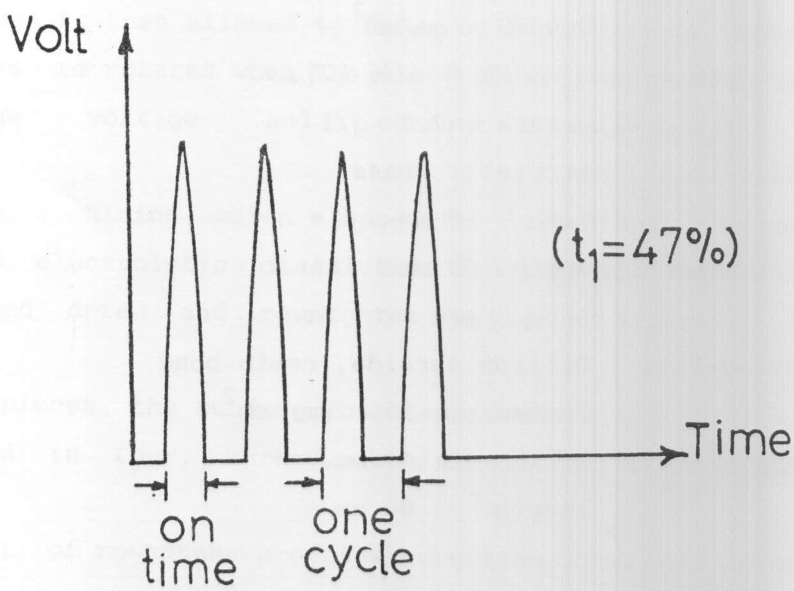


Fig. 4 Voltage wave form used.

3. Results and discussions

Theoretically, the volumetric removal rate can be calculated using Faraday's laws.

$$G = \frac{60}{96500} \cdot \frac{A}{W} \cdot I.T \qquad (1)$$

Where G : Weight separated from the anode (gm)

A : Atomic weight

W : Valency of anodic material

T : Machining time (min)

I : Machining current (Amp.)

For stainless steel 304, used in the present investigation, A/W= 27.65
Then the stock removal rate G is given by

$$G = 0.0171817.\ I \quad \text{gm/min.} \qquad (2)$$

or

$$G = 2.176 * I \quad mm^3/\text{min.} \qquad (3)$$

Since the volume removed during machining (G.t)

$G.t = \pi\ D.\ \delta R.L$

where, δR is the reduction in workpiece radius

L : Workpiece length

It follows that the reduction rate in workpiece radius is given by,

$$\frac{\delta R}{t} = \frac{2.176}{\pi D.L}$$

or $$\frac{D_i - D_f}{2} = 0.307.\ I \quad mm/min. \qquad (4)$$

where D_i : the initial workpiece diameter

D_f : Final workpiece diameter.

Fig. 6 shows the increase of linear removal rate with duty cycle. The intersection of the experimental lines, with the vertical axis, represents the linear removal rate caused due to mechanical scrubbing (MS). A rise, in duty cycle, up to 20 % does not contribute to metal removal by the electrolytic dissolution phase. Under such circumstantial conditions, the average working voltage is lower than the polarization level [8].

At greater duty cycles, the energy available becomes high. This, in turn, is associated with raised current density and, according to Faraday's laws, higher removal rates become explainable.

If the removal rate (M) is decomposed to that caused by the ECD phase and that due to mechanical scribbing action (MS), then

$$M = MS + ECD$$

The percentage contribution of each phase, in the overall removal process, can then be calculated as follows

$$ECDR = ECD/M \quad \% \quad \text{and} \quad MSR = MS/M \quad \%$$

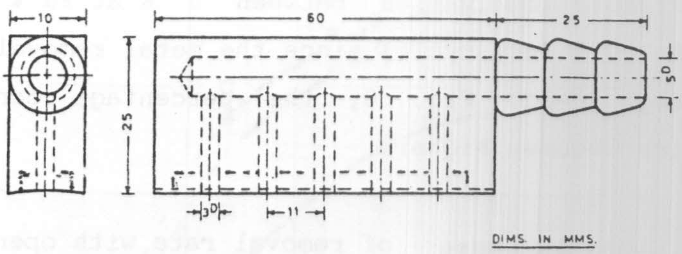


Fig. 5 Cathodic-tool shape and dimensions.

