IMPROVED PERFORMANCE IN MODERN MACHINING PROCESSES

(A REVIEW)

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ABSTRACT

In an era of rapid and continuous changes in technological, economical and social conditions, demands are constantly being made towards increased performance in both productivity and surface quality. The present work reviews the highlights of various trends to attain to an ever-increasing degree this goal. The two main trends to attain such a goal of improved performance are the optimization of process parameters and the modification of tool design with improved consitions for EDM dielectric, ECM electrolyte and USM slurry systems. The objective is to furnish the production engineers with recommendations in the form of empirical approaches, special tool deign or improved flow system to enable him reach a reasonable solution towards improved performance.

INTRODUCTION

In an era of rapid and continuous advances in engineering materials and components design together with the need for increased performance, modern industry has had to adjust to such demands through the development of new machining techniques. Products with intricate and complex shapes from hard or "impossible-to-machine" materials with conventional mechanical processes can now be efficiently handled with EDM, ECM and USM.

Working of metals by EDM involves the removal of surface particles in the form of craters with complex geometry. The finish of a surface worked with electro-sparking is thus determined by the geometrical dimensions, mutual overlapping and interference of such craters.

In ECM, metal removal takes place by ionic dissolution and it is a function of various electrochemical and hydrodynamic conditions in the inter-elctrode gap.

In USM, disintegration of metal can be attributed mainly to micro cracks and chipping by abrasive particles provoked either by direct impact or cavitational shock waves.

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The object of the present work is to recommend solution for optimizing the process parameters and possibilities for modifying tool design. Increasing performance through improving flow conditions for EDM dielectric, ECM electrolyte and USM slurry systems is presented.

OPTIMIZATION OF PROCESS PARAMETERS

With EDM, the productivity problem lies in how to reach the optimum working conditions i.e. those of highest removal rates under minimum tool wear conditions and acceptable surface finishes. In order to achieve consistent metal removal rates with high productivities it is necessary to optimize the process.

Cornelissen, Snoeys and Kruth [1] defined the performance of an EDM system in a three dimensional diagram (technological surface) representing the removal rate, surface finish and relative electrode wear. Despite the fact that the technological surface could be used for comparing EDM systems, it lacks the advantage of being used by an EDM operator.

It would be more beneficial for the production engineer to define an equation in the form of roughness as a function of the process parameters. Ghabrial and Ebeid [2] attempted to analyse and define a simple relationship betwen surface roughness and energy spent in an EDM gap. The theoretical assumption on which the work was based has been verified experimentally using different spark-erosion machines and various tool and work piece materials. The results of previous investigators were plotted to find out the variation of the factor n in the relation

$$CLA = n \cdot U^{2/3} \cdot C^{1/3} \qquad (1)$$

where U and C are the gap breakdown voltage and capacity of the condenser respectively. The results in Fig.1 show that under each set of working parameters, n assumes practically constant value for a wide range of surface roughnesses. In practice the value of n can be assessed by few preliminary experiments under the prevailing working parameters regarding work piece-tool materials and dielectric system.

By correct control of the ECM system we can attain maximum metal removal rates with high dimensional shape accuracies under acceptable surface finishes. Four effects may occur within the electrolyte which limit the feed rate namely, boiling, choking, sparking and cavitation. The ECM characteristic curve introduced by Thorpe, Zerkle and Jollis [3] combines both the choke and boiling limits, thus giving a safe working region. This could be applied practicaly by giving the minimum flow rates to be used with various feed rates.

Sparking is particularly troublesome when high feed rates and low voltages are used specially with passivating electrolytes. Ebeid, Baxter and Larsson [4] studied the effect of sparking on tool damage under various combinations of voltages, feed rates and back pressures. The results showed a strong positive correlation between sparking rate and feed rate; a typical example of which is shown in Fig.2. For cheap simply designed tools and expensive hourly rates of electrochemical machines it would be more economic to accept low sparking rates and work under high feed rates. On the other hand with complicated designs of tool dies it would be more advantageous to work at low feed rates to avoid tool damage.

