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An intelligent wheel position searching algorithm for cutting tool grooves with diverse machining precision requirements

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A R T I C L E I N F O

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A B S T R A C T

Searching for and adjusting to the appropriate wheel positions for designed grooves are among the key issues in the manufacturing of the end mill, drill and other integral cutting tools. Along with the increasing requirements of product categories and quality, a large number of non-traditional and customized grooves continuously appear. However, as multivariable, nonlinear and multiple target problems, it is difficult to obtain the desired wheel position. Therefore, we introduce an intelligent method to search for the optimum wheel position for the designed groove with the known wheel geometry. According to practice, the basic parameters of the groove and wheel geometries are introduced, and the problems studied in this paper are explained. As a foundation, a robust algorithm is built to predict machined grooves with a series of equal distribution points and three parameters: the rake angle, core radius and groove width. The influence that the wheel positions have on groove geometries is then analyzed. Then, an objective function considering different machining requirements is built, and the optimum wheel positions are searched for while the function is solved. Furthermore, an enhanced niche particle swarm optimization (NPSO) algorithm is developed to solve the problem. Finally, 6 experiments are carried out to verify and analyze the algorithm. The results show that the algorithm can effectively find the desired wheel positions according to different machining precision requirements.

1. Introduction

A groove is a key component of the structure of end mills, drills and other integral cutting tools. It has a great impact on the tool stiffness, practical rake angle, cutting force, cutting temperature, and chip removal ability. To obtain satisfactory cutting performances, more new and different grooves are being designed according to today's diverse processing requirements. Thus, an efficient, accurate and economical method to machine the designed groove is desired.

Currently, the designed groove can be machined in two ways: (1) by matched forming wheels and (2) by existing wheels with 5-axis grinding machines. The second method is more economical and time saving and its key bottleneck is to find the appropriate wheel positions to meet the groove design precision. Basically, two problems need to be solved: (1) predicting the machined groove with the known wheel geometries and positions and (2) finding a rule for how the wheel positions influence groove geometries.

The groove is mainly predicted by three methods: analysis, graphic and Boolean. The analysis method primarily predicts the machined groove with the implicit or explicit mathematical expressions. Kang [1] and Hsieh [2] established their method with the contact line formula derived by the envelope theory. Armarego and Kang [3,4] built it with the trajectory of the singular point located on the wheel generatrix. Additionally, Zhang et al. [5] solved the connected point of the envelope and trajectory groove by translating the surface envelope to the curve envelope. Alternatively, Nguyen and Ko [6] built a universal groove prediction model by substituting the singular points with a series of normal vectors. Thus, the model was simplified and could be solved using envelope theory. Wang and Chen [7] deduced a prediction model for the 1V1-type wheel by combining the analysis and graphical methods. Xiao et al. [8] derived the explicit expressions of groove geometries, including the rake angle, core radius and groove width. The graphical method focused on finding groove section points by dispersing the wheel and the tool blank. Ko [9], Uhlmann and Hübert [10] obtained the groove section

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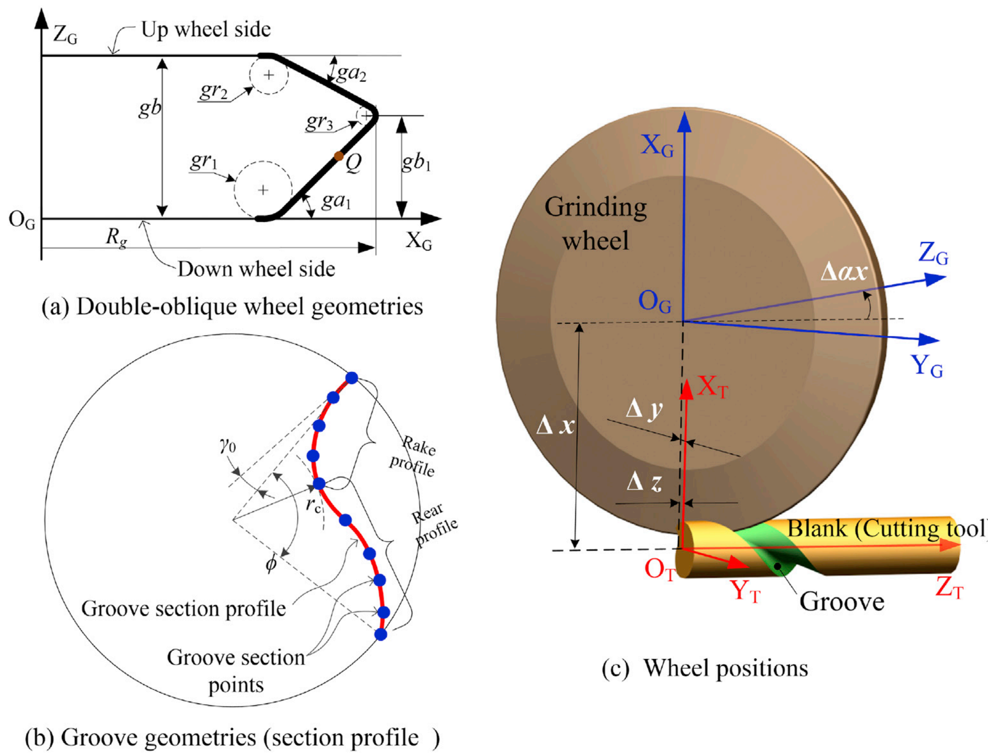

