BENEFICIAL EFFECT OF SHAPING WITH TUBULAR CATHODE IN ELECTROCHEMICAL MACHINING PROCESSES

A. M. ABDEL MAHBOUD

ABSTRACT

Although ECM is one of the most widely used machining processes, it is felt that its capability has not been fully exploited due to difficulties encountered in tooling design. This paper proved the powerfullness of using a tubular cathode as a simple available tool which gives comparatively accurate results. Theoretical analysis based on a modified ECM theory was made for estimating the process variables. Comparison with experimental results yielded a good correlation. Moreover, preliminary tests were carried out for comparison between tubular and single pointed cathodes.

INTRODUCTION

ECM with tubular cathode is not popular (1-2), inspite of its advantages over other ECM tools. The use of tubular cathodes offer the following advantages,

i) Absence of flow problems due to the presence of initial hole.
ii) Small power consumptions.
iii) Manufacturing complex shapes with high degrees of accuracy.
iv) Simple, effective, available and economic ECM tools.
v) Easy to be replaceable.

With tubular cathode any forms of straight, curved or spiral slots can be obtained by controlling the relative motion between workpiece and cathode. Fig. 1 illustrates straight slots with different forms depending on tubular tip form shown in Fig. 2. Also serrated or sprocket wheels can be obtained. However, little workers investigated such concept. Kargin (1) examined the efficiency of tubular cathodes of 5 mm. external diameter, wall thickness of 0.5 mm. and 1 mm., flushing diameter spaced at 2 mm. intervals for formation of semi-circular, rectangular and triangular surfaces. Streeniya (2) used tubular cathode with three longitudinal slots in their wall for making three-dimensional machining. Thus, Previous

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work is limited. Therefor, the need was felt toward comprehensive theoretical and experimental investigation of shaping with tubular cathodes.

This paper reports the experimental and theoretical findings about the anode profile obtained during ECM with tubular cathodes to prove the capacility of such process. Moreover, experimental and analytical comparative study with pointed cathodes was made.

THEORETICAL ANALYSIS

In the present work slots with both circular tubular and single pointed cathodes were considered as indicated in Fig. 3. Kawafune et al. (3) used the general side gap equation as follows,

$$Y_s = \sqrt{\nu^2 Y_e^2 + 2bY_e}$$

Where,

Y_e is the equilibrium gap and can be calculated by,

$$Y_e = \xi \frac{(v - \Delta v)\ \varepsilon\ k}{F \rho m \ v_f}$$

ν is a gap correction factor which takes different values as summarized by Ebeid (4).

v_f electrode feed rate mm/min.

Δv is the over potential $v = 2.3$ volt (5).

ξ current efficiency (100%) (6,7,8).

The slot width can be defined by,

$$w = d + 2Y_s \qquad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (2)$$

Accurate prediction of the goemetry of a generated slot surface is possible when accurate estimates for the current density at different points are available. Therefore, an idealized electrolyte resistance model is proposed (9).

The individual electrolyte resistance can be computed using equation (3).

$$R_i = \frac{Y_i}{A_i\ K} \qquad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3)$$

In the present case the total electrolyte resistances are,

$$\frac{1}{R_{tot}} = \frac{1}{R_I} + \frac{1}{R_{II}} + \frac{1}{R_F} \qquad \ldots \ldots \ldots \ldots \ldots \quad (4)$$

$$\frac{1}{R_{tot}} = K \frac{A_I Y_{II} Y_F + 2A_{II} Y_I Y_F + A_F Y_I Y_{II}}{Y_I Y_{II} Y_F} \qquad \ldots \ldots \quad (4)$$

where,

$Y_I = 1.5 \ Y_e$

. . .

$$Y_{II} = Y_e + 0.5\ Y_s$$

$$A_i = \alpha_i\ b\ (r_o + Y_i)$$

Power consumption and current density on cathode and anode surfaces can be estimated as follow,

$$I = \frac{v - \Delta v}{R_{tot}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

$$J_c = \frac{I}{\pi r_o b + \pi/4\ (d_o^2 - d_i^2)} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

$$J_a = \frac{I}{[\alpha_1\ (r_o + Y_I) + 2\ \alpha_2\ (r_o + Y_{II})]B} \quad \ldots \quad \ldots \quad (7)$$

The metal removal rate is a function of the chemical composition and is at 100% current efficiency directly proportional to the electrolysing current. The removal rate can be calculated from Faraday's law by the following equation,

$$VR = \frac{I}{F} \times \frac{\text{Atomic Weight}}{\text{Valence}} \times \frac{1}{\text{Density}} \times \frac{1}{\text{Area}} \quad \ldots \quad \ldots \quad (8)$$

For both circular and single pointed tools volumetric metal removal rate can be defined in the general form,

$$VR = \frac{\varepsilon}{F\ \rho_m} \cdot J\ W\ B \qquad mm^3/min \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

For other tubular cathode tips, the corresponding areas are indicated in Fig. 2.

Using Equations numbers 1 to 9 electrolysing current, current desity, metal removal rate, etc. in interelectrode gap could be computed and then anode profile during machining with tubular and pointed cathode could be obtained.

EXPERIMENTAL WORK

In order to test the validity of ECM with tubular and pointed cathode, a conventional drilling machine was adopted to meet such experimental requirments as shown in Fig. 4. (Plate 1).
Test specimens were made from mild steel of 23 mm. diameter. Two types of flow arrangements were designed and developed as indicated in Fig. 5. Tubular cathodes with external diameters of 5.5 and 2.5 mm. and wall thicknesses of 0.35 and 0.425 mm. respectively were used. Moreover, two types of brass pointed cathodes of 1.65 and 3 mm. diameter were employed. All tests were carried out with Sodium Chloride Solution of 0.015 $\Omega^{-1}mm^{-1}$ conductivity. The resulting workpiece surfaces were measured by a projector of 10 : 1 magnification.

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RESULTS AND DISCUSSION

Analytical and experimental study of shaping with tubular cathodes could help in better understanding of such new concept. Such information are useful for better design of simple, economic and effective ECM toolings. Moreover, optimum conditions for manufacturing complex shapes such as spiral slots, serrated and sprocket wheels can be determined.

Generation of solt surfaces that are straight, flat and parallel to the feed direction is governed by Equation (1). This equation would yield accurate results only when simultaneous effects of different parameters are accounted for. Several methods of side surface generation and computational techniques have been reported by Narayakkara and Larsson(10)

In Fig. 6. experimental results are compared with analytically predicted values based on a modified ECM theory proposed herein. For tubular cathods gap correction factor was found to be dependent on tubular wall thickness and external diameter as the experimental results revealed. The gap correction factor amounted to 1.67 for tubular wall thickness of 0.425 mm. and 2.5 mm. external diameter, thus, equation (1) is valid for slot width estimation.

