Life prediction system using a tool’s geometric shape for high-speed milling

Abstract In recent years, machinery and tool technology has been developing rapidly. The accuracy of operations have also become more and more exact. Elsewhere, raw materials have also been honed, hoping to provide more useful properties than previously. Thus, how to find the best way to prolong the life of a tool subjected to hardened material cutting is the target of this research. Three kinds of tool angle of the endmill are used in this research; clearance angle, rake angle, and helical angle. The cutting conditions are the same; we only change the tool angle for all the cases studied. We attempt to discover better tool geometrical angles for the high-speed milling of NAK80 mold steel. The tool wear rate was measured through a toolmaker’s microscope and the roughness of the machined surface was measured by the roughness-measuring instruments after several complete surface layers were removed from the workpiece in the experiment. Also, a noise-mediator was used to detect the level of cutting noise during each surface layer workpiece removal of the high-speed milling process, and different noise levels were then compared with the tool wear rates for identifying noise characteristics in the case of an over-worn tool state. An abductive network was applied to synthesize the data sets measured from the experiments and the prediction models are established for tool-life estimation and over-worn situation alert under various combinations of different tool geometrical angles. Through the identification of tool wear and its related cutting noise, we hope to consequently construct an automatic tool wear monitoring system by noise detection during a high-speed cutting process to judge whether the tool is still good or not, and, so, the cost of milling can be reduced.

Keywords Tool geometry · Tool wear · Cutting noise · High-speed machining

1 Introduction

High-speed cutting technology is already a smart tool in the skillset of manufacturing plants for matching the production methodology of lower quantity and more styles in the market. In tooling production, increasingly more accurate products with a shorter delivery time and lower cost are usually essential at the present time. High-speed machining is a potential method to meet these challenges. The most potent application for high-speed machining is in the manufacturing of extremely accurate dies and molds, where it may reduce the amount of work involved in subsequent grinding or polishing operations.

Nowadays, high-speed machining and milling has gained a good reputation in that the main advantages are: shortened cutting times; improved productivity and efficiency; increasing the surface quality of the workpiece; decreasing the cutting resistance and surface temperature of the workpiece, and so on. Hence, thinner-ribbed components can be machined and it accords with the questioning of environmental protection. Looking from the development of the market, the techniques of machine tools in the future are concentrating mainly on two parts: that is,
hardened material cutting and lightweight-component high-speed machining with a higher precision.

Tests for the materials typically used in model and prototype manufacturing have been performed [1] in order to determine the minimum reliably achievable thickness-to-height ratio for thin ribs. Products made of hardened tool steel and comprising three-dimensional surfaces have been milled successfully with special CBN endmills without any significant tool wear. The milling of aluminum alloy using a specially designed diamond endmill and a high-speed spindle was experimented upon, and some characteristics of the machining process were analyzed [2]. It was possible to obtain a mirror-like surface of aluminum alloy which did not require polishing after milling in the experiments. A predicted milling force model for the endmilling operation is proposed [3]. The speed of spindle rotation, feed per tooth, and axial depth of the cut are considered as the affecting factors. An orthogonal rotatable central composite design and the response surface methodology are used to construct this model. Dagiloke et al. [4] developed a software package to describe high-speed machining applied to a number of metal-cutting operations. The method of formulating the input and output variables has been presented and discussed, followed by an approach to the selection of cutting equations for the process of high-speed machining. Cutting temperature and tool wear in the high-speed machining of aerospace materials, such as Inconel 718 and Ti-6Al-6V-2Sn alloys, have been investigated [5] by means of cutting experiments and numerical analysis. The results show that the tool wear is developed by an abrasive process rather than by a thermally activated mechanism. El-Wardany et al. [6] dealt with an experimental and analytical investigation into the different factors which influence the temperature distribution on a ceramic tool’s rake face during the machining of difficult-to-cut materials. Temperature measurements on the tool rake were verified using the predictions of the finite element analysis. Experiments were performed to study the effect of cutting parameters, different tool geometries, tool conditions, and workpiece materials on the cutting edge temperatures. Dewes and Aspinwall [7] reviewed high-speed milling machinability work over the last decade and includes tool life, workpiece surface finish/dimensional accuracy, and cost data. Sample components are illustrated and the machining parameters are correlated against workpiece hardness. Sutter et al. [8] designed a new high-speed machining experiment to obtain orthogonal cutting in a wide range of cutting speeds of up to 100 m/s. The measurement of the longitudinal cutting force reveals the existence of an optimal cutting speed for which the energy consumption is minimum. The genuine tool–workpiece–material interaction can be analyzed with that experimental evidence.

Process features such as tool geometry and cutting conditions directly influence the chip morphology, cutting forces, product dimensionality, and tool life. Tool wear is a significant factor affecting the machined surface quality. The wear of a tungsten carbide tool with Ti-series compound coatings during high-speed machining downgrades the machined surface finish to some extent before tool failure, and it will also damage the machined surface’s integrity. Therefore, it is of great significance to obtain a better understanding of the physical aspects of the wear for the Ti-series compound coatings tool and, consequently, to acquire a precise knowledge of the optimal range of cutting parameters.

2 Basic theory

2.1 Cutting theory

When the cutting tool and workpiece are cut by a relative movement, the parings removed from the workpiece are called chips, which are as the tool edge cuts into the workpiece material, imposes the tool edge and the material, and makes plastic shear deformations of the workpiece. Because the cutting action causes chip removal to the first chip and repeats constantly, then, as a result, the chips gradually pile up and slide out along the rake face of the tool (Fig. 1).

The zone of chips formation, from the tool edge to the connection of the chips and the material, is called the primary deformation zone. Chips sliding out along the rake surface of the tool is the secondary deformation zone. There are four basic cutting conditions related to the milling operation, which are: velocity, feed, radial depth of cut, and axial depth of cut:

1. Velocity \( (V) \): the higher the cutting velocity, the lower tool life. As a result, it is important to choose an adequate cutting velocity for a balanced economic consideration. The velocity can be expressed as:

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V = \frac{\pi \times d_0 \times n}{60 \times 100} \text{ (m/s)}
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where \( d_0 \) is the diameter of the endmill in mm and \( n \) is the rotational speed in rpm.

![Fig. 1 The formation of chips](image)