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INFLUENCE OF VARIOUS PLUNGE MILLING STRATEGIES ON THE SURFACE QUALITY AND THE PRODUCTIVITY

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Abstract: *The objective of our work consists of identifying the relevant parameters of plunge milling operation and to show its performance for the realization of mould and dies. In this framework, we have defined the trajectory of machining and the various strategies adapted to the plunge milling operation. Then, we have determined the machining time and the surface quality (scallop height) for the various strategies suggested. A technical-economical comparison between the various strategies and the determination of machining times and scallop height are also presented.*

Key words: *plunge milling, machining trajectory, machining strategies, scallop height, machining time.*

1. INTRODUCTION

The evolution of the production means and the international competition impose an increasingly high profitability. For this reason, we want to identify the plunge milling operation and its associated problems.The operation of plunge or axial milling is used more and more for realization the dies and moulds in rough machining. The dies and moulds are generally composed of materials with high mechanical strength and require the use of high performance and high cost cutting tools. The optimization of machining times and in consequence the final cost is an economic obligation. The research of the technical-economical machining in plunge milling must be done by the search of a good generation of tool trajectory and a good machining strategy, which produces the best surface quality [1]. The goal of this work is to present various machining strategies, and from those, we will establish a technical-economical comparison on the level of the surface quality (scallop height) and machining time. This comparison shows the most effective strategy for an operation of plunge milling.

2. TRAJECTORY OF MACHINING

A good generation of tool trajectory enable us to minimize its wear and consequently to improve its life time. The trajectory of a tooth in the material follows a spiral curve determined by the movement of a point fixed on the cutting edge [2]. In general, tool trajectory follows the sequence "Approach – Machining – disengagement".

The actions of approach and disengagement correspond to traditional trajectories outside of the material. The action of machining comprises a position of engagement, the cut itself and a position of disengagement (Fig. 1).

3. MACHINING STRATEGIES

Each machining strategy is based on the automatic generation of the successive tool trajectories. The principal objectives for an effective machining strategy are: the respect of quality and the productivity (material removal rate and minimization of the machining time). The choice of scallop height (H) and pick feed (P) depends in fact on a great number of factors (machine tool, workpiece, material and techniques of polishing). The pick feed represents the distance between two successive passages of the tool in the part. The modification of the pick feed produces a change in the chip geometry and the scallop height. It is obvious also that the use of a significant scallop height decreases the overall length of cut. In this work, we propose three types of machining strategy in plunge milling [3], zigzag-partial engagement, snake-partial engagement, snake-complete engagement (Fig. 2). The three strategies are based on the evaluation of the significant cutting parameters in plunge milling (scallop height and radial engagement).

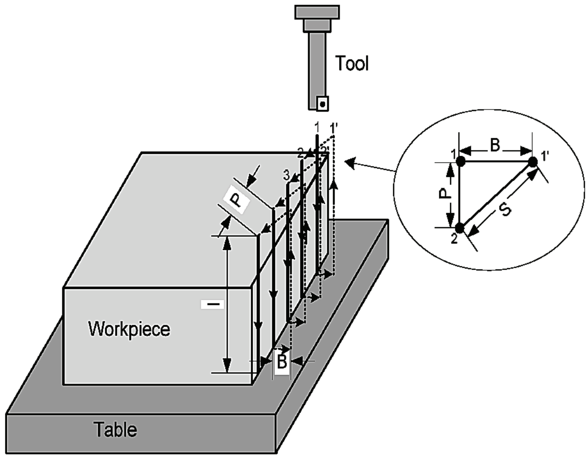

Fig. 1. Trajectory of machining.

4. QUALITY OF SURFACE

The machining strategy plays a very significant role in the surface quality. For various strategies, it is possible to determine a criterion such as the scallop height (macro-geometry). This height corresponds to the residual thickness left by the tool on the part after machining. The choice of scallop height and pick feed depends in fact on

