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# ELECTROCHEMICAL MACHINING OF AIRFOIL GROOVES

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## ABSTRACT

Rapid and continous development of materials having special mechanical and physical properties such as titanium and chromium alloys, has led to the development of nonconventional machining processes. Electrochemical broaching (ECB) as a new technique of Electrochemical machining (ECM) was developed. The application of ECB for the aviation industry is under research and trials are made to solve the problems associated with its utilization.

This paper deals with the problems accompanying the application of ECB for the production of airfoil slots using special refractory alloys, which are used in aviation industry. This was done in cooperation with SNECMA factory in France. The results were convenient and usefull for the application of this process in a large scale.

## INTRODUCTION

Electrochemical machining as one of the most widely used nonconventional manufacturing processes, is based on the phenomena of metal removal by electric dissolution. This process employs an electrolytic cell formed by tool and workpiece using an electrolyte flowing between them with high velocity. ECM processes have found wide applications in industry due to its high dissolution rate and good surface quality [1-4] . Previous studies have analysed the relationship between the tool and workpiece geometry. This problem was stated in the following ways: First," the analytical problem" which consists in finding the work surface geometry for a given tool shape [5-8] . The second is "the design problem" in which the workpiece geometry is given and the family of admissible tool surfaces is to be determined [9-12] . It is noted that the design problem is not unique

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In view of the complexity of the general problem, mathematical models for its solution were based upon simplification. Yet the complexity of the physicochemical changes occuring in the inter-electrode gap make the surface generation difficult to be controlled, also the mechanism of metal removal is not fully understood. Even today, engineers rely heavily on final empirical development of the tool behaviour during machining.

Electrochemical broaching(ECB) operation is cosidered as a new concept inspite of being used in some industrial plants [13] .An experimental investigation for the various parameters governing this process were studied [14-15] . Tools used have a tapered configuration with different cross-section geometry. Used feed rates are considered relatively higher compared with other ECM processes due to nonfrontal cutting. Much information about the realization of ECB process for producing complex profiles are not available. Despite the problems which have been discussed, the field of its application is widening beyond the aircraft industry, although it is still the main user. Moreover,machining of some aircraft engine parts by ECM process is prefered compared with EDM process, because the later creates a deep surface damages which seriously decrease the fatigue strength.

Ghabrial et al [16] presented a theoritical model based on mapping function [17] for predicting various airfoil sections of turbine blade. Their results emphasize the powerfulness of the application of complex functions for shape prediction in ECM process.

The present work aims to prove the feasibility of ECB process for producing airfoil grooves in a special refractory alloys (Inconel-718: French Standard) used for producing turbine disc. These alloys are characterized by very high strength, hardness and low machinability.The problems associated with the process application and the necessary machining conditions are given.

## EXPERIMENTAL WORK

In order to realize ECB of airfoil slots, a special test cell was constructed (Fig.1). The was mounted on a special electro-chemical grinding machine where the tool feed is given by the machine table (Fig.2,3). Two sets of experiments were carried out. The first for broaching a parallelogram using a special tool made of brass (Fig.4), which has an inclination of 5 in the cutting part and final cross-section of 28 4 mm. Test specimens were produced by EDM as a semiproduct where a small parallelogram is slotted in with a cross-section of 8 4 mm (Fig.5).

The second set of experiments was performed to broach the airfoil slot. The specimen material was INCONEL-718,(45%Ni,19%Cr,18%Fe, 5%Nb), and its rectangular outer shape is guided in the cell with three pins to secure its positioning relative to the tool. Specimens were provided with initial airfoil slots made by EDM (Fig.3) The tool with airfoil cross-section was fabricated from stainless steel by wire errosion. Tool length was 153 mm, which permits a machining width of 2 mm with respect to the initial airfoil slot (without considering the machining side gap). A special tool holder was designed from the same material as the tool to avoid the change in potential difference, and was mounted on the machine head.

6 The ECB process was realized using a solution of sodium nitrate ($NaNo_3$) as an electrolyte with a concentration of 150 g/L. The inlet pressure was fixed at 25 bar and the back pressure was varied by controlling the outlet electrolyte flow using a special valve. The measurement of pressures ($p_1$,$p_2$), temperature and working current were grouped on a central electronic digital unit. The geometry of broached slots was measured by travelling tool maker microscope.