The voltage/feed rate ratio has been proposed by Ebeid [5] as a main parameter in controlling and optimizing the ECM process. Results of the voltage/feed rate ratio in controlling radial overcut is shown in Figs.3 and 4. Both curves show ratios ranging from 4 to 20 v/mm/min. Fig.3 shows the effect of the voltage/feed rate ratio on the ratio between the side gap and the equilibrium gap in cae of drilling using an insulated tool. Whereas, Fig.4 shows the variation of overcut with the voltage/feed rate ratio in the case of drilling under two different cell back pressures. Thus the voltage/feed rate ratio can be beneficially used in controlling component sizing and in limiting sparking.

The direct effect of tool feed rate on the width of cut for the case of ECM wire cutting [6] and on the side gap for the case of broaching [7] is shown in Figs.5 and 6 respectively. Both relations indicate that an increase in the feed rate results in a remarkable decrease in the working gap.

USM has solved the problem of machining hard and brittle materials whether conducting or non-conducting. Its performance proved to be acceptable for machining glass, quartz, diamond, ceramics, hard and heat-resistant alloys, semi-conducting materials and porous materials like graphite.

Smith [8] stated that frequency was found to be by far the most important parameter with amplitude second. Their influence on the removal rate was 2 to 3 times that of either static load or grain size. Kazantsev [9] stated that the removal rate is proportional to frequency, while the non-linear frequency dependence is due to the variation of the abrasive concentration and removal rate in the working zone.

An empirical relation for the removal rate, V, has been suggested [10] by introducing an "USM Factor C" and allocating a value for the power exponent of the amplitude, A, as follows:

$$V = C \cdot A^{x} \cdot P_{st} \qquad (2)$$

V: removal rate, mm/min,
A: amplitude, μm
P_{st}: static pressure, kg/sq.cm,
x: exponent,

C: ultrasonic machining factor.
C and x vary for different materials and can be defined by running few trial tests under any set of prevailing working conditions.

Previous analysis carried out by Markov [11] on the experimental results of ENIMS yielded a wide range for the power exponent relating the removal rate for glass with amplitude for different static pressures. The values ranged from 0.5 to 1.7 and were given in a form of table. Such information cannot evidently be of much practical value to assess the productivity under certain prevailing working conditions .

The same results have been carefully analysed [10] and an adequate definition of the power exponent has ben achieved as illustrated in Fig.7. Its value for the ENIMS test conditions was found to be 1.2 for the lower range of amplitude up to 20 μm (such range may be approppriate to finish machining). For the higher range of amplitude from 20 to 45 μm, the power exponent asumed a value of 0.5 (such higher range may be preferred for rough machining).

MODIFIED TOOL DESIGN

a. Special tools

Despite the fact that non-conventional machining processes prove to be adequate in different fields, still they face certain problems. Unless working parameters and tool design are to be correctly chosen, difficulties arising with such processes can hinder their action and restrict their applications. The effect of tool design on the drilling performance as applied to EDM is shown in Fig.8. In order to improve flushing conditions and to minimize the hole overcut, the use of button electrodes have been introduced. Higher penetration rates have been achieved with smaller overcuts and improved performance. Still the same result was observed when a through hole was drilled inside the tool. Solid button electrodes decrease the radial overcut but could still show slight signs of swarf coagulation at the bottom of the drilled hole [12] .

The results of a button tool with successive lands and a through hole are also shown in Fig. 8. This tool shows nearly the same penetration rate as the tool with one land. However, the multi-land tool showed a greater overcut than the one-land tool. Multi-land tools do not show any advantage over single land tools unless when they are used for roughing and finishing operations consecutively.

With the case of ECM, broaching tools proved to be beneficial in increasing feed rates [13] , improving flushing conditions and attaining higher conformity between tool and workpiece for both triangular and square cross-sectioned tools [7] .

