Cutting Tool Strategies for Multifunctional Part Configurations: Part II – Discussion of Experimental and Analytical Results

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The analytical models, developed in Part I [Int J Adv Manuf Technol (1992) 7: 59-69] for the optimisation of multistep cutting tools, are evaluated using experimental data. The effectiveness of the proposed approaches utilising the mathematical models from Part I for multifunctional tools, including both multi-step and combination tools, are demonstrated through simulations. The solution schemes and heuristic algorithms used for optimising the aforementioned cutting tool designs are described and explained through simulation examples which involve several tool configuration situations often applicable in a production environment. When the aforementioned cutting tools are utilised in mass production applications, the advantages of lower production cycle time and cost, become obvious through the tutorial of the examples. These simulations clearly demonstrate the benefits obtained when the mathematical models and analytical schemes, developed in Parts I and II, are incorporated in the manufacturing process and system design optimisation analytical tools or expert systems for justifying the use of multi-functional cutting tools.

Keywords: Multistep tools; Combination tools; Tool design; Tool optimisation; Cutting tools

1. Introduction

Analytical models for optimising the cutting conditions of multifunctional cutting tools, such as multistep and combination tools, were derived in Part I of this paper [1]. The procedure assumes that the tool life equation for each tool step or function is available and is usually obtained from similar single step or function tools. The independent property is considered among the tool’s steps or functions for predicting the tool reliability. The physical constraints of the tool’s steps or functions can be utilised in the optimisation procedure. This enables the optimum cutting conditions, cutting speed and feed, to be calculated on the basis of an objective function, incorporating either one or both the production cost and cycle time, for the economical evaluation and justification of the aforementioned complex tools for their comparison with the simpler single step conventional tools.

An objective of this study was to determine the analytical models for the optimisation of the cutting conditions for multifunctional tools. The models for the multistep tools were evaluated through experimental results presented in the first example. The analytical schemes and heuristic algorithms are utilised for the evaluation and justification of the aforementioned complex tools incorporating the derived mathematical models. Simulations for three different configurations and operations of stepped parts, found often in practice, are considered in order to evaluate two multistep drills and a bore-reamer and to show the effectiveness of the analytical results for the determination of the optimum cutting conditions for all the tool steps. Finally, a simulation on a combination tool is presented where the problem is attacked from a complete system approach view point. These simulation examples have been conveniently worked out by hand as described below.

2. The Solution Scheme for Multistep Tools

The simulation algorithm for the justification of a multistep tool consists of the following heuristic scheme:
**Step 1:** Define the maximum surface speed of the tool material used for the tool steps.

**Step 2:** Determine the tool life equation for the tool steps if it is not available from single step tools. The same tool life equation can be used for all the tool steps made of the same material and applied to similar operations.

**Step 3:** Evaluate the total production cycle time and cost when conventional single step tools are used to machine the multistep part configuration. Therefore, determine the optimum cutting conditions for all the required single step tools.

**Step 4:** Define the requirement of using through the tool coolant in order to remove the chips, especially with multistep tools.

**Step 5:** Determine the maximum or optimum spindle rpm and feed for the multistep tool. Calculate the production time and cost. Use the constant rpm approach solution unless the diameter change between the steps is very significant or different tool materials are used for different steps.

**Step 6:** Calculate the amount of lifetime sacrificed when the multistep tool is used at a constant rpm (utilise Eq. (21)). Continue with step 7 if the percentage of the tool cost lost is significant. Otherwise, proceed to step 10.

**Step 7:** Determine the possibility of using the constant surface speed or variable rpm approaches. This step should be considered with motorised machine spindles.

**Step 8:** Evaluate the advantage of using constant surface speed or variable rpm approaches for different tool steps. Therefore, obtain the maximum or optimum spindle speed for all the steps. The production time and cost reduction when constant surface speed or variable rpm are used for the significantly different tool step diameters as opposed to the constant rpm approach.

**Step 9:** Calculate the time requirement for the speed transition at a tool step, during constant surface speed or variable speed approach, in order to ensure that it meets the process limitations and is feasible.

**Step 10:** Determine the most viable approach for a multistep tool. If step 9 is satisfied and there is an advantage with the approach in step 8 as opposed to step 5, consider the constant surface speed or variable rpm approach. Otherwise, the constant rpm approach is accepted.

**Step 11:** Compare the viable operation approach in step 10 for a multistep tool with that of the conventional process approach in step 3, in order to justify the multistep tool approach.

**Step 12:** The change in feed for various steps can be incorporated, if necessary, in the aforementioned approach of step 8 since it is similar to that of the variable speed approach.

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**2.1 Numerical Examples**

In order to demonstrate the analytical results and the computational approach for obtaining the optimum cutting parameters such as speed and/or speed and feed of multistep tools presented in Part I [1] and their justification analysis discussed in the previous section, an experimental example for earlier work [2] and three numerical examples are presented.

**Example 1**

The tool wear curves of a single step carbide drill when drilling 390 aluminium alloy at three different speeds (of 240 m/min, 400 m/min and 600 m/min) and at 0.254 mm/rev feed are shown in Fig. 1. The flank wear response with the application of cutting speed change during the drill life is shown in Fig. 2. The first

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**Fig. 1.** Flank wear growth as a function of cutting time at three different speeds for a carbide drill.

**Fig. 2.** Flank wear transition on a carbide drill at two cutting speed levels for three different cases.