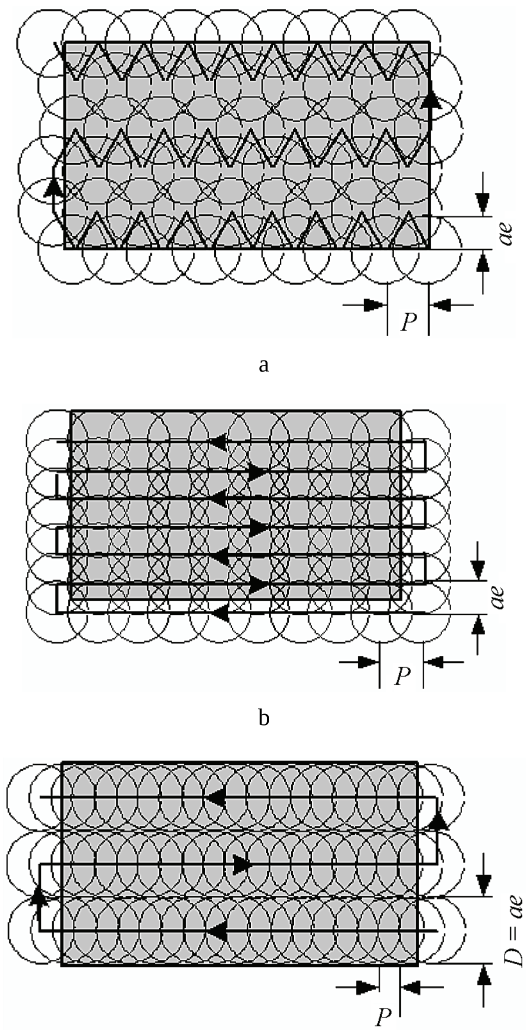

Fig. 2. Machining strategies: a) zigzag-partial engagement; b) snake-partial engagement; c) snake-complete engagement.

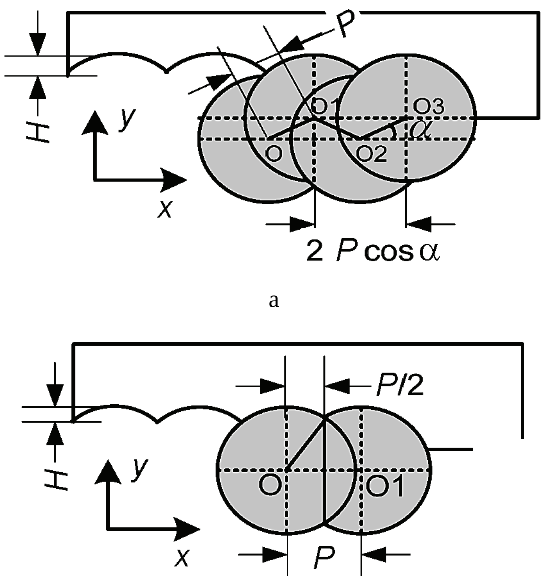

Fig. 3. Scallop height: a) case of zigzag strategy, b) complete engagement.

large numbers factors, in particular: the machine tool, level of part complexity, material selected, price and life time of the cutting tool, cost and time of production. For the various strategies suggested, the scallop height corresponds to the trace left by the cutter during each vertical penetration of the tool (Fig. 3). The parameters used to determine this height correspond to the tool diameter (*R*) and the pick feed (*P*). We determined this height for the three strategies suggested. For the strategies of types snake-partial and (Fig. 3.b), the height (*H*) is given by the equation (1).

$$H = R - \sqrt{R^2 - \frac{P^2}{4}}. \tag{1}$$

In the case of zigzag strategy (Fig. 3.a), we can determined the scallop height by using the equation (2).

$$H = R - \sqrt{R^2 - (P\cos\alpha)^2}. \tag{2}$$

5. MACHINING TIME

The cycle of plunge milling consists of the plunging itself, the release of tool according to axis Z and the extra tool displacement to join the second point of plunge milling. The cycle time is determined by the following relation: *Tc* = Σ *(Times of: manual work, change of tool, displacements of fast speed)* + Σ *(Times of: approach, machining, disengagement)* + Σ *(Times taken for placement of the tools)*. In this study, we are exclusively interested to determine the machining time for the different strategies suggested for calculate the machining cost [4, 5]. Fig. 4 shows the procedures to determine the machining time in the case of plunge milling. In plunge milling (case of rough machining), we can summarize the machining time by the cutting time (t_c) and the extra machining time (t_h). The cutting time needed for realizing a cavity in rough machining is determined from the length of cut (*L*) and the advance speed (*Vf*) by using the equation (3), where (*n*) is the number of tool passages, (*l*) is the length of cut for each tool passage.

$$t_c = \frac{L}{Vf}; \quad L = nl. \tag{3}$$

The extra machining time (t_h) (Fig. 1) is calculated starting from the extra tool path length (L') and fast speed (Vf') by the equation (4).

$$t_h = \frac{L'}{Vf'}; \quad L' = n\left(l + B + \sqrt{P^2 + B^2}\right). \tag{4}$$

6. TECHNICAL-ECONOMICAL COMPARAISON BETWEEN THE DIFFERENTS STRATEGIES

To ensure an equitable comparison between the different machining strategies, we position ourselves in the range of machining a simple workpiece, its shape corresponded to a cube (90 × 90 × 90) (Fig. 1). Moreover, we used the same cutting conditions for each strategy. The steps of comparison define the parameters and the formulations which control the milling operations. This comparison is