On the other hand, equation (1) reveals a fractional gap correction factor for tubular cathodes of 0.35 mm. wall thickness and 5.5 mm. external diameter. This correction factor value is not realistic. Therefore, it is suitable to assume the side gap to be,

$$Y_s = \nu_1 Y_e \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

For that case, experimental results yielded ν_1 to be 1.4. In the case of single pointed tools having sizes ranging from 1.65 to 3 mm. diameter the gap correction factor was independent on point size and amounted to 1.1. Thus, equation(10) is valid to estimate slot width as shown in Fig. 7.

Current per unit slot depth and current density distribution are plotted in Figs. 8 and 9. Both values were found to increase with the increase of gap voltage.

The volumetric metal removal rate is governed by permissible current density (Fig. 8) in both forntal and side cathode surface were showed in Fig. (10). It is noted that the volumetric removal rate was found to increase with the increase of volt/feed rate ratio. The results indicated a difference between experimental and theoretical values. This difference could be accounted for by the current efficiency. The dependance of current efficiency on current density, electrolyte type (passive of non passive), electrolyte temperature, electrolyte concentration, flow rate of the electrolyte (velocity) and anodic material were summarized in Fig. (11). Whereas, the gap voltage has no influence in current efficiency (6).

In making the calculations, the assumption was made that the iron dissolves in a 2 valent (F_e 2+) process and departure from a 100% efficient reaction may be due to departure from this assumption, i.e. that some iron dissolves to Fe^{3+} and/or existance of alternative anodic processes.

Results as shown in Fig. 6 — 10 prove the applicability of such concepts in making straight slots with high degrees of accuracy and the validity of a modified ECM theory to predict all process variables.

Discrepancey between experimental and analytical results is also reflected to erros encountered in experimental results and difficulties in controlling working conditions, especially rise in electrolyte temperature.

It is evident by comparison of Fig. 6 – 10 that no significant changes in both processes behaviour which could be stated that both processes are to be similiar in spite of each process has its own machining problems. However, more experimental and analytical work is currently in progress towards improving performance of each process. It is also recommended that for still better accuracy tubular cathodes should be employed due to inherent flow facilities. Furthermore, these new concept are highly promising for best possible precision in ECM.

CONCLUSIONS

1. Tubular cathode proves its powerfullness as a simple, economic and effective ECM tool due to inherent flow facilities which is not available in single cathodes.
2. Modified ECM techniques proved to be suitable as a simple approach to analyze and predict process variables for both cases.
3. Feed rates are limited due to small current carrying capacity on thin tubular walls or point size.
4. Future investigation can be devoted to the utilization of tubular and single cathodes for manufacturing complex shapes such spiral grooves, sprockets and serrated wheels.

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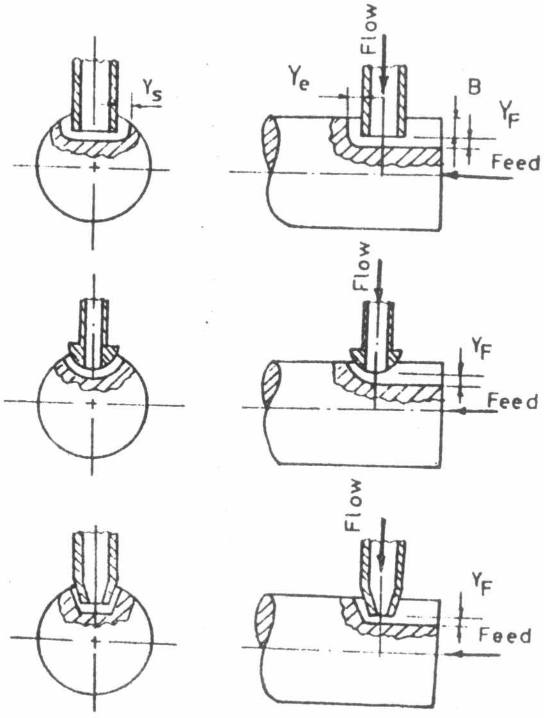


Fig.(1) Straight slots with different forms

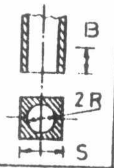
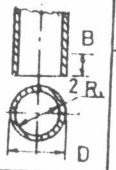
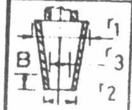
Tip form	Working area
	square $\frac{SB}{2}+(S^2-\pi R^2)$
	cylindrical $\frac{\pi DB}{2}+\frac{\pi}{4}(D^2-4R^2)$
	conical $\frac{\pi}{2}(r_1+r_2)B+\pi(r_2^2-r_3^2)$
	spherical $\frac{\pi R^2}{2}$

