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Correcting geometric deviations of CNC Machine-Tools: An approach with Artificial Neural Networks

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ABSTRACT

This paper presents an experimental methodology of Design for Manufacturing (DFM) used for survey and analysis of geometric deviations of CNC Machine-Tools, through their final product. These deviations generate direct costs that can be avoided through the use of Intelligent Manufacturing Systems (IMS), by the application of Artificial Neural Networks (ANNs) to predict the fabrication parameters. Finally, after the experiments, it was possible to evaluate the experimental methodology used, the equations, the variables of data adjustment and thus enable the validation of the methodology used as a tool for DFM with high potential return on product quality, development time and reliability of the process with wide application in various CNC Machines.

1. Introduction

Along with machine-tools (MT) evolution, there have been great advances in machining processes. However, obtaining complex surfaces with tolerance in the micrometric range has become extremely difficult. At the same time, the machining manufacturing process control has been evolving to attend the technical challenges imposed by complex requirements of form, by narrow specification limits and by the frequent introduction of new materials, tools and operational variables that originate new interactions in the processes with non-linear and non-standardized characteristics [1–4].

In the current manufacturing environment, indirect manufacturing operations generate direct costs that can be avoided or reduced by using control systems [5,6]. The use of Intelligent Manufacture Systems (IMS) has been researched through the application of Artificial Neural Networks (ANNs) since 1980 [7].

In this context, an important methodology of predictive engineering is the Design for Manufacturing (DFM). It incorporates, in the project processes, information referring to the manufacture, also allowing for the project to be adapted during each stage of production [8].

This paper presents a study where, at first the geometric deviations of a machine-tool are analyzed through the unfinished product. Afterwards, ANNs are used to develop models to minimize error prediction of the milled surface. A DFM approach is proposed to implement in the Computer-aided design (CAD) software, through the existing Application Programming Interface (API), the parameter soft correction/control of the geometric deviations compensation, before the manufacturing of the products. Finally, some practical experiments are discussed to evaluate the proposed approach.

2. Literature review

2.1. Machine-tools

Machine-tools (MT), also called tooling machines, were initially defined as machines used in the manufacturing of pieces of

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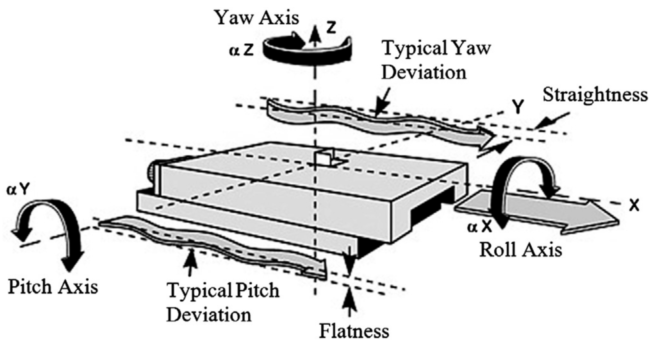

Fig. 1. Geometrical errors on the trajectory of a positioner.

various materials through the mechanical movement of a tool kit. As early as the 1970s, with the development of microprocessors and precision technology, the computerized numerical command (CNC) made possible the so-called CNC manufacturing [9].

A manufacturing center is a CNC machine-tool equipped with tool magazines that allow the execution of a group of sequential manufacturing operations. These machines have automatic systems of tool changes and a set of indexed axes. The displacements of these axes are based on the definition of the coordinates of the points to be covered. This axes system is defined by DIN 66217 standard, according to ISO R841 recommendation. However, CNC programming starts by the geometric elements definition (dimensions, solids, 3D, etc.) in a Computer-aided manufacturing (CAM) system. Based on this information, the elaboration program takes place. The designer can opt for the following methods: (a) manual programming; (b) interactive graphic programming; (c) CAD/CAM systems [10].

2.2. Geometric errors or beat deviations (runouts) in machine-tools

According to Schwenke et al. [11] and Tian et al. [12] there are three main geometric errors sources for machine-tools, namely: (1) errors due to geometric deviations, (2) errors due to heat effects and (3) errors due to forces.