## RESULTS AND DISCUSSION

The results obtained for the first set of experiments (broaching of parallelogram) showed the possibility of using different values of back pressure ranged between 3 and 10 bar (Fig.8,9). The maximum feed rate reached was 28 mm/mn at a value of back pressure equal 10 bar. At zero back pressure the maximum feed obtained was 20 mm/min, due to the shortage of electrolyte flow in the tool corners. A remarkable differences in the values of side gap allover the workpiece circumference was noticed. This is mainly due to the static cutting resulting along the tool parts of smaller inclination (Fig.10). Furthermore, higher values of back pressure will produce tool vibration due to the originated moment on tool cutting area (Fig.11), which will cause sparking and stopping the cutting process.

Using the second tool with airfoil cross-section, the maximum feed rate obtained was 10 mm/min. Beyond that value , cutting is accompanied by sparks which deteriorated the tool trailling edge (Fig.12).That is due to the great difference in the gap dimension in both x and y directions which will change the electrolyte flow.Also the electrolyte conductivity is more difficult to control, as it depends on the flow rate, composition and temperature.

The effect of the tool feed rate on the gap distribution around the tool was illustrated (FIG.13). It has been shown that the falling tendency of the maximum gap in y direction as the tool feed increases. However regarding the variation of the back pressure between 6 and 10 bar , no significant changes in the maximum overcut were