Fig.(2) Tubular tip forms

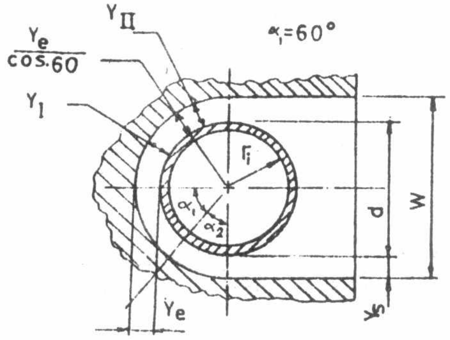


Fig.(3) Tubular model

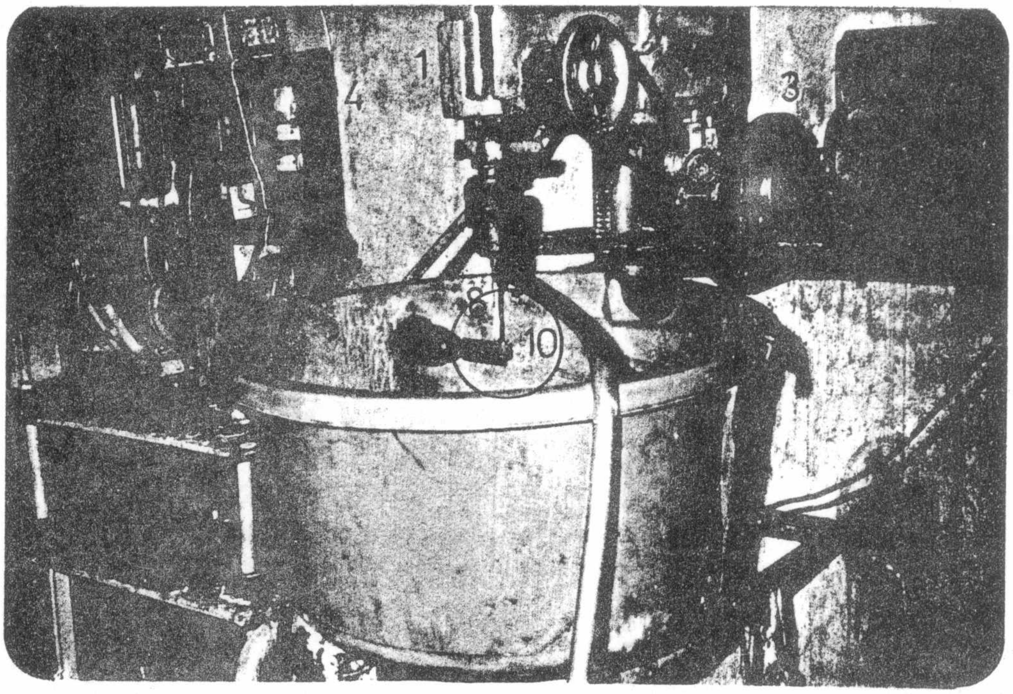


PLATE (1)

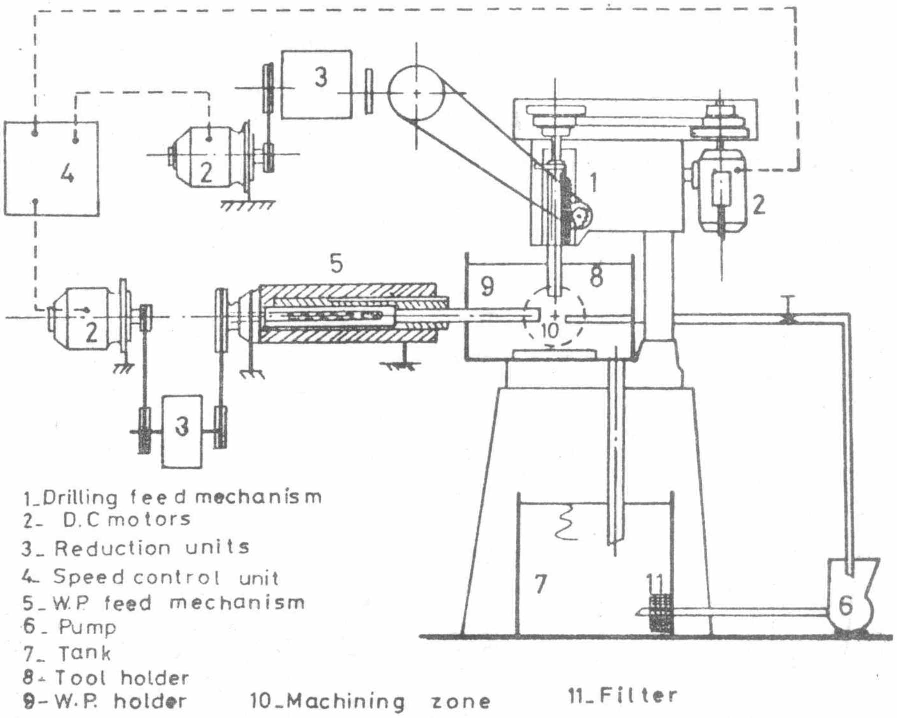


Fig.(4) Layout of experimental ECM set_up

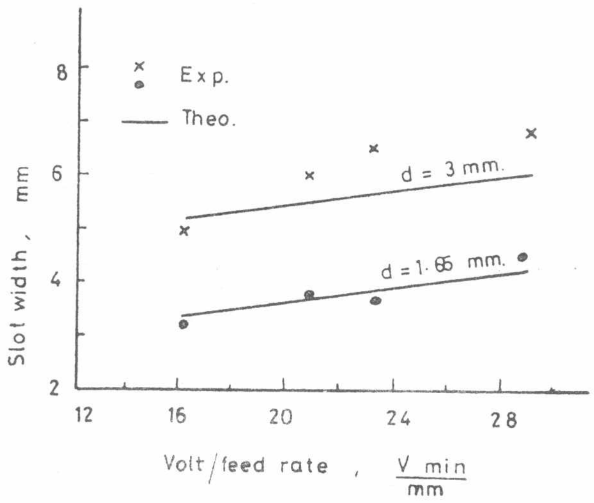


Fig.(7) Comparison between experimental and theoretical results for single pointed tools

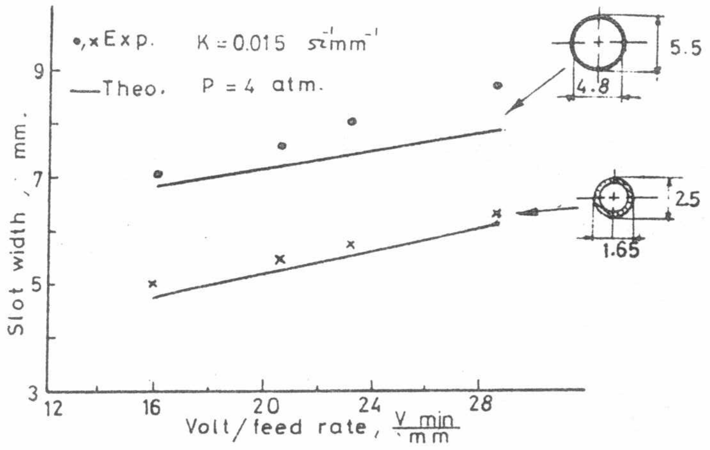
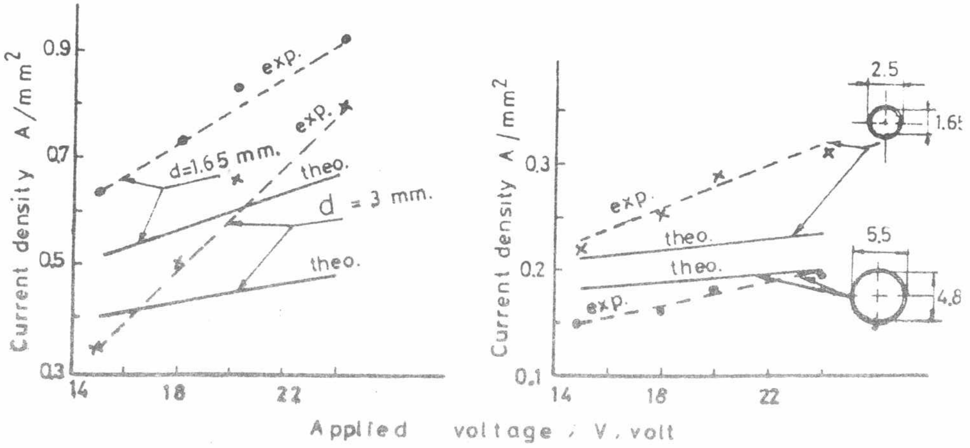