Gauging-land tools and grooved tools proved to be successful with USM [14] . Fig.9. shows the effect of decreasing the land on improving the penetration rate. The removal rate amounted to about 270 cu.mm/min at a penetration rate of 0.7 mm/min for the 5 mm land tool; while it was 230 cu.mm/min at a speed of 0.6 mm/min for the 10 mm land tool. Provision of

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the land with helical grooves resulted in a significant improvement and the removal rate amounted to 380 cu.mm/min at a speed of about 1.0 mm/min. It is to be noted that the improvement in the removal rate was combined with a constant speed during tool penetration. This is due to improved slurry circulation leading to continuous renewal of abrasive.

b. Orbital Motion

To machine under optimum working conditions in EDM and USM, machining has sometimes to be carried out using more than one tool for roughing and finishing operations. However, this aim can be achieved through only one tool by introducing orbital motion. With orbital motion is meant that any straight line on the tool electrode is always allowed to move parallel to itself being in the same plane.

The drop in overcut as speed increases [15] is an indication for better evacuation imparted by orbital motion. As the orbital head turns, the tool electrode causes a pumping effect within the inter-electrode distance at any cross-sectional plane. This action reduces the formation of electric bridges, which are a source of increasing overcut., In addition to the tool central flushing hole, orbital motion aids flushing causing the eroded particles to leave the erosion zone in the form of a swirl action. Thus the increasing difficulty for the eroded particles to leave the erosion zone as hole depth increases is found no more. The increase of the turning speed raises the kinetic energy of the eroded particles enhancing them greater liability to escape from the erosion zone thus reducing overcut.

For the case of USM, results showed [14] that as eccentricity was increased, removal rate was increased depending on the tool from and depth of penetration. Fig.10 shows the variation in the removal rate with the eccentricity when machining by a cylindrical tool. The curves clearly show the beneficial effect of orbital motion in increasing the removal rates. The improvement can be explained by the induced favourable slurry circulation, the continuous renewal of abrasive which is the decisive factor in material disintegration.

By controlling eccentricity and turning speed, the same tool can be used for obtaining various component shapes under the required dimensional tolerances. Or in an another manner the same tool can be used for roughing snd finishing operations, thus reducing cost and tool manufacturing processes.

c. Wire-Shaped Tools

Wire-shaped tools proved great success when machining by electrochemical [6] or electric spark actions. The process of wire cutting is a cost-effective industrial potential in dealing with the difficult-to-cut materials. This process resolves into either slitting or component profiling.

Previous tests [6] showed the beneficial influence of increased feed rates regarding the desirable reduced width of cut for both rectangular and circular shaped wires. Fig.5 shows the decrease in width of cut with the increase in wire tool feed rate. As regarding the effect of feed rates, results indicated that an increase in the feed rate yields a similar increase in consumed current. As the feed rate increases the equilibrium gap decreases and thus, the electrical resistance is reduced. Higher feed rates are desirable for improved productivity and geometry of cut. However, high feed rates are accompanied with increased current densities which may lead to wire damage.

IMPROVED MACHINING FLUID SYSTEM

Experiments carried out while machining graphite by USM have shown [14] that artificial aspiration leads to a significant improvement in metal removal rate while maintaining a steady machining speed during penetration. Fig. 11 shows the effect of aspiration on the penetration rate for the case of a square ended tool.

With the case of ECM, improved electrolyte systems could be obtained through pressurised cells. When machining under no back pressure, cavitation and sparking are quite liable.

Larsson and Baxter [16 and 17] showed that the possibility of spark occurance increased when machining with small gaps and it was thought that this was because the solution flow rate was reduced thus increasing the gas volume fraction. The conducting area of the electrolyte would be reduced to small channels between the bubbles and a high potential gradient sufficient to cause a spark would develop in these threads of electrolyte. However, the new interesting feature investigated by Ebeid, Baxter and Larsson [4] is that the sparking rate is decreased by increasing back pressure which indicates that the sparking phenomena is connected with gas bubbles in the gap. It is also highly significant that in Fig. 2 the regression lines representing the high and low back pressures, converge at virtually the same threshold feed rate. It would appear then that below this feed rate, there are either no bubbles or more likely the bubbles do not coalesce to cover a major part of the tool surface.

Other changes occuring in the electrolyte medium which may hinder the increase of productivity in ECM are due to the accumulation of sludge. However, this did not increase the frequency of sparking as was expected before [4].