noticed. The gap distribution along the whole circumference was found to be varied (Fig. 14).Flow pattern and static cutting were responssible for the nonhomogenity of the gap distribution. In addition, the problem of static cutting arises due to the great variation of tool inclinations from one side to the other which will effect the produced shapes ($S_x$ is very small compared with $S_y$ )(Fig.13).

At a very small values of back pressures (p2 = 2 bar), all trials were failled, and maximum feed rate obtained was 1.5 mm/min. This is attributed to severe sparks caused by flow leakage around the tool trailling edge. Increasing back pressure more than 25 bar results in a lower flow rate.

## CONCLUSION

- The results give guidelines for the feasibility of using ECB for producing airfoil slots in the refractory alloys.
- For broaching the airfoil slots, the maximum feed rate obtained was 10 mm/min. The variation of the back pressure between 6 and 10 bar has no influence on maximum feed rate.
- For the broaching of the parallelogram, a great variation in the dimension of the side gap in x and y directions was noticed due to the effect of static cutting in y direction.
- These tests are a start point and must be followed by some modifications in the tool design to obtain a symetrical gap around the tool cutting part.

## ACKNOWLEDGEMENT

The authers thank all the staff of SNECMA factory, and ENSAM in FRANCE, for their cooperation in the production of the tools used in these experiments.

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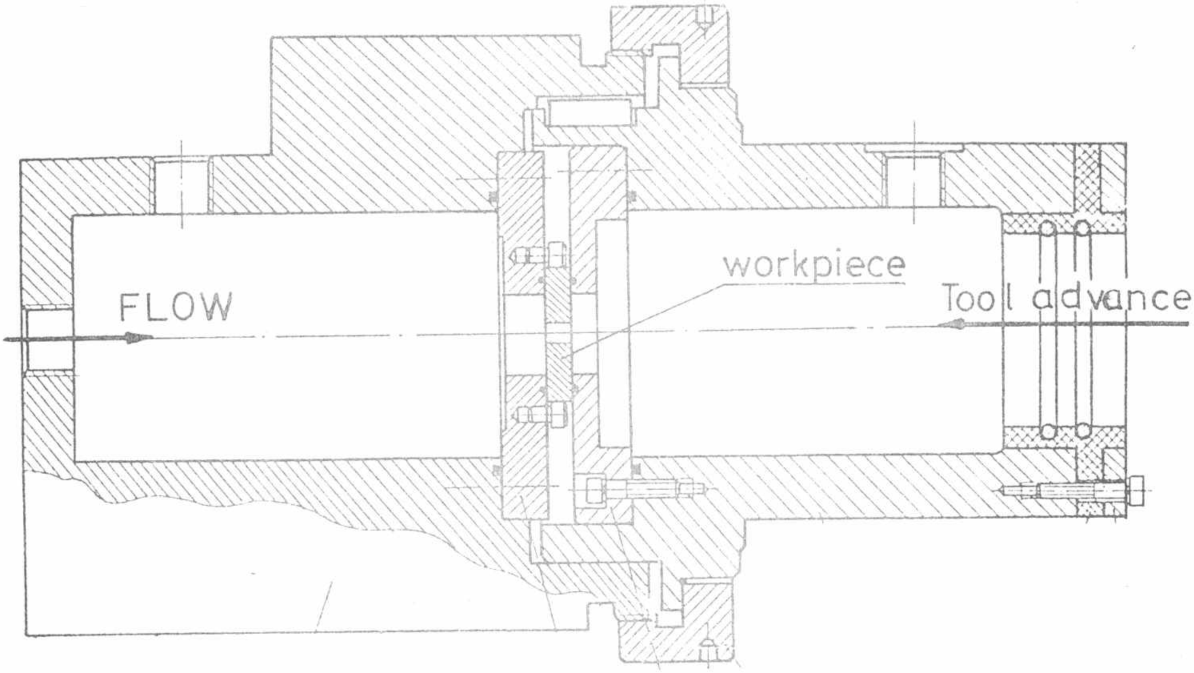