Fig.(6) Comparison between experimental and theoretical results for tubular tools



(a) Single pointed tools (b) Tubular tools

Fig.(8) Effect of applied voltage on current density

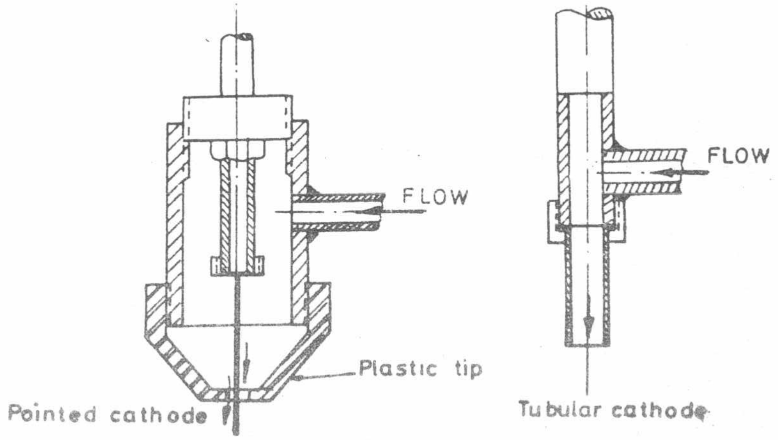


Fig.(5) Tool holder and flow arrangement

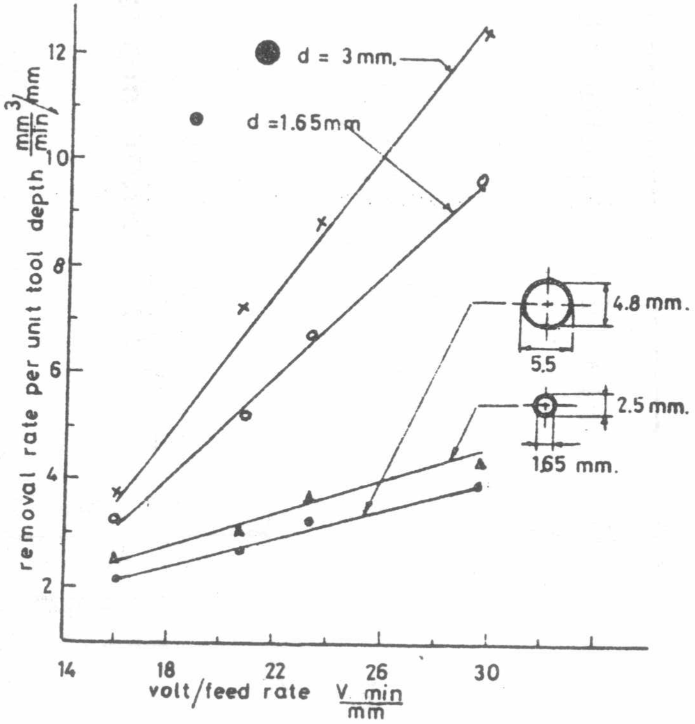


Fig.(10) Effect of volt/ feed rate on removal rate

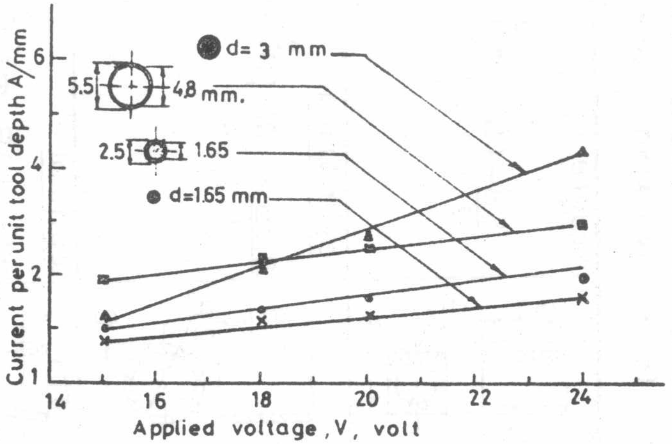


Fig.(9) Effect of applied voltage on consumed current

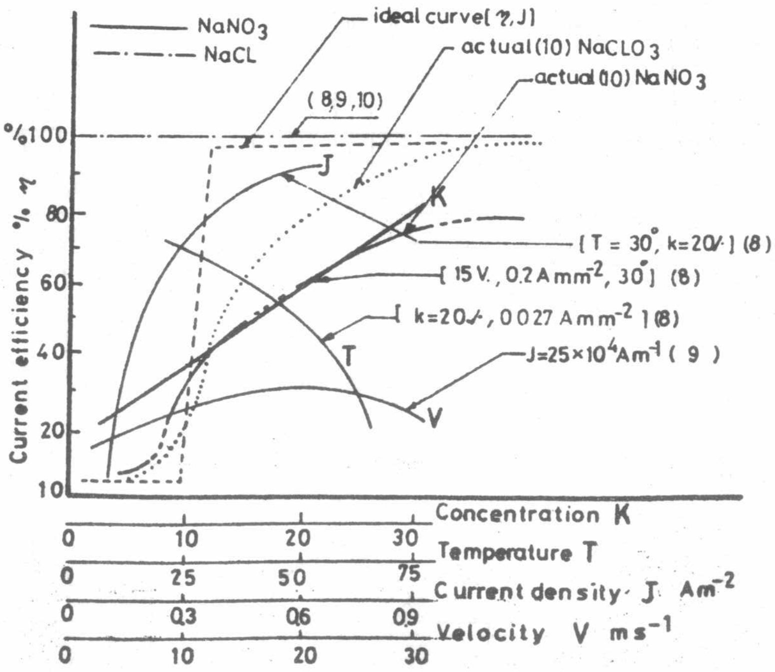
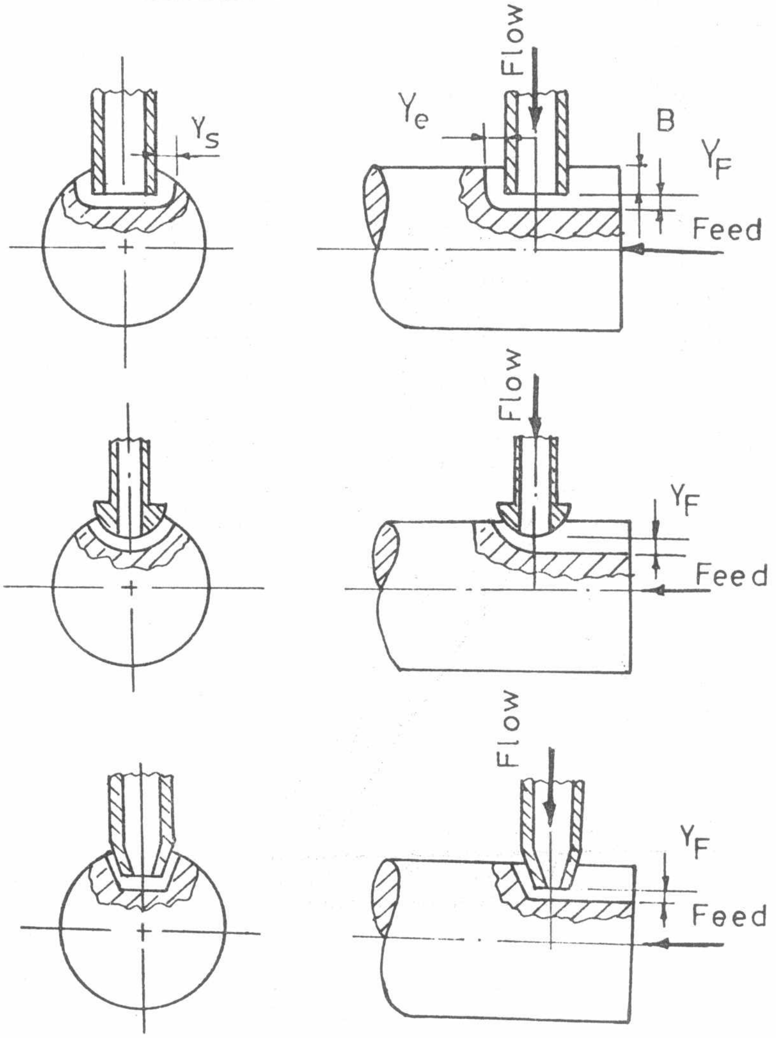


