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Optimisation of roughing operations on CNC machining centres for complex sculptured surfaces using AI methods

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Abstract

In industrial practice, rough machining of sculptured surface parts is planned on a CAM system; users choose the roughing strategy, the milling parameters and their values. According to these choices, the CAM system creates toolpaths, performs machining simulations, and extracts statistics of the created toolpaths, such as machining time, toolpath length, etc., as well as the machined product model. Thus, rough machining quality of a sculptured surface part depends on the user's choices, which are based on his/her personal experience of the machining process and his/her familiarity with the specific CAM system.

The main objective of the current thesis is formulation and development of a methodology, which provides the optimal cutting conditions for sculptured surface part roughing, regardless of the user's experience, and actually improving on the current industrial practice.

Application of such an optimisation methodology requires suitable modeling of the studied problem, as well as determination of quality goals regarding the machining process result.

Development of the methodology is demonstrated on a typical and widely employed commercially available CAM system (PowerMill). Under the scope of full exploitation of the CAM system's routines and operations, software was developed in Visual Basic for Applications to automate argument passing to the CAM system and essentially drive it externally, so that it can interact with other software.

A first approach into rough machining optimisation was formulated as follows: a typical Genetic Algorithm (GA) exploits the output of Artificial Neural Networks (ANN), which predict the rough machining Quality Characteristics, thus constituting the Objective Function of the GA, after appropriate weighing. The first step in this approach is to determine the statistically significant rough machining parameters, based on Design of Experiments (DoE) as introduced by Taguchi. DoE is followed by ANalysis Of VAriance (ANOVA), which points out the statistically influential process parameters according to the proposed Quality Characteristics (Machining Time and Total Remaining Volume at the end of rough machining). ANNs were trained by the data set – input and output values – gathered through the implementation of DoE; thus, the ANNs were used as surrogate models (meta-models) of the machining process, predicting Quality Characteristics' values. The proposed method was implemented for a certain sculptured surface part. It was proven that, despite ANN fast response, ANNs are not precise enough, when trained by a limited size data set, as the one resulting from DoE implementation, however appealing this notion originally appeared. Besides, ANN model performance depends strongly on the geometry of the part under study.

In a second approach, a two-objective (Machining Time and Total Remaining Volume) rough machining optimisation problem was formulated, bypassing the use ANN prediction models. Optimisation was realized on evolutionary optimisation software (EASY). Three two-objective optimisation methods were applied – GA, GA with Inexact Pre-evaluation (IPE) phase and GA with a specially shaped Two Player Nash Game, in order to determine optimal rough machining parameter values. These methods were compared to each other as far as computational cost was concerned. Although the Nash Game was proven as fast computationally as the GA with IPE phase, it still presents a single optimal solution, by contrast to GAs offering a set of optimal solutions, and, in addition the optimal solution value depends on the variable distribution among the players of the Game.

The notion of the third approach stems from the fact that the two objectives mentioned above lead to optimal solutions that ignore the local shape of the remaining volume of the roughed part. Thus, a new – original – optimisation objective is formulated as the Standard Deviation of Difference in "Shape" between roughed and designed part. At first, a calculation method of the Standard Deviation was developed utilizing projection routines available in the CAD software; projections were determined from the roughed part onto the designed part. Levene hypothesis test was used to prove that a small portion (3% in cases studied) of the triangles, which describe the roughed part, is sufficient to reliably calculate the Standard Deviation of Difference in "Shape". This projection method, however, is computationally very expensive owing to the repetitive usage of "expensive" CAD functions. A much faster method was developed instead, which takes advantage of a "cloud" of points taken from the designed part for the calculation of the difference in "shape".

A three-objective (Machining Time, Total Remaining Volume and Standard Deviation of Difference in "Shape" between roughed and designed part) optimisation of rough machining parameters was ultimately developed conjugating two evolutionary algorithms: a commercially available GA (EASY) and a Micro-Genetic Algorithm (μ-GA) that was developed from scratch. Conjugation of the two algorithms was realized in such a way that no approximations were needed in modeling the rough machining problem, thus avoiding partially optimal solutions. The μ-GA was used to determine optimal Z height distribution of the rough machining strategy slices. The μ-GA performs single-objective optimisation and its Objective Function is the weighed geometric mean of the values of the objectives mentioned previously. The GA performs three-objective optimization, while it optimizes the values of the rough machining parameters, as they are defined in the used CAM system. The design variables of the GA are: Cutting Tool, Stepover, Thickness, Number of Stepdowns, Profiling switch, Raster Angle, Allowance switch, Infinite Range switch, Feed per Tooth of the Cutting Tool and Spindle Speed of the CNC machine tool. Conjugation of GA and μ-GA enables the method to cope with problems related to modeling parameters that vary in number and value at the same time, such as the Number of Stepdowns parameter of the proposed rough machining strategy. Thus, the value of Number of Stepdowns parameter determines the size of μ-GA population chromosome. The GA and the μ-GA exchange data concerning parameter and objective values via files.

The optimization method of the conjugated GA and μ-GA was implemented for three sculptured surface parts: a simplified hip prosthesis, similar to the ones used in the Orthopedic Surgery, an industrial compressor fin and a turbo-machine fin. Different design techniques were used for each part and their real-world counterparts are functionally different. The resulting Pareto fronts consist of sets of optimal solutions, out of which solutions corresponding to different objective values may be selected, depending on the machining goals of the user or the machinist.

The main contribution of the thesis in the field of planning rough machining of sculptured surface parts is that it proposes evolutionary methods as practically viable, it copes with a large number of optimization parameters, it proposes multi-objective optimization and alternative regions of optimal solutions and, last, but not least, it builds directly on the same practical tool as the one used in industrial practice, i.e. on CAM systems.