The electrolyte medium could be also improved by the use of special additives to increase removal rates. Air-electrolyte mixtures proved to be beneficial in improving both surface and geometry of the work-piece; deburring, striations and dull spots were significantly diminished [18]. For the case of stationary ECM, Fig. 12 shows the effect of the air-to-electrolyte ratio on the gap (i.e. the removal rate) and thus offers the possibility of removal rate control through adjusting the air-to-electrolyte ratio. Therefore, a roughing operation could be performed by using an electrolyte solution while finishing operations could be obtained by increased air-to-electrolyte mixtures.

To attain consistent and reliable EDM working conditions, the spark gap should be maintained under very close tolerances. Uncontrolled gap distances can affect metal removal rate, electrode wear, surface roughness and resulting accuracy. The dielectric may be greatly affected by swarf coagulatioon under poor flushing conditions thus affecting the inter-electrode distance. Bommeli [19] showed that the renewal of the dielectric fluid greatly influences the process and that by varying the supply of the new dielectric the spark generating medium could be strongly modified. Geometrical deformations could be attenuated or even avoided by the use of pulsed injection or dielectric aspiration.

On the other hand Bruijn [20] attempted to clean the gap through the application of an external magnetic field. Despite the fact that this system seems to be interesting as it eliminates any additional machining in the tool as holes or slots for flushing, however, the building up of a magnetic field around various components of different shapes and sizes is not easy. The other defect in this system is that it has to be applied with magnetical materials.

As most of the machines are fitted with large dielectric tanks, it was thought to use closed cells similar to those employed in ECM. This idea was performed by Larsson and Wong [21] in which they fitted a closed cell to a Sparcatron EDM machine. They concluded that EDM operations under high static pressure are not always advantageous but can result in an order of magnitude increase in machining rate. ALso the use of pressurised dielectric is likely to be most beneficial for roughing operations. They also found that electrode wear increased at a faster rate than the removal rate when increasing pressure. Thus pressurised chambers could be useful for roughing operations in cases of simple tool design where high wear ratios are to be expected.

Experiments have shown [12] that great changes in machining parameters could occur depending on the flow conditions. Changes in flushing direction, flow rate or inlet pressure may improve removal rate and accuracy and reduce electrode wear.

CONCLUSIONS

The foregoing analysis shows that modern machining processes are inevitably associated with various problems which may apparently hinder their potential as production techniques. The present proposed recommendations whether in the form of empirical approaches, modified tool designs or improved flow systems are intended to aid production engineers who apply such processes in industry.

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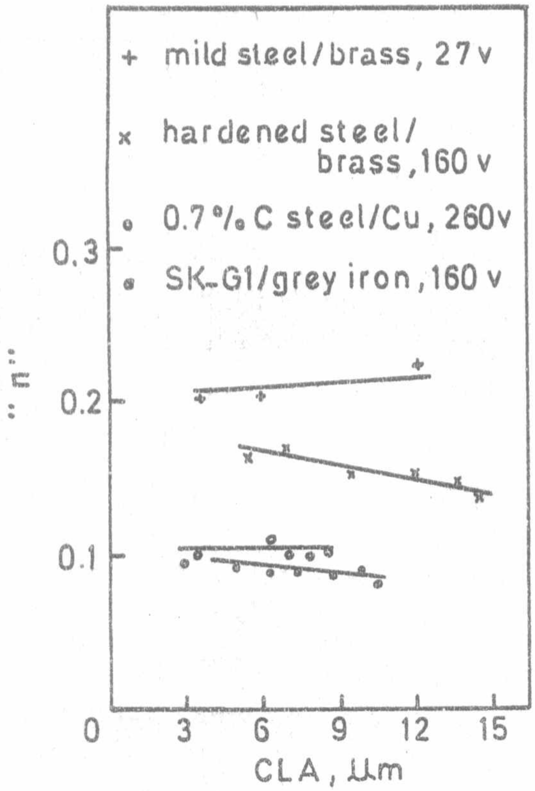