Fig.(11) General trends of factors affacting on current efficiency



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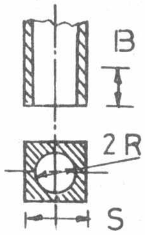
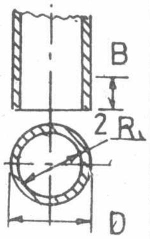
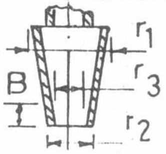
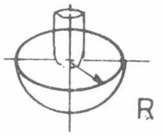
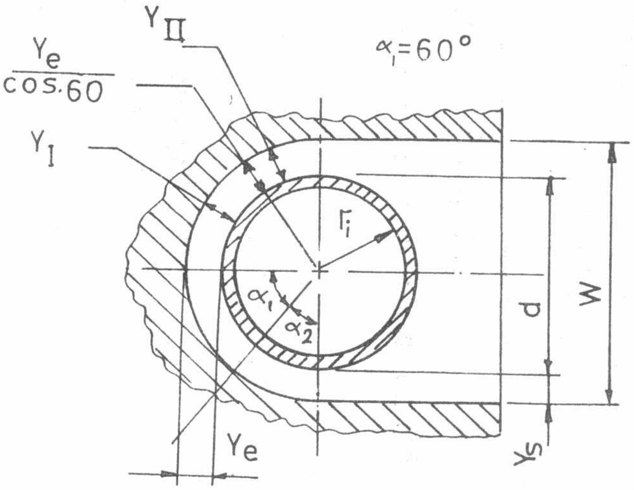
	square $\frac{SB}{2}+(S^2-\pi R^2)$
	cylindrical $\frac{\pi DB}{2}+\frac{\pi}{4}(D^2-4R^2)$
	conical $\frac{\pi}{2}(r_1+r_2)B+\pi(r_2^2-r_3^2)$
	spherical $\frac{\pi R^2}{2}$

Fig.(2) Tubular tip forms



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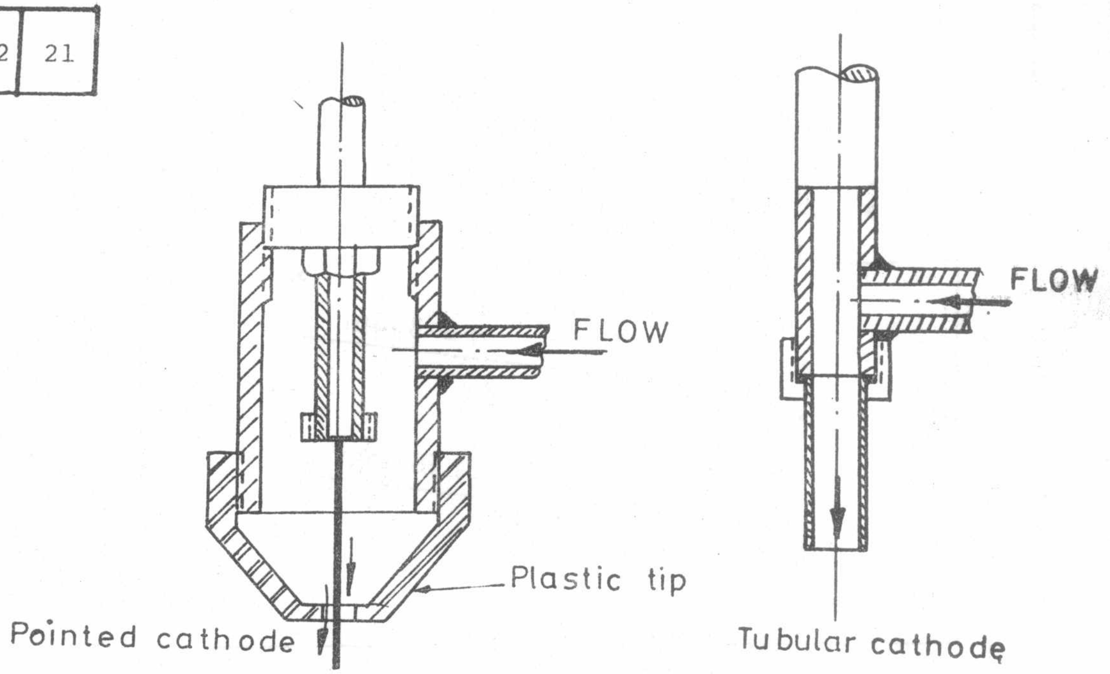


Fig.(5) Tool holder and flow arrangement

PLATE (2)