Fig.1 Electrochemical broaching cell

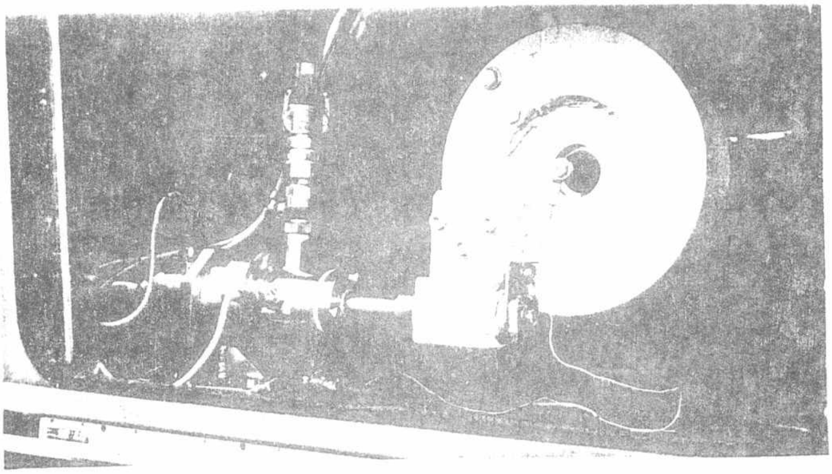


Fig.2 The mounting of the cell on the EC grinding machine

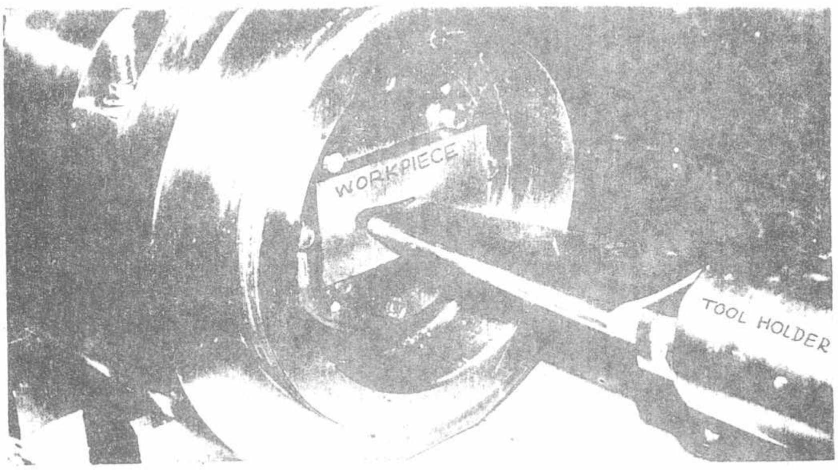



Fig.3 Tool and workpiece used for airfoil EC Broaching

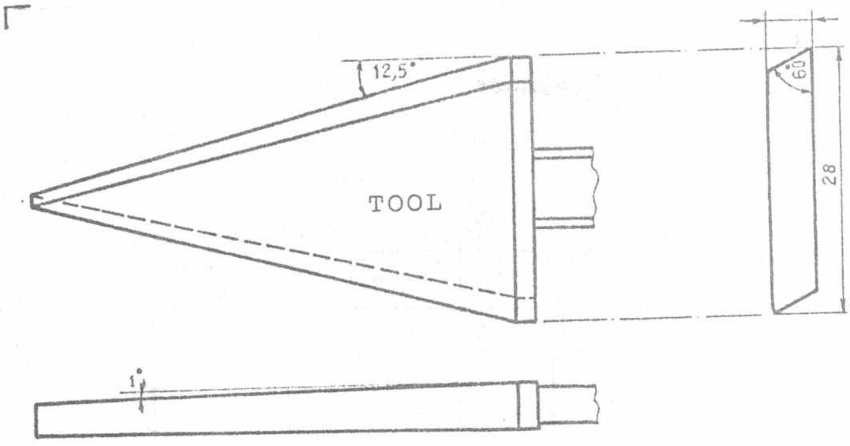



Fig.4
Tool used for producing parallelogram slot.

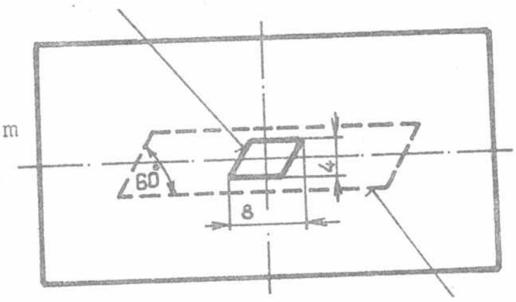



Fig.5 Workpiece used for producing parallelogram slot.