Fig.1 Variation of n with CLA

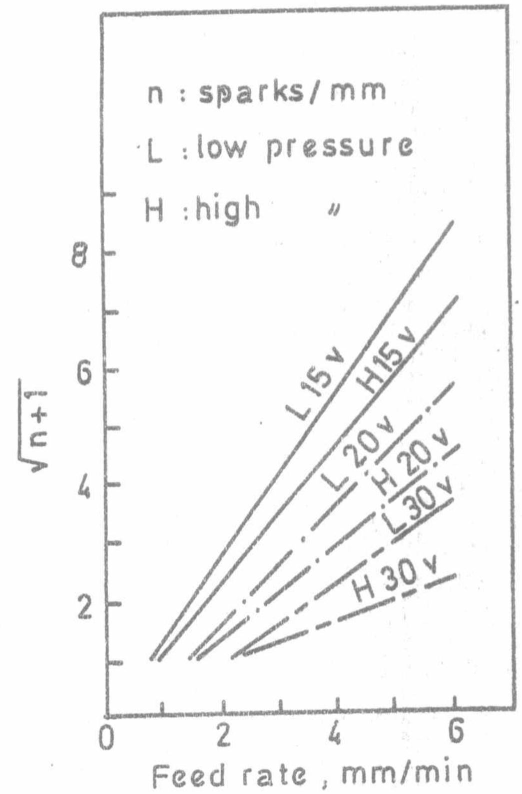

Fig.2 Sparking rate versus feed rate

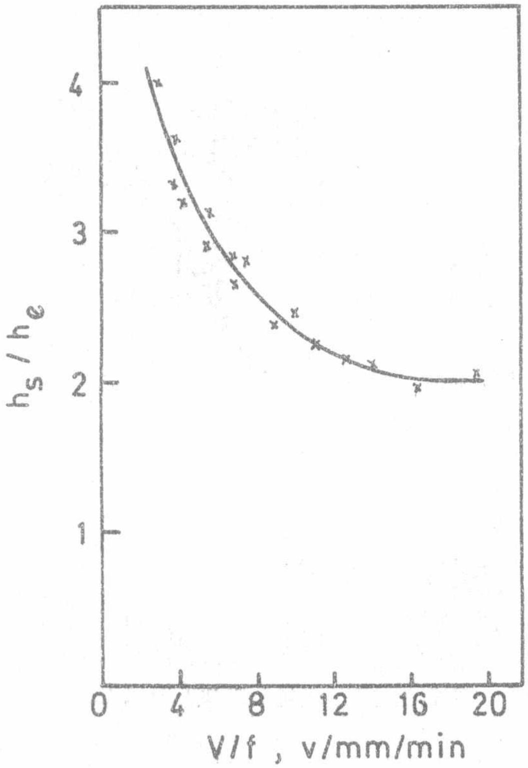

Fig.3 Gap ratio versus V/f

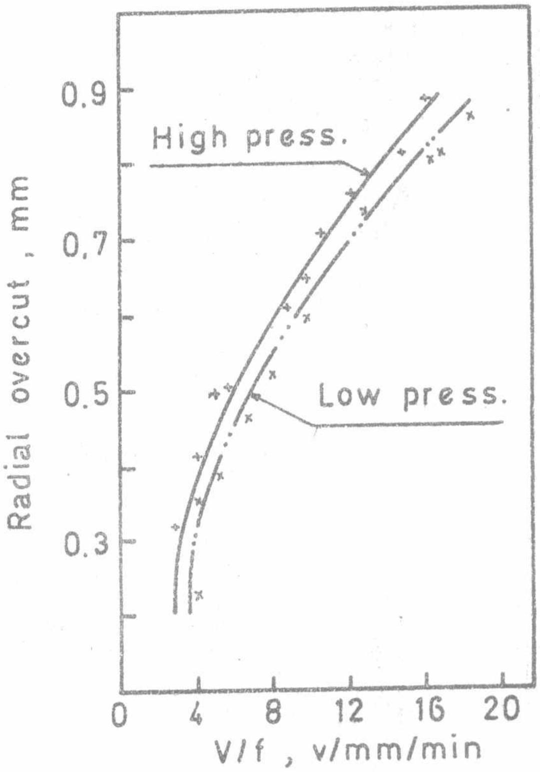