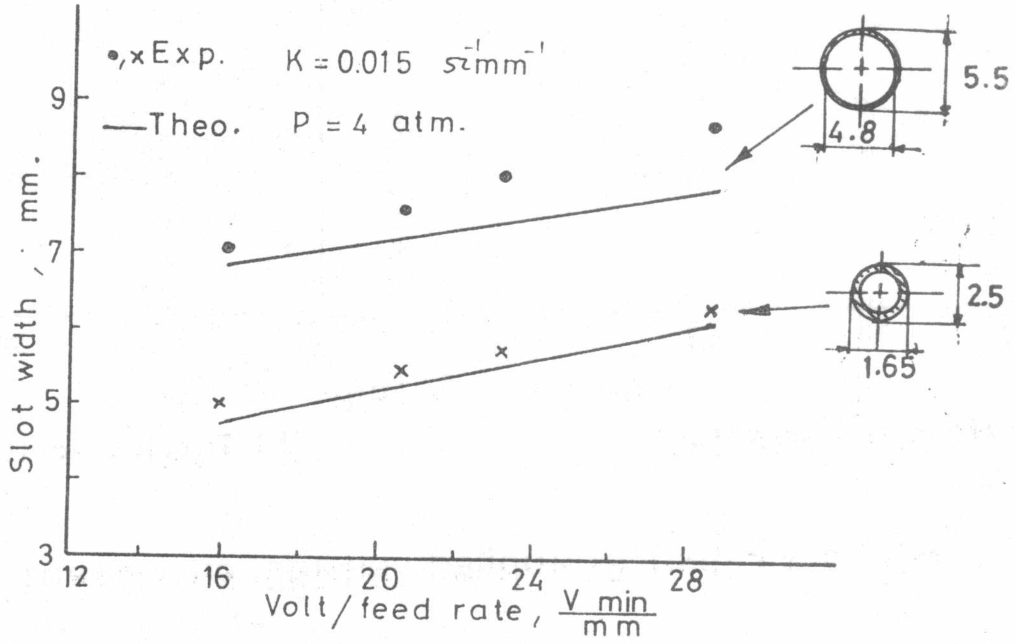


Fig.(6) Comparison between experimental and theoretical results for tubular tools

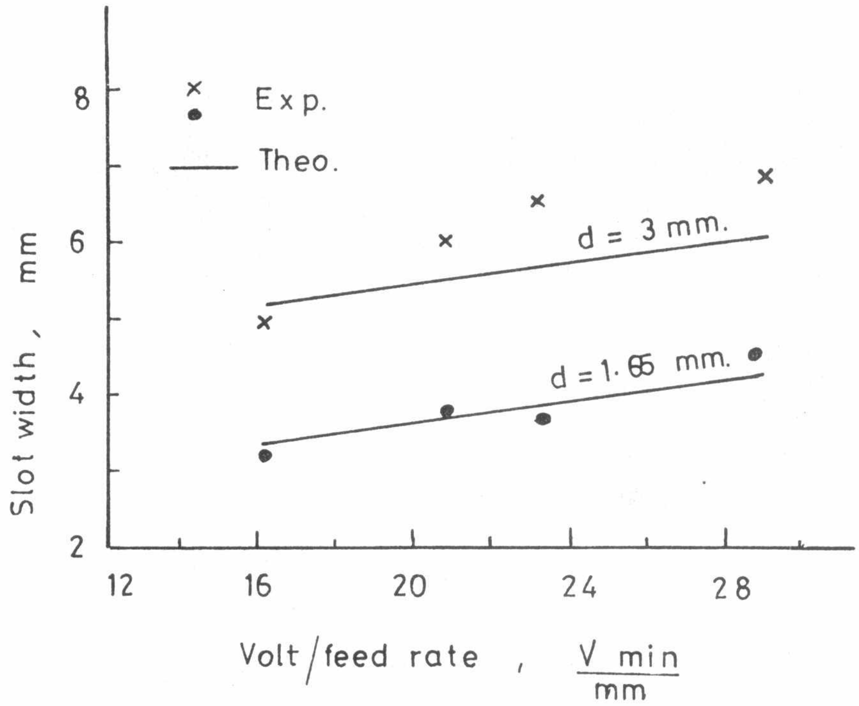
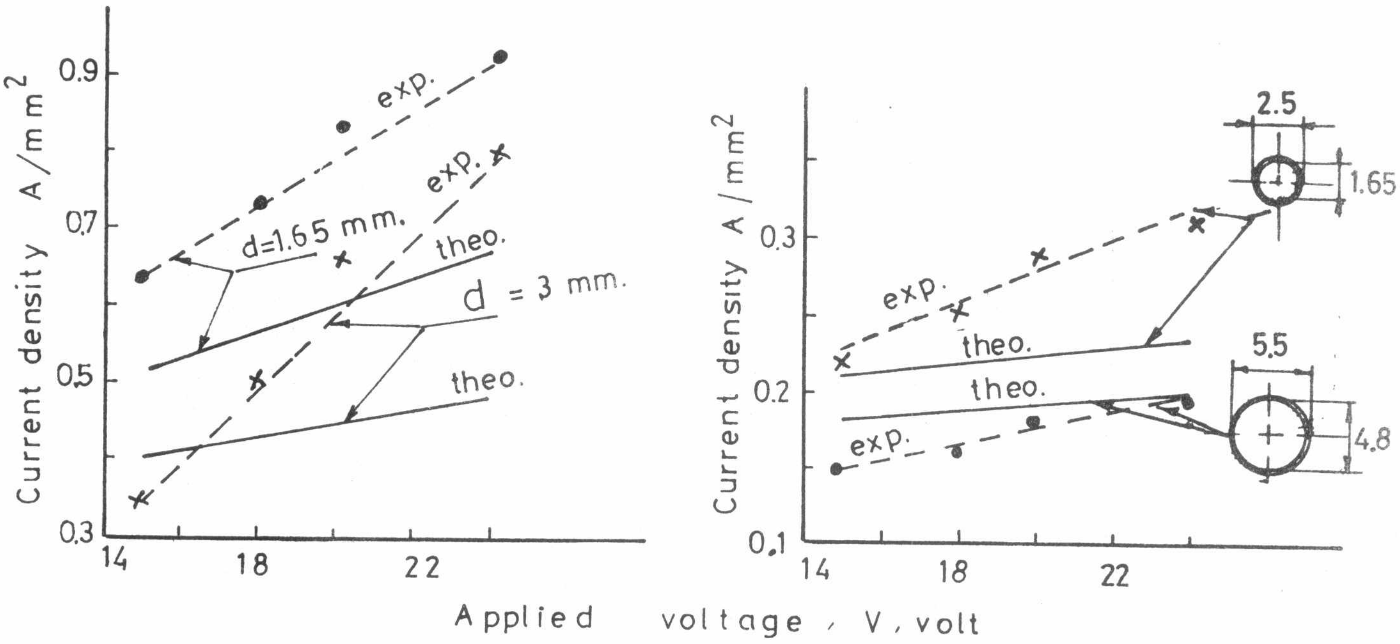