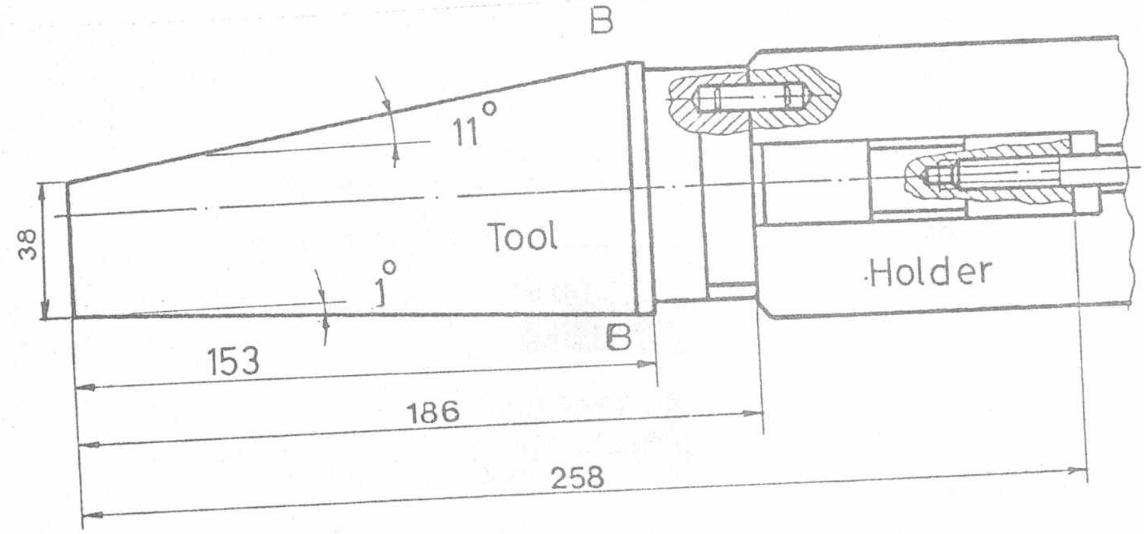



Fig.6 Tool and Tool Holder used for broaching airfoil slot

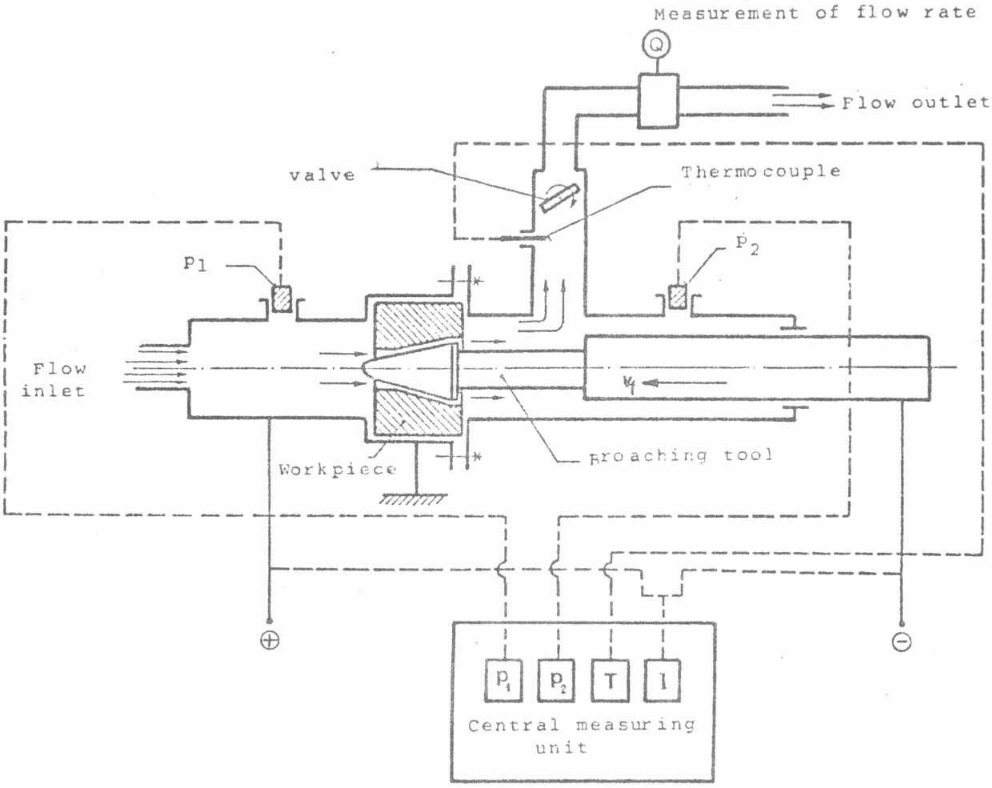



Fig.7 Schematic drawing of ECB cell with all measured parameters.