Fig.4 Radial overcut versus V/f

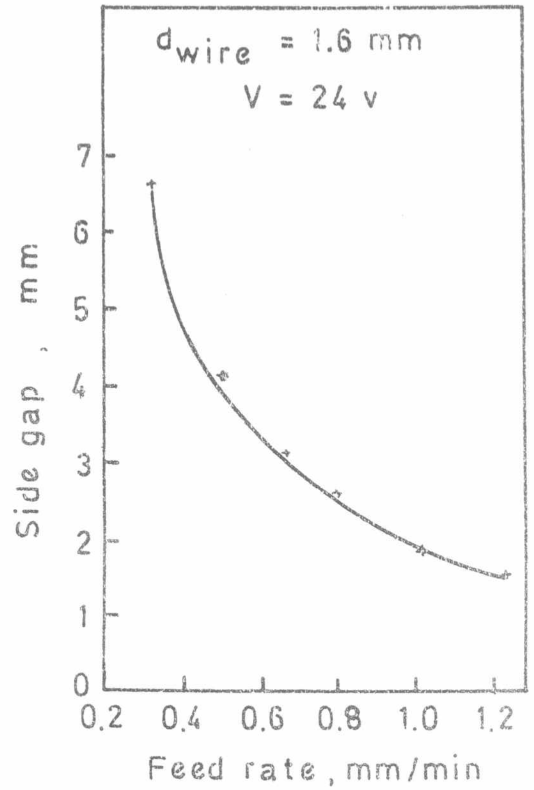

Fig.5 Side gap versus feed rate for wire cutting

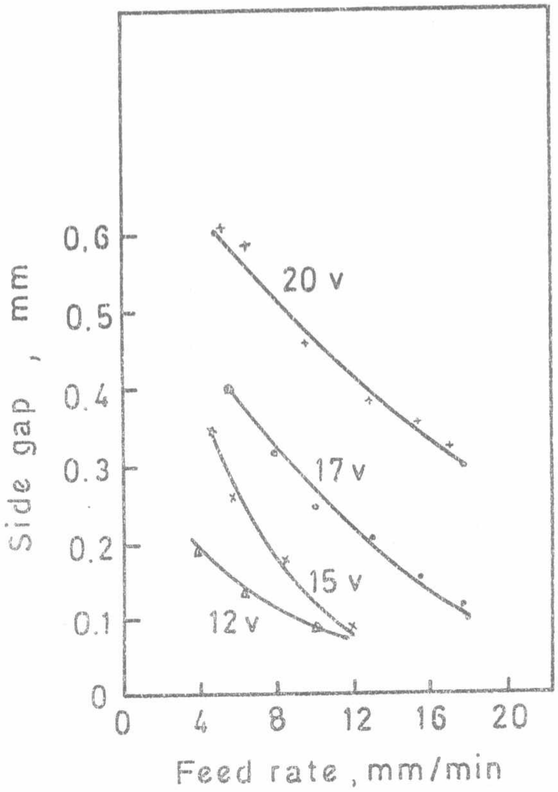

Fig.6 Side gap versus feed rate for broaching

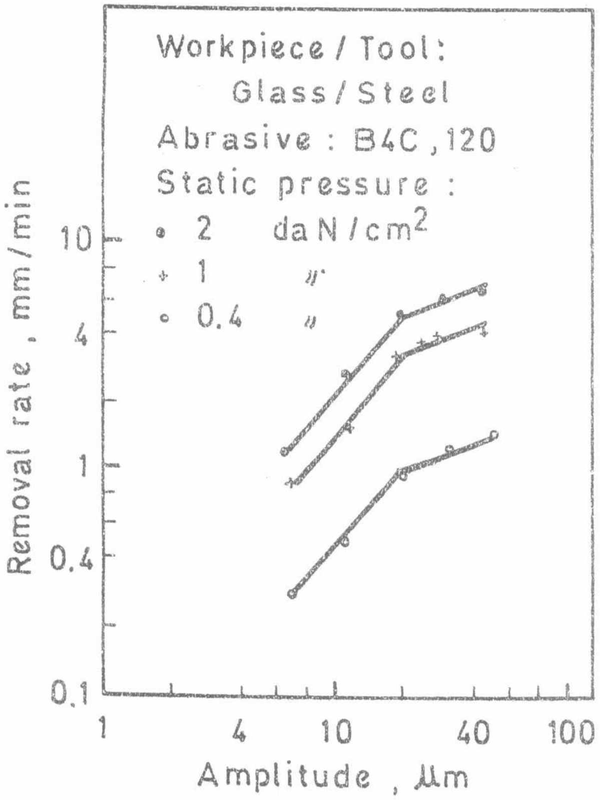

