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3-Dimensional kinematics simulation of face milling

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ABSTRACT

Face milling is currently the most effective and productive manufacturing method for roughing and finishing large surfaces of metallic parts. Milling data, such as surface topomorphy, surface roughness, non-deformed chip dimensions, cutting force components and dynamic cutting behavior, are very helpful, especially if they can be accurately produced by means of a simulation program. This paper presents a novel simulation model which has been developed and embedded in a commercial CAD environment. The model simulates the true tool kinematics using the exact geometry of the cutting tool thus accurately forecasting the resulting roughness. The accuracy of the simulation model has been thoroughly verified, with the aid of a wide variety of cutting experiments. The proposed model has proved to be suitable for determining optimal cutting conditions for face milling. The software can be easily integrated into various CAD–CAM systems.

1. Introduction

The kinematics of face milling is widely known and is similar to conventional milling. As presented in Fig. 1 the kinematics of the process of face milling consists of a rotation and a translation of the tool. The rotation has an axis of revolution parallel to axis Z, while the translation is made along the X axis of the part and depends on the feed per tooth (f_z). Each pass cuts a specific depth of cut (t_z) as it can be illustrated in the middle picture of Fig. 1.

The process is affected by a series of parameters, which can be divided into two categories. The first category includes the geometrical characteristics of the cutting tool, while the second contains the cutting process parameters. Some of the above parameters are the cutter diameter (D), the number of teeth of the cutter (z), the feed per tooth (f_z), cutting speed (v_c), the axial depth of cut (t_z), the radial depth of cut (t_{xy}), the axial rake angle (γ_a), the radial rake angle (γ_r) and the shift of the cutting edge (s).

This paper presents a novel simulation program, the so-called FaceMill code, which is able to determine the produced surface, the resulting surface roughness and the cutting forces, for every possible milling strategy and cutting tool. The completeness of the simulating software has been thoroughly verified with the aid of a wide variety of cutting experiments. Hereby, several roughness and cutting forces measurements were carried out on workpieces which had been cut using a 3-axes milling center. In a step forward, the proposed model was proved suitable to determine optimal cutting conditions.

2. State of the art

Face milling process has been studied by many researchers. The main research subjects are cutting forces, surface roughness, search of optimal parameters and tool wear. An area of great interest is the optimization of cutting parameters where researchers [1,2] have developed optimization models based on genetic algorithms for the selection of the optimal cutting parameters for multipass face milling. Another approach in this area was suggested by Lin [3], who used Taguchi's method with multiple performance characteristics in order to optimize a series of characteristics of stainless steel, produced with face milling. Some other works made in the field of face milling include the development of models that predict the burr formation and suggest the optimal parameters which

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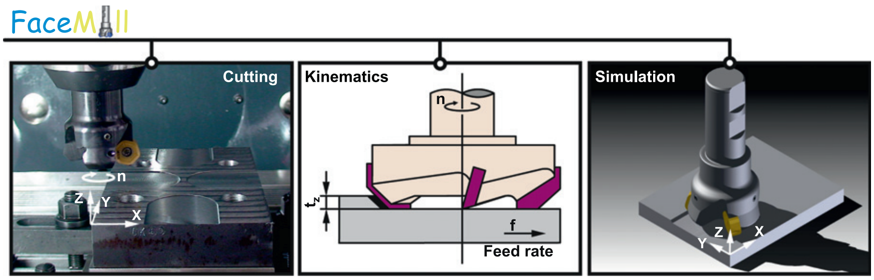

Fig. 1. Face milling kinematics.