Adding to the above, geometrical errors are a linear part (versus angular) of the non-axial errors. That is, geometrical errors can be characterized by two orthogonal straight components, one measured on the deviation plan (straightness) and another measured out of the deviation plan, (flatness) [13,14], as shown Fig. 1.

Geometrical errors are originated from mechanical imperfections in the machine-tools structure and the misalignment of their components [11]. As a result, we have a lack of parallelism and perpendicularity in the movements of many components, causing errors of form and position [12]. Inclination and oscillation errors (Tilt, Wobble) correspond to the angular part of geometrical errors. They represent the deviations between the ideal straightness movement and the real movement in a translation. The inclination and oscillation problem has three orthogonal components called Roll, Pitch and Yaw, also shown in Fig. 1. These terms are generally used to name the global geometrical error of the positioner, since it contemplates all deviations of this kind [11].

Gangwei et al. [14] and Ramesh et al. [15] cite other sources of possible errors, among them: radial error, tilt error around an-axis, errors due to heat effects, errors due to forces, kinematic errors, errors due to material instability, instrumentation errors, cut tool wear, fixation errors and servo-position errors (movement and interpolation errors). In Okafor and Yalcin [16], Chana and Parnichkun [17] and Chen et al. [18], 21 different geometrical errors are cited, being possible to occur in a 3-axis vertical machining.

2.3. Design for Manufacture

According to Bogue [19], Design for Manufacture (DFM) originated in 1960 in the General Electric Corporation. In the 1970s, Boothroyd and Dewhurst presented studies which brought many productive factors to the product development using the assembling time as a parameter for the product analysis. For Bralha [20] and Boothroyd et al. [8] DFM today tries to conciliate simultaneously the project goals with the manufacturing limitations, emphasizes manufacturing and processes aspects avoiding manufacturing problems in future stages. DMF is therefore a systematic approach that allows the engineers to foresee production problems at the beginning of the conception process.

According to Hoque et al. [21] the difficulties found in the implementation of this technique are directly related to the need to work in a Computer-Integrated Manufacturing (CIM) environment and the availability in the market of few CAD, CAM and computer-aided process planning (CAPP) systems that offer the possibility of estimating manufacturing costs and processes optimization.

2.4. ANN and machining processes

The use of Manufacturing Intelligent Systems (MIS) by applying artificial neural networks (ANNs) has been researched since the 1980s. Several researchers have proposed the use of machining models as a solution to many problems using Computational Intelligence (CI) techniques [1–7].

In this context, ANNs are been employed and applied with the objective of controlling and optimizing of cutting conditions [22]. Tandon and El-Mounayri [23] studied the cutting force for developed a model to predict parameters for end milling. On the other hand, Panda et al. [24] and Yang et al. [25] used ANN for prediction of drills wear out through data capturing by sensors, measuring and controlling of machining forces. Briceno et al. [26] developed an ANN with *back-propagation* (BP) training to estimate milling parameters, Zuperl and Cus [27] applied a similar network to predict the three cutting forces (*Fx*, *Fy*, and *Fz*) in the machining of molds. Similarly, Zuperl et al. [28] developed two supervised network models to control the three components of forces using many parameters of entries, such as, cutting fluids, hardness, material, etc. Leite et al. [29] studied and developed ANN models for evaluating the influence in the geometry and surface finish of different milling strategies, thus generating a set of maps/answers of analysis and prediction.

In his work on machinability of reinforced polyamide composite, Karnik et al. [30] studied the drilling of composite plates through ANN to develop a prediction model for the drilling effects under different conditions. For its part, Mishra et al. [31] developed a predictive model of the residual resistance to traction to perforate plastic reinforced fibers (FRP) using ANN.

Finally, the surface quality, mainly characterized by the surface roughness, is an area for which the machinability models using CI techniques have also been investigated, for example, in the prediction of surface roughness in high-torque face milling operations, combining multilayer perceptrons (MPL) with genetic algorithms [32–35]. However, ANN uses for control of roughness statistical are characterized by a great variability in the adopted techniques, as described both in Correa et al. [36] as Çaydas and Hasçalik [37].

3. Methods

This paper uses the DFM methodology described by Gupta and Nau [38] to evaluate machining capability during the initial phase of a work-piece's project, based upon its geometry and on the tolerance of each operation involved in its fabrication to generate