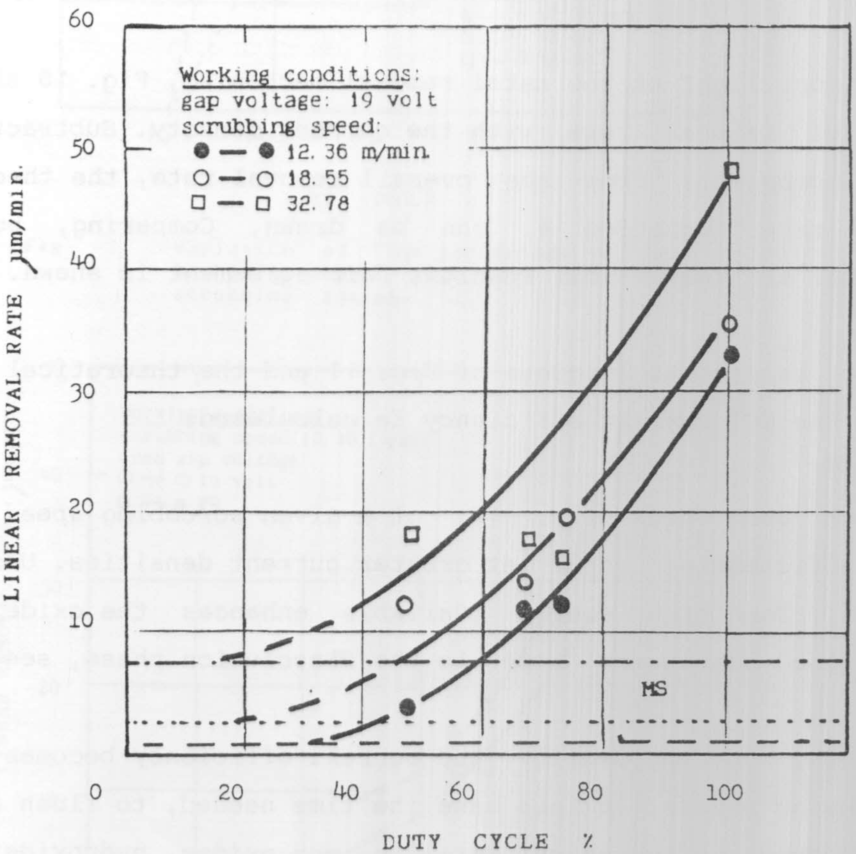


Fig. 6 Variation of linear removal rate with duty cycle and scrubbing speed.

As can be seen from Fig. 7, the percentage contribution of electrolytic dissolution varies between 0 % at 20 % duty cycle to about 95 % at 100 % duty cycle, since the metal removal rate M rises with scrubbing speed, Fig. 6, the percentage contribution of mechanical action becomes higher.

Fig. 8 shows the increase of removal rate with open gap voltage. Since, the scrubbing speed of 12.36 m/min. was mantained, the dissolution process becomes more intense, Fig. 9 with a consequent rise in overall removal rate.

To shed more light on the metal removal mechanism, Fig. 10 shows the increase of removal rate with the current density. Subtracting the chipping component, from the overall removal rate, the theoretical removal rate, equation 4, can be drawn. Comparing, both the experimental and theoretical results, fair agreement is shown.

Using the experimental points of Fig. 11 and the theoretical removal equation, the ECD current efficiency is calculated.

As can be seen from Fig. 12, at a given scrubbing speed, higher current efficiencies occur at greater current densities. Under such conditions. The high energy available enhances the oxide removal process with consequent rise in the dissolution phase, see Fig. 8.