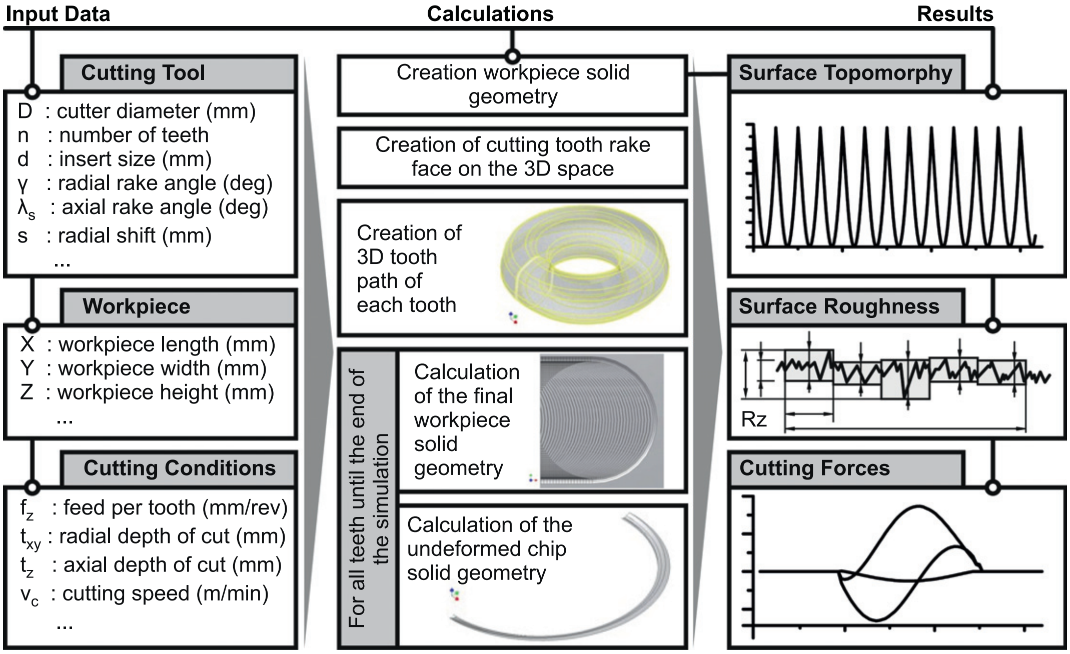

Fig. 2. FaceMill simulation algorithm.

minimize its formation [4,5] as well as studies on the behavior of burr [6]. As for the tool wear in the face milling, in-process models are used in order to measure cutting forces and determine the wear of the cutting tool [7–9]. In their study Sampath et al. [10] used an acoustic finite element model to predict the cutting noise produced by the face milling process. Wu [11] investigated the effect of milling strategy on the produced part while face milling large surfaces. Machining experiments are usually conducted in order to observe the influence of cutting parameters on tool wear, tool life, cutting forces, surface roughness or chip morphology [12–15]. Li et al. [16,17] and Zheng et al. [18] used analytical models in order to predict cutting forces with cutter runout. In their work Patel and Joshi [19] and Baro et al. [20] used also analytical force prediction models for face milling cutters, with self-propelled inserts. Another approach was made by Aykut et al. [21] who used an artificial neural network to predict the cutting forces in face milling of stellite 6 cobalt alloy. In the field of surface roughness Baek et al. [22] and Sastry et al. [23] developed models that optimize the cutting parameters in order to minimize the effect of run-out on the roughness of the final workpiece. Saï and Bouzid [24] used a mathematical model to predict surface roughness, using an experimental system method. Similar models but with the use of another objective function was developed by Bagci and Aykut [25], who used Taguchi's optimization method and Lela et al. [26], who used regression analysis, support vector machines and Bayesian neural network for this task's. Benardos and Vosniakos [27] also used neural networks and the Taguchi design of experiments in order to predict the surface roughness of machined parts. Franco et al. [28,29] developed a geometric model that predicts the surface roughness and profile in the process of face milling with round insert cutting tools. Their work was focused on axial and radial runouts. The experiments that they conducted were with 1 and 4 cutting inserts.

The development of cutting force models is the main subject of many researches. Chang [30] and Zheng et al. [31] developed a mechanical model with empirical