Fig.7 Removal rate versus amplitude

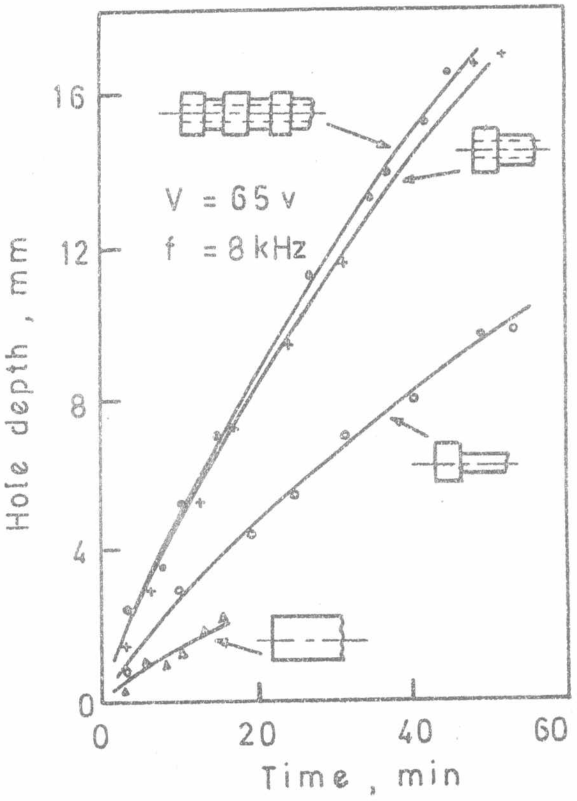

Fig8 Effect of tool design on penetration rate

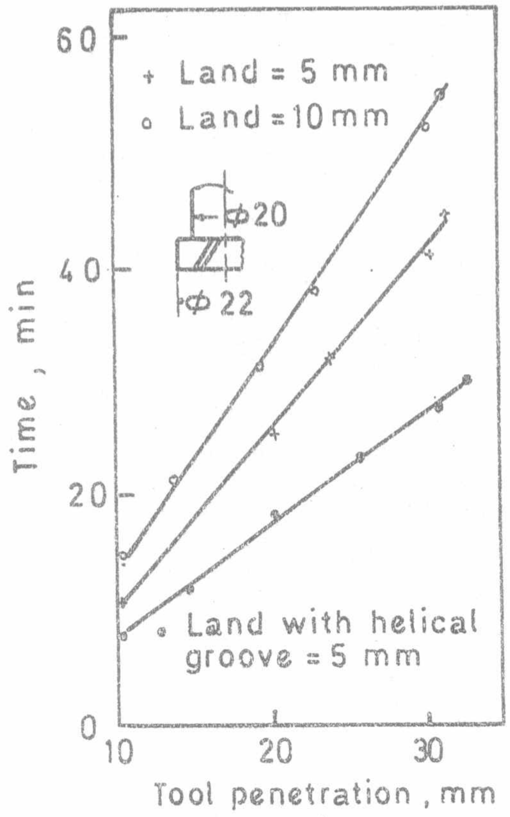

Fig.9 Tool penetration versus machining time