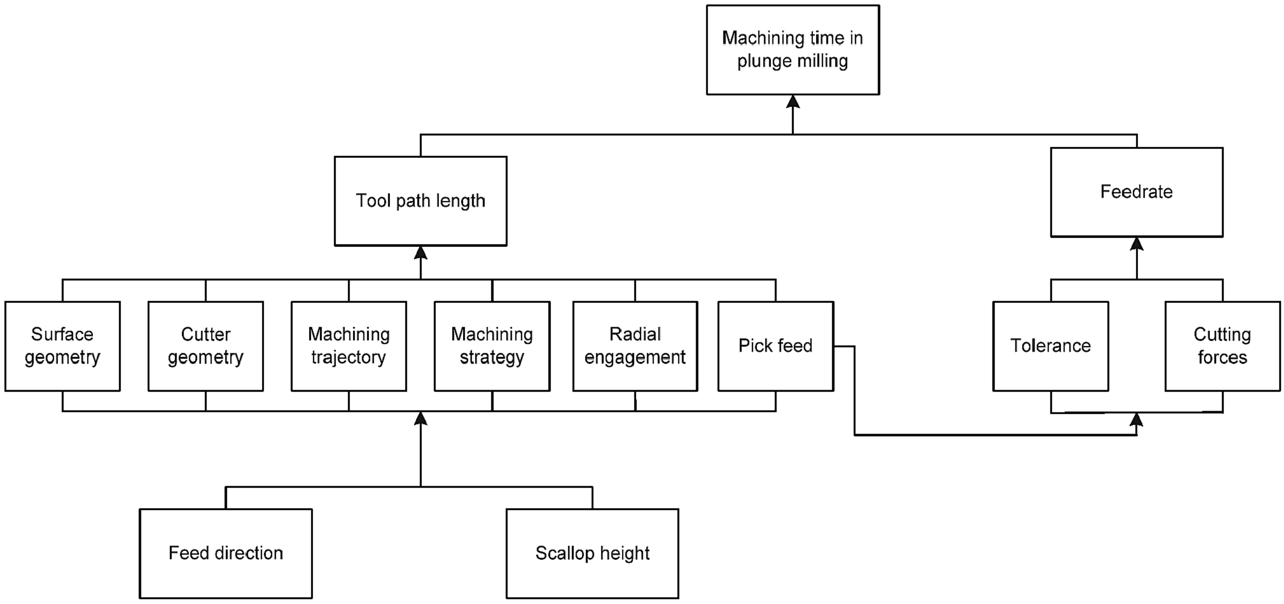

Fig. 5. Procedures for calculated the machining time.

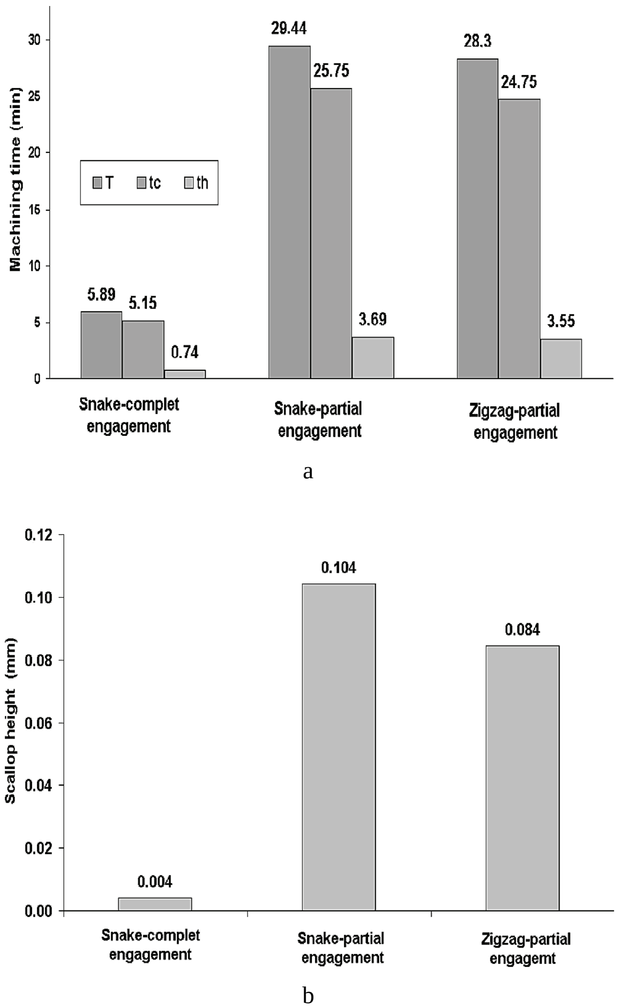

Fig. 4. Machining time and scallop height in function of machining strategies: a) theoretical machining time; b) theoretical scallop height.

realised according to different criteria: machining time, and scallop height for each strategies suggested.