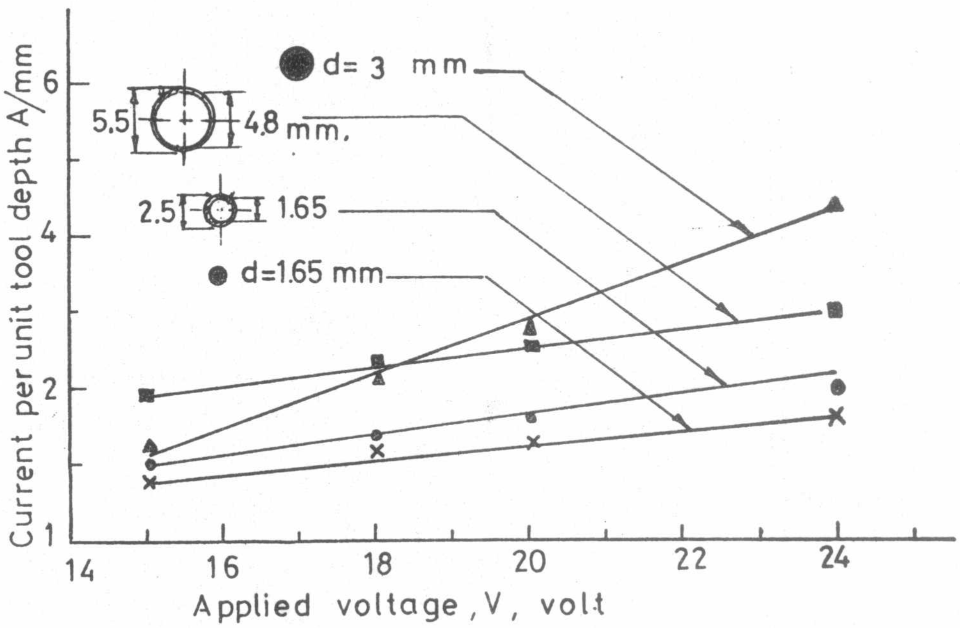
Fig.(7) Comparison between experimental and theoretical results for single pointed tools



(a) Single pointed tools

(b) Tubular tools

Fig.(8) Effect of applied voltage on current density



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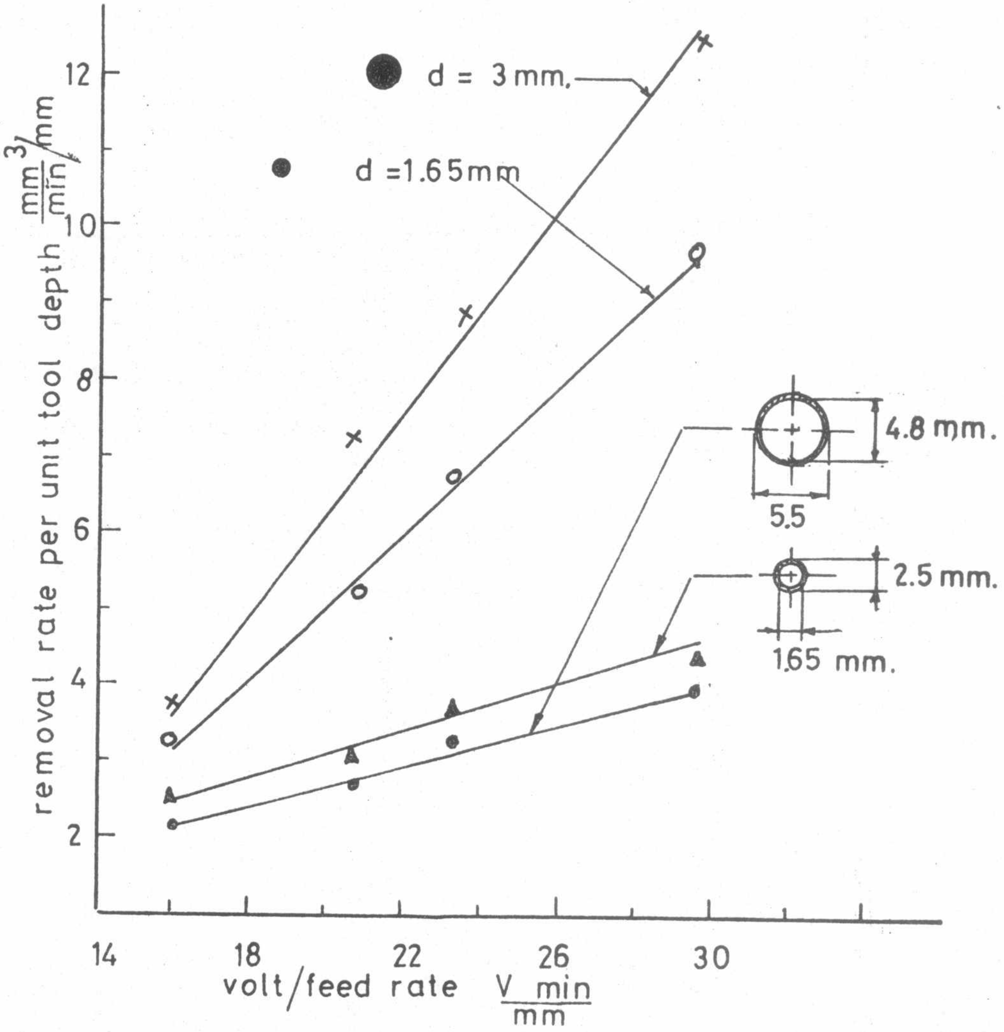
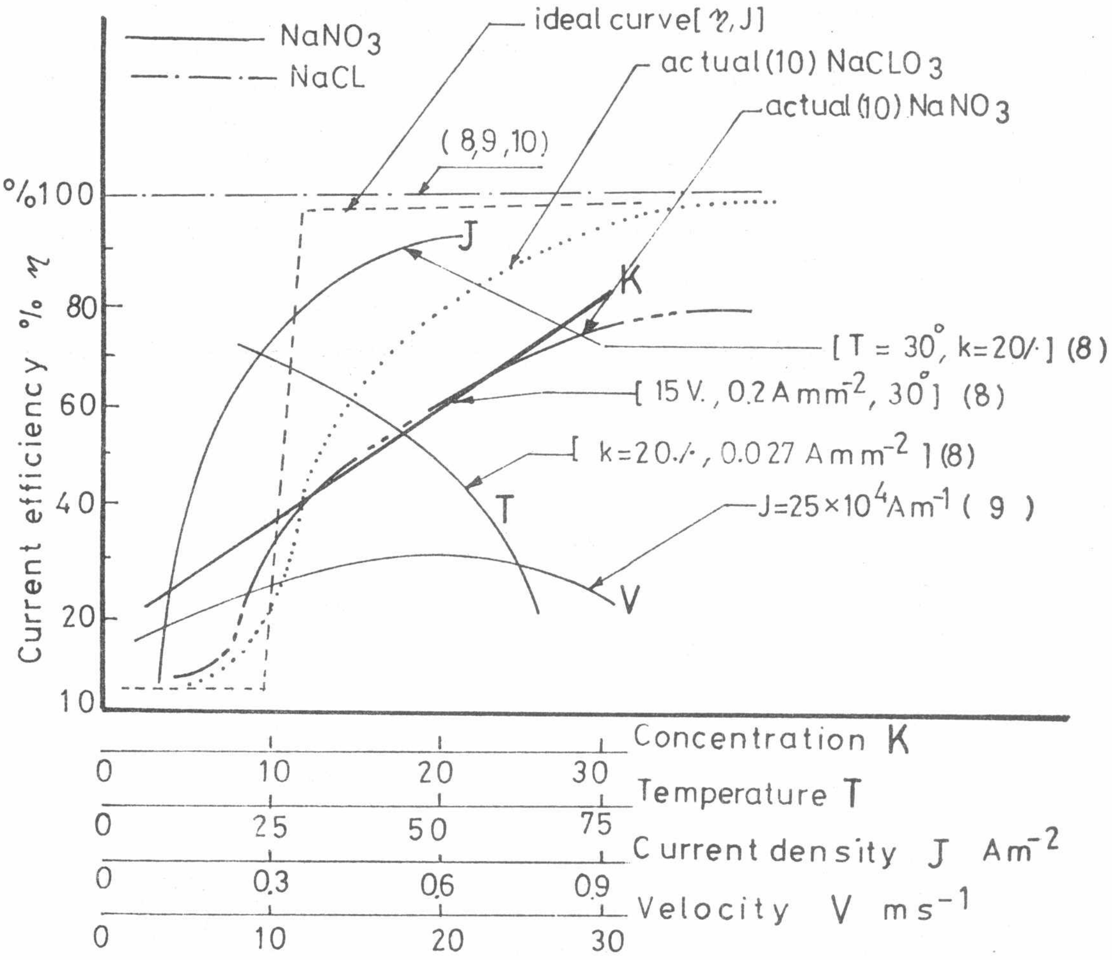