At a given, current density, the current efficiency becomes high at low scrubbing speeds. In this case the time needed, to flush away the machining products,increases. Metallic ions oxides, hydroxides on the anode which form a concentration boundary layer as they carried away

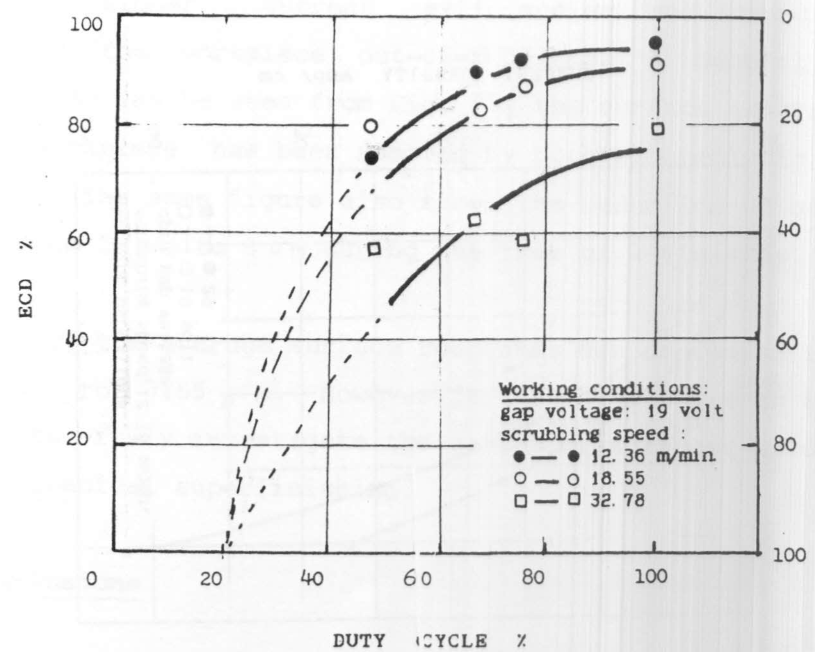


Fig. 7 Variation of the percentage of each machining phase with duty cycle and scrubbing speed.

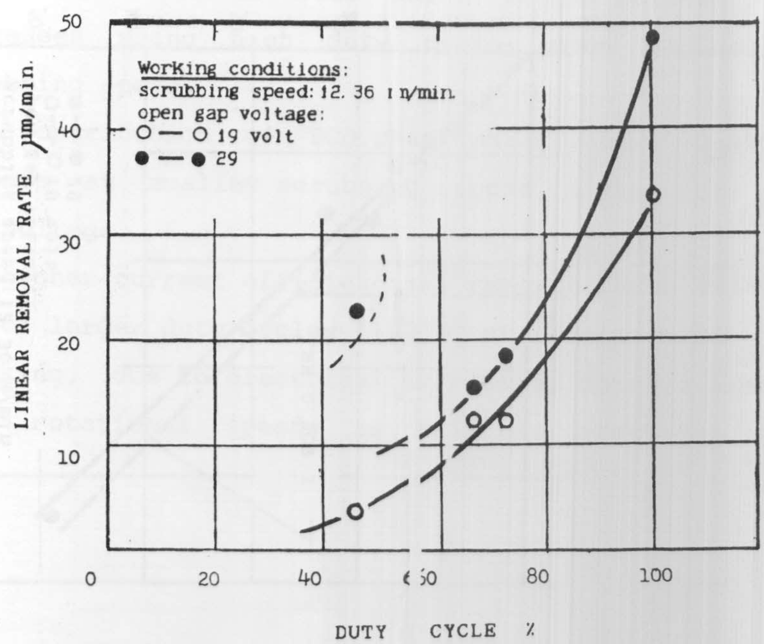


Fig. 8 Variation of linear removal rate with open gap voltage and duty cycle.