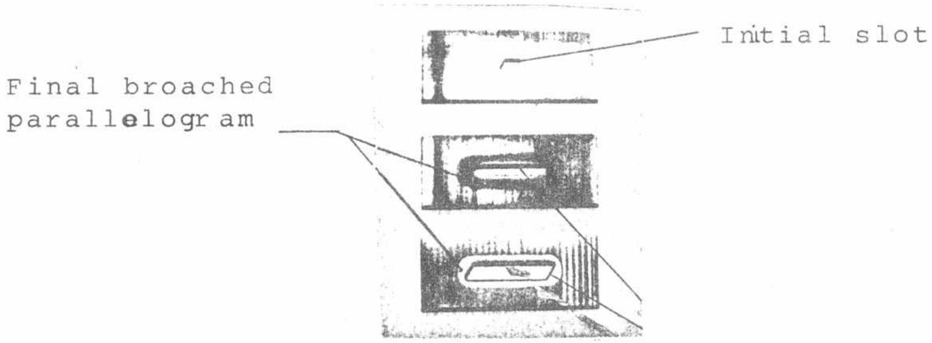
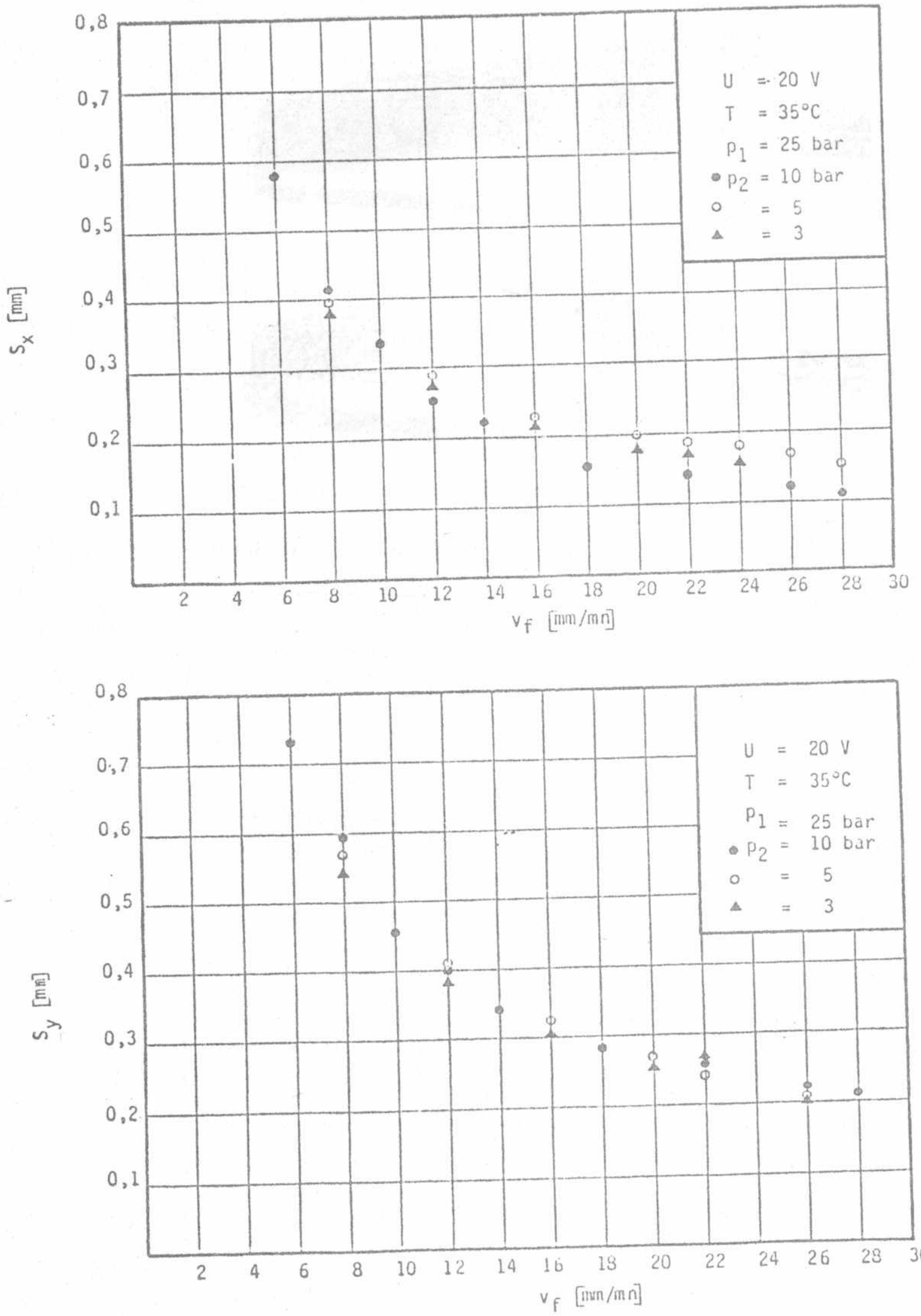



Fig.8 Example of electrochemically broached workpiece.