Also, we chose an inserted cutter with three teeth and a diameter of 30 mm (*Mitsubishi*, *PMR 40500Á22R*). The workpiece material used was (*40CrMnMo8*). The spindle speed corresponds to 1 500 rpm, the feed rate per tooth is 0.3 mm/tooth and the cutting modes correspond to up milling. We varied the engagement and the pick feed which are the most significant parameters in plunge milling.

We calculated the cutting time (t_c) and the extra machining time (t_h) needed to realized our part by the three strategies suggested, equation (3, 4). From these two times (t_c, t_h), we then determine the machining time (T).

Fig. 5.a shows the machining time, the cutting time and the extra machining time for each strategy suggested. Fig. 5.b presents the theoretical values of scallop height for the various strategies suggested equation (1, 2). The cutting conditions (pick feed, and radial engagement) are not the same ones for the three strategies. For this reason, we took the cutting conditions producing the same machining time for each strategy. Then, we compare the scallop height for each of the three machining strategies. The most significant parameter in plunge milling is thus the pick feed.

Consequently, its influence over the machining time and the scallop height for the three strategies were evaluated. We observe that the increase in the pick feed reduces the machining time and augment the scallop height (Fig. 6).

7. CONCLUSION

This work enables us to identify and characterize two essential parameters of plunge milling operation according to the type of trajectories and machining strategies. These parameters are the scallop height (quality of surfaces obtained) and the machining time (productivity). A comparison between the three machining strategies gives the following results.

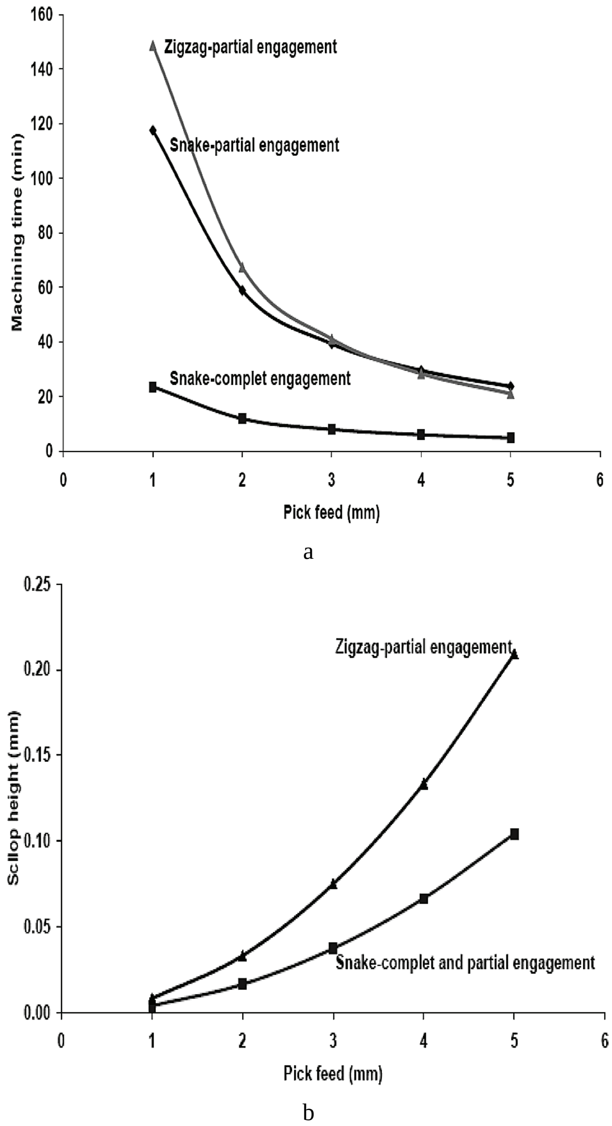

Fig. 6. Evaluation of machining time and scallop height in function of pick feed: a) machining time; b) scallop height.

- The pick feed is one of the operating conditions significant to evaluate the quality of the machined surfaces as well as the productivity. We propose the following rule in plunge milling: the increase in the pick feed decreases the machining time and increases the scallop height.
- The machining by plunge milling using the strategy of snake-complete engagement gives the least machining time and produces a surface of good quality (low scallop height). On the other hand the chip section and the cutting forces are more significant. This last reasoning requires experimental validation.
- The extra tool movements in plunge milling consume a considerable part of the machining time. Nevertheless, this constraint is strongly related to the performances of the machine tool (fast speed).

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