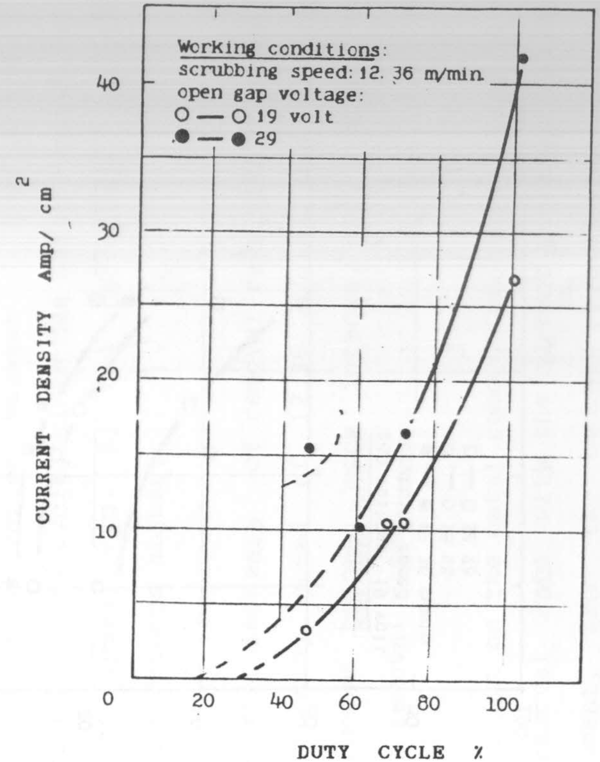


Fig. 9 Variation of current density with open gap voltage and duty cycle.

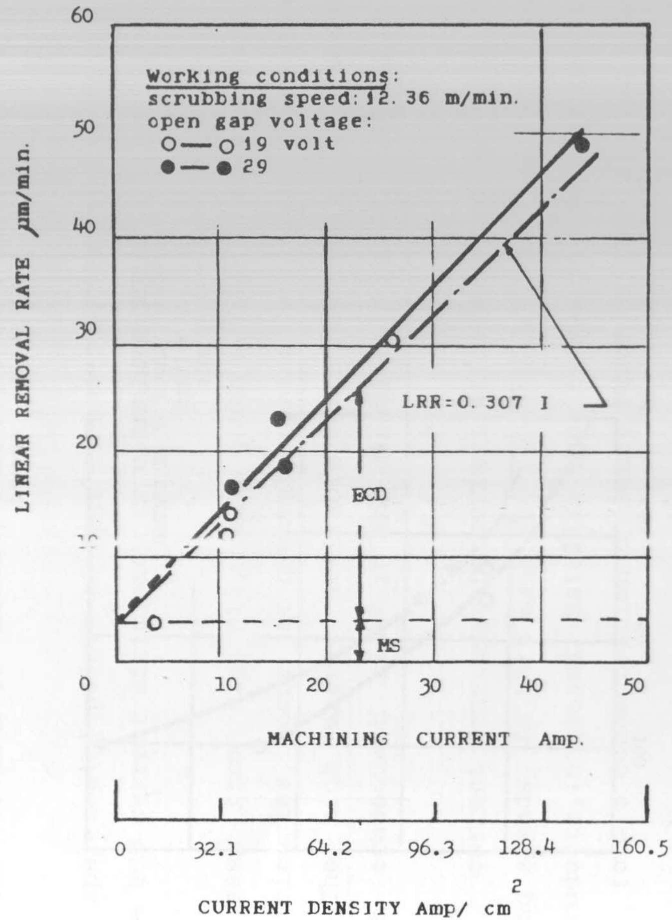


Fig 10 Variation of linear removal rate with current density at different gap voltage

by the electrolyte flow are removed from the machining gap thus, causing higher current efficiencies and dissolution ratios. Regarding the workpiece out-of-roundness a general improvement is noticed. As can be seen from Fig. 1:, the surface asperities of the a anodic workpiece has been removed by both electrolytic and mechanical actions. The same figure also shows the reduction of out-of-roundness error from 24 μm to 8 μm during the time of 2 minitues.

Similarly, the average surface roughness has decreased from 2.25 μm Ra (turned) to 0.65 μ m. However furither tests are to be conducted in order to fully investigate the nature of surfaces produced by pulsed electrochemical superfinishing.

