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Intelligent optimisation system for sculptured surface finishing on CNC machining centres.

PhD Thesis
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Abstract

The present Ph.D. thesis deals with the development of an intelligent optimization system for the manufacturing of sculptured surface mechanical parts. More specifically, for those sculptured parts that are manufactured by conventional cutting processes, the finishing stage is examined.

The main goal of the finishing stage is to satisfy all the morphological (for example dimensional and/or geometrical tolerances) and qualitative (for example surface roughness) requirements that would render the final part in accordance with its technical specifications. This presupposes the appropriate choice of the process parameters' values, so as to give the final part the desired characteristics.

The most important obstacles in achieving the above goal are three. Firstly, the fact that there is not a unique correlation between the process parameters and the result of the process, meaning that there is not only one combination of values that satisfies the accuracy requirements. Secondly, the fact that there is a possibility for the process parameters to constantly change along the toolpath due to the complex geometry f the sculptured surface parts, meaning that the values of the process parameters must change accordingly. Thirdly, the particularities of the equipment used, especially of the machine tool – cutting tool – workpiece system. Despite the efforts to address these obstacles, a comprehensive and practically feasible methodology for the determination of the process parameters' values has not been established until today and therefore the finishing stage mostly remains experience based.

The main objective of this thesis is to develop a methodology that not only takes into consideration all of the above problems but at the same time formulates and applies criteria based on which the finishing stage can be optimized. The key hypothesis is that even though the cutting forces are relatively small in magnitude during the finishing stage, their fluctuation can be large enough to be responsible for dimensional accuracy and surface quality errors in the final part. In this aspect, the methodology initially determines the cutting force through an artificial neural network (ANN) model and then the optimal process parameters' values through a genetic algorithm (GA).

The detailed presentation of the development of this methodology is carried out in the seven chapters of the present thesis.

In the first chapter, the literature survey is given regarding the relationships between the cutting forces and dimensional accuracy and surface quality characteristics both for conventional cutting forces in general and for sculptured surface parts in detail.

The second chapter acts as a bridge, presenting the philosophy of the methodology and its basic hypotheses. The various components are commented on as well as the methods and tools that were selected to materialize them. In brief, the cutting force is calculated through an ANN model that contains controllable process parameters in the input layer. The model is trained with experimental data measured and recorded with the help of a low cost cutting force measuring assembly, developed during the thesis, allowing for the experiments to be executed in the same equipment that the actual cutting process will be carried out. The trained ANN model is subsequently incorporated in a GA responsible for optimizing the process parameters' values.

In the third chapter, the description of the calculation of a crucial element of the ANN model is given, which is the removed material volume per cutting tool revolution. Its importance lies in the fact that it is able to correlate the part geometry with the shape of the toolpath, thus providing a representation of the resistance that the cutting tool is experiencing at any given moment during cutting. At first, a Z-map approach was attempted, to be finally rejected due to great computational cost in favour of an alternative approach based on geometric Boolean operations between accurate 3D solid CAD models of the roughed workpiece and the cutting tool.

In order for the good performance of the ANN model to be guaranteed, a new method for determining the best feedforward ANN architecture was created and is presented in the fourth chapter. Essentially, it is an evolutionary process relying on criteria that quantify both the generalization ability of the ANN model as well as the complexity of its architecture.

The fifth chapter encompasses the experimental procedures of the thesis. The Design of Experiments (DoE) procedure is described that produces the necessary data to train the ANN model for the determination of the cutting force. This data contains the particularities of the machine tool – cutting tool – workpiece system, as they are reflected in the measured cutting forces. The latter were measured and recorded with the help of a low cost, piezoelectric sensor based, measuring assembly, which was designed and developed within the scope of the thesis.

In the sixth chapter the optimization method of the finishing stage is described that, as has already been stated, uses a GA incorporating the ANN model. The main optimization criterion is the minimization of cutting force fluctuations, but the fact that the ANN model is incorporated in the GA practically means that any desirable cutting force pattern can act as the optimization criterion. Emphasis is also placed on the ability to apply the methodology either to the whole toolpath or to certain sections of it and with varying resolutions (density of cutting tool positions). Finally, the results from the application of the methodology to case studies are also presented in this chapter.

The seventh chapter deals exclusively with the critique of the results and the corresponding conclusions. It is proved that the developed system is capable of determining the optimal process parameters' values, simultaneously containing the knowledge that, until today, the human factor should possess and all this through a directly practical and applicable to real life conditions procedure. The thesis concludes with suggestions for possible future extensions.

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