Fig.(10) Effect of volt / feed rate on removal rate



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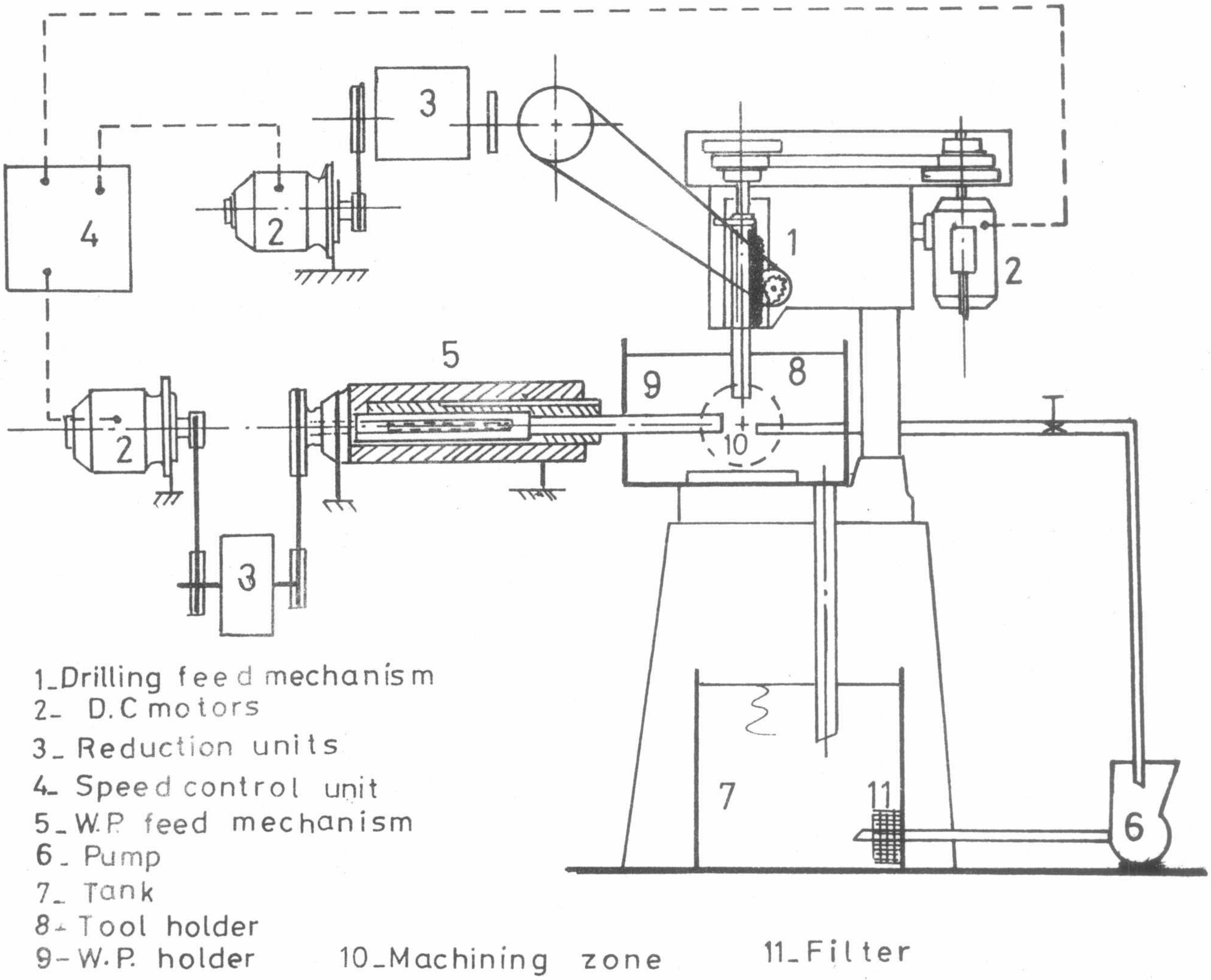

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