4. Conclusions

Based on the experimental results, the following are concluded:

1. The linear removal rate which ranges between 5 and 50 μ m/min increases using high duty cycle, open gap voltage as well as scrubbing speed.
2. The contribution of ECD phase which ranges 60-95 % becomes more intense at smaller scrubbing speeds, higher duty cycles and open gap voltage.
3. For higher current efficiencies, removal rates and ECD ratio, the use of larger duty cycles (100 %) are recommended.
3. Sparking, due to electrical breakdown, becomes liable to occur at high rotational speeds as well as open gap voltages (29 V).

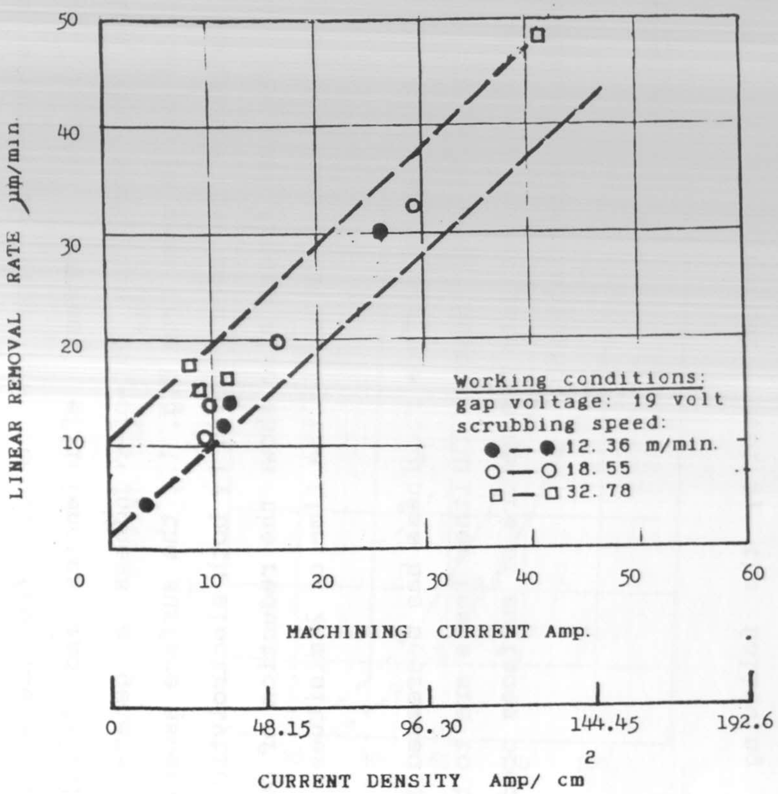


Fig. 11 Variation of linear removal rate with current density and scrubbing speed.