Fig,9 Effect of feed rate on side gap dimensions

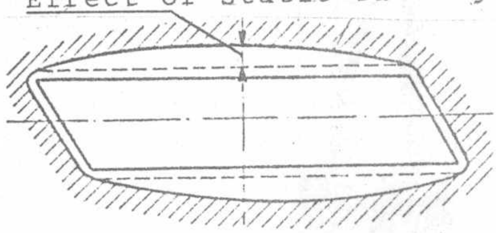



Fig.10 The influence of static cutting on final shape

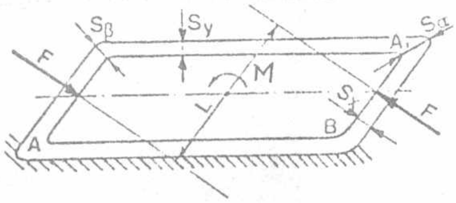



Fig.11 Moment on tool at higher back pressure

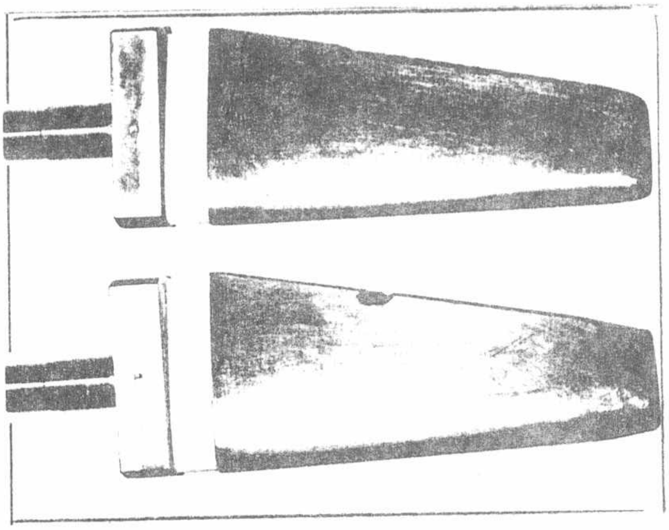


Fig.12 The deterioration of the tool at higher feed rates

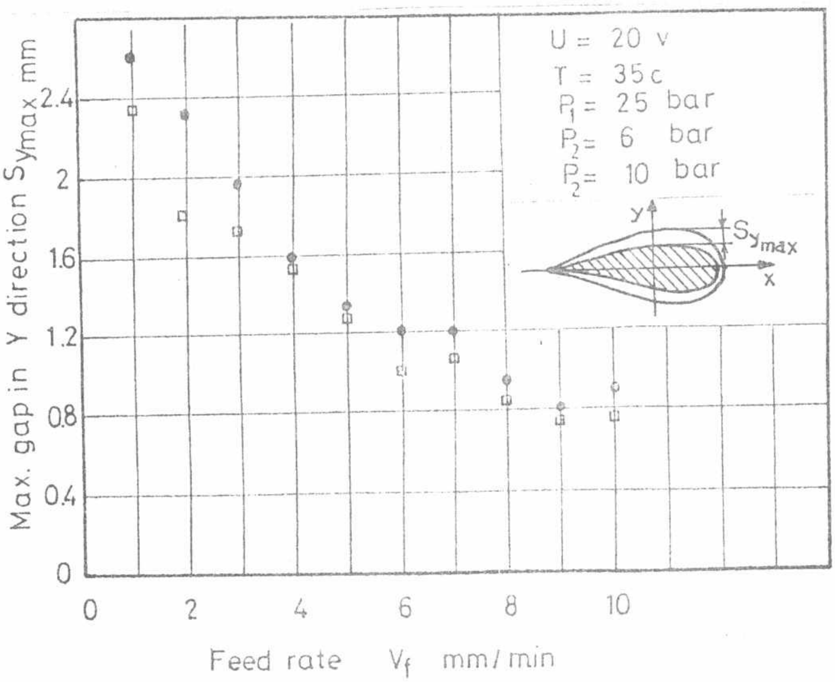



Fig.13 The effect of feed rate on max. gap dimension

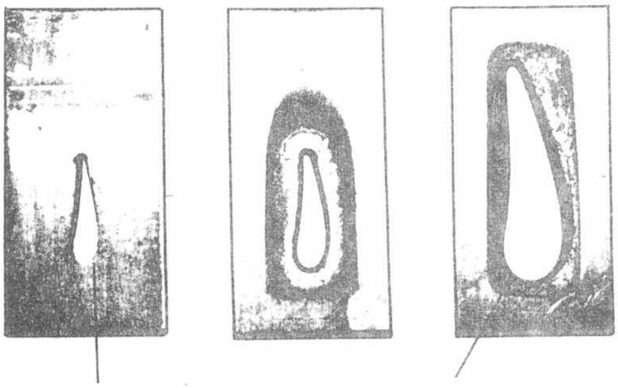


Fig.14 The shape of the final broached airfoil slot.