Fig. 1. Basic parameters for cutting tool groove manufacture. (Three basic groove parameters: rake angle γ_0; core radius r_c; and groove width ϕ).

points by dispersing the wheel and tool blank into a series of discs and tubes. Alternatively, Beju et al. [11], Li et al. [12] and Karpuschewski et al. [13] calculated the points set on the blank section plane left by the wheel surface family during the machining process. The groove section curve was then identified by a boundary searching method. In the Boolean method, the groove machining process was treated as a series of Boolean subtraction operations, where the tool blank was the "objective" and the wheel was the "tool". With the development of secondary technology, the groove prediction model was obtained using AutoCAD and UG software [14–18]. Most grooves can be predicted by the methods mentioned above. However, the intelligent wheel position searching process discussed in this study needs a more efficient and robust groove prediction method because inconceivable grooves may be machined during the searching process and many iterations may be executed.

To find the rule determining the influence of wheel positions on groove geometries, Ko [9] discussed the overcut defect in the groove machining process and noted that the improper wheel diameter and positions are the main reasons. Kang [19] and Hsieh [2] stated that the

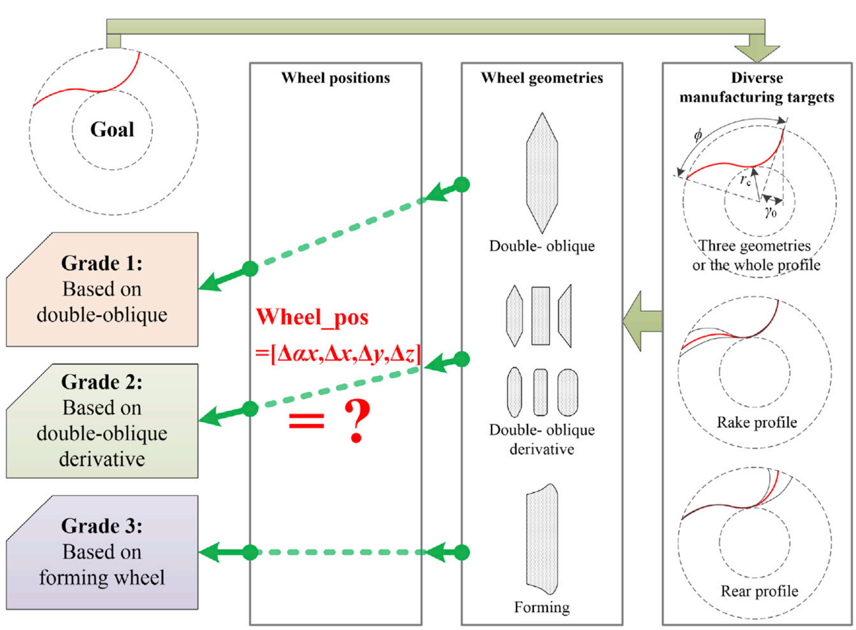

Fig. 2. Three machining grades for cutting tool grooves with diverse machining precision requirements (Grade 1: machining the designed groove with the existing DOB-type wheel by adjusting its position; Grade 2: machining the designed groove by adjusting the DOB-type wheel geometries and positions; and Grade 3: machining the designed groove by the forming wheel.).