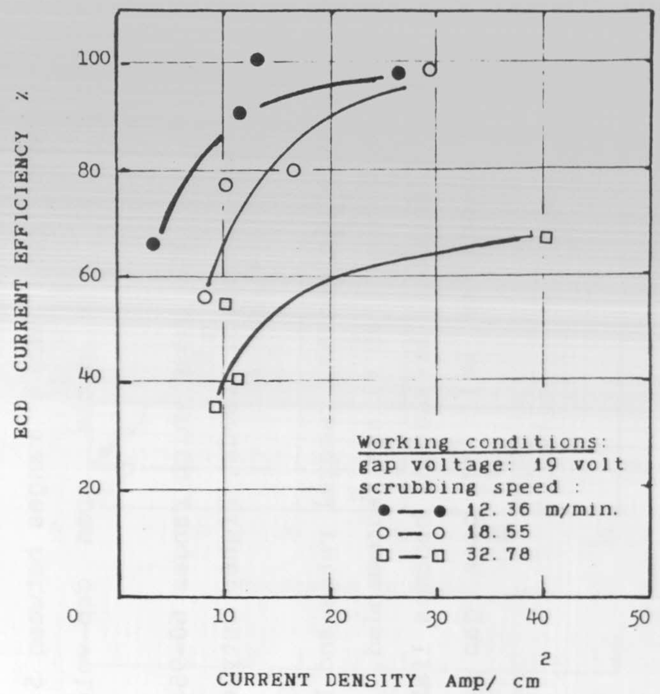
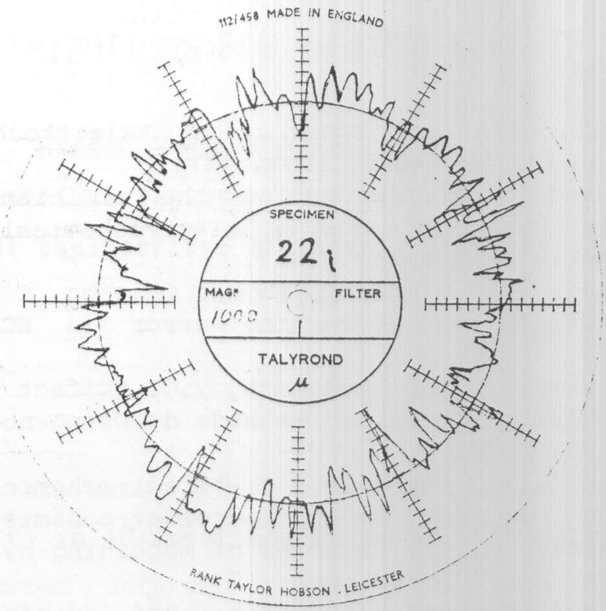
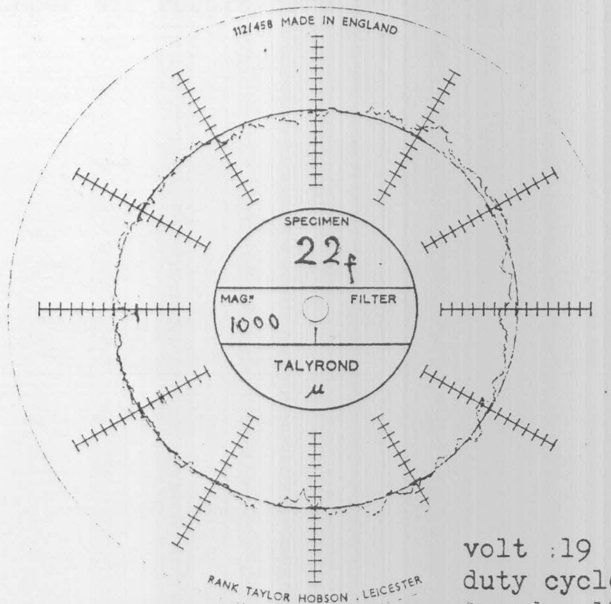


Fig. 12 Variation of ECD current efficiency with current density and scrubbing speed.



INITIAL O.R.(24 μm)



volt :19
duty cycle:67 %
speed : 18.55 m/min.

FINAL O.R.(8 μm)

Fig. 13 Out of roundness profiles.

5. References

[1] Randlett, E.A and Myron, P.E "Electrochemical honing" ASTME, Paper number MR68-815, 1968, 11P.

[2] El-Lawendy, M "Increasing the efficiency of superfinishing process by superimposing electrochemical effect" M.Sc. Thesis, Alexandria University, 1977.

[3] Guoqiang, W; Mianhong, W and Chiping, C "An investigation into the ability of correcting error in ECH" CIRP 35/1/1986, pp. 125-127.

[4] Kupfuswamy, G and Venkatesh, V.C. "Effect of a magnetic field on electrolytic grinding" Methods d' Using non traditionales proc., Paris V2, 1974.

[5] Datta, M and Landolt, D, "Electrochemical saw using pulsating voltage" Journal of applied electrochemistry 13 (1983) 795-802.

[6] Kaczmarek, J, "Principles of machining by cutting, abrasion and erosion" Peter Peregrince, 1976.

[7] Machinability data handbook, 3rd edition, Machinability Data center Vol 2, 1980.

[8] Youssef, H.A " Electrolytic superfinishing of sintered carbides Bulletin of the faculty of engineering, Alexandria University Vol X-1971, pp 209-231.