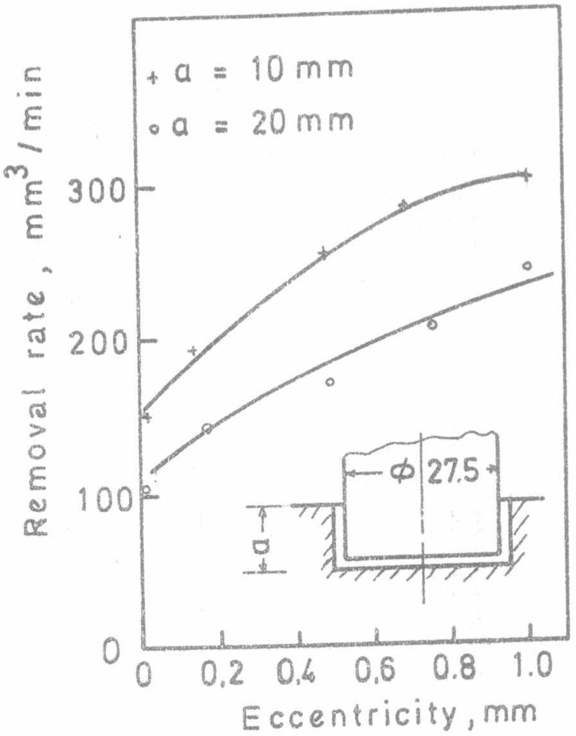

Fig.10 Removal rate versus eccentricity

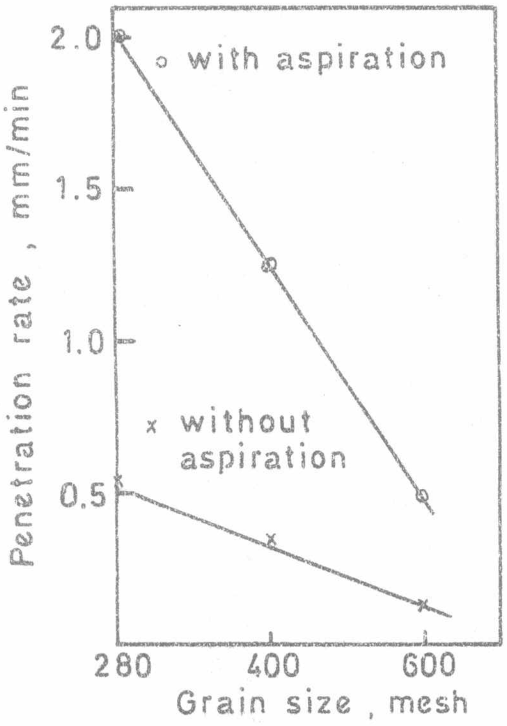

Fig.11 Penetration rate versus grain size

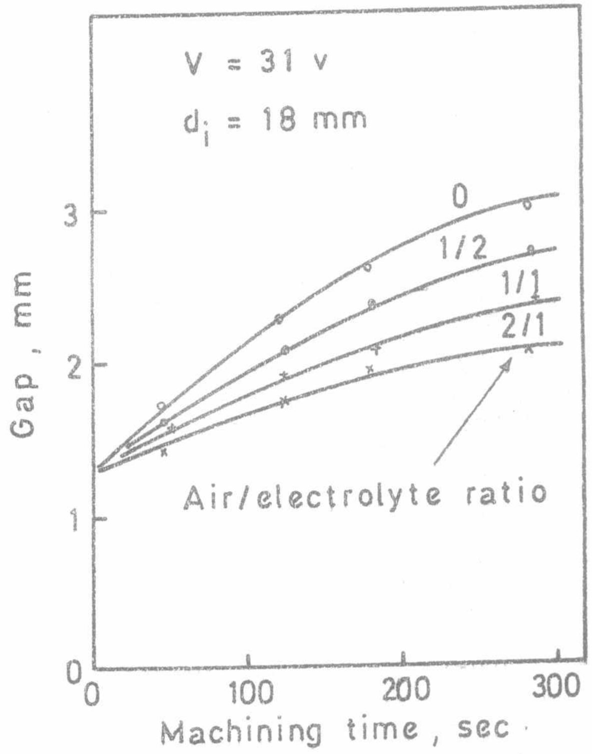

Fig.12 Gap versus machining time