Dynamic modeling of cutting processes

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Abstract
The prediction of the tool tip deflection, both static and dynamic, is a very hot issue for the machine tool and CAM manufacturers. Once a reliable prediction would be possible, the correction of the tool path will improve considerably the machine accuracy or allows faster production cycle. This paper proposes a general scheme of a simulation model based on the adaptive FE mesh of a machined component that take care also of the tool and machine deflection due to inertia and cutting forces. The model is programmed to include as modular blocks all the previous feature in order to save computational time. The results of experimental tests to validate some modules are reported.

Keywords: dynamic simulation, flexible multibody, cutting forces

1 INTRODUCTION

In the last years many efforts have been dedicated to the improvement of the accuracy of three and five axes machine tools. However, if the optimization methods based on simulation work well for the three axes machine [1] this is not fully true for the five axes machine, due mainly to the greater geometrical complexity and difficult error measurement. For these machines the most common solution is the development of a error map to predict the quasi static error, as suggested by Kiridena et al. [2] or more complex volumetric error model as the Denavit-Hartenberg transformation proposed by Srivastava [3]. These models are however static or quasi static while an open issue is still the dynamic behavior of the machine. Most recent studies have been so focused on the modeling and often improvement of the dynamic behavior of the machine tools in order to increase their performances. Interesting approaches have been proposed by Ast et al. [4] for the implementation of an active damping system and by Lin et al. [5] that proposes a strategy based on the introduction of counterweight to reduce the vibrations. Regarding the static deflection most of the authors, like Lei et al. [6], proposes solution based on the inverse kinematic analysis of the geometric errors of the machine in order to correct automatically the tool path. The general idea of this paper is to develop a fully simulative model that would take into account both the kinematic and the dynamic behavior of the machine, including also the regenerative vibration due to the machining process. This issue is rarely included in the simulation of milling process due to the complexity of the geometry but it is usually included in turning simulation. With this simpler machining process the application of predictive and corrective action to take care of this problem have proven very good results, as presented by Devillez [7] . An analytical model to predict such behavior in milling has been recently proposed by Arizmendi et al. [8] even if it is limited only to very simple tool path. The proposed approach has been applied to a Mori Seiki NMV1500DCG, a 5 axes high performance milling machine, kindly loaned to the authors by the MTTRF foundation.

2 DESCRIPTION OF THE MODEL

The general scheme of the model developed includes some different modules for the evaluation of the vital issues of the machining simulation. These modules are organized as in the scheme reported in Figure 1.

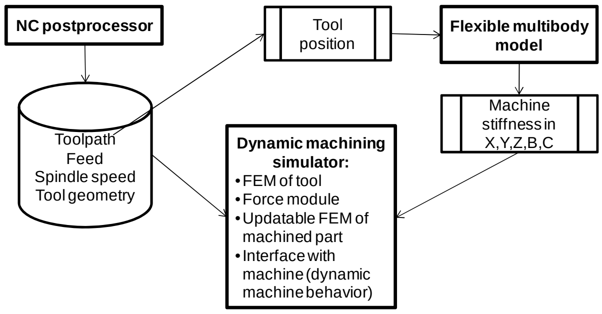

Figure 1: Scheme of the organization of the simulation approach

The core of the system is the dynamic simulator that predicts the temporal behavior of the tool based on the information of the flexible multibody and force evaluation modules. The dynamic simulator is a dynamic Finite Element (FE) simulation of the product to be machined and of the tool: this is able to predict the tool deflection due both to vibration and cutting forces. The FE model of the milling tool could be assumed as a cylindrical part with a bending and torsional stiffness along its axis that must be representative of the true behavior of the tool. This means that the tool behavior could be simulated using its true geometry, or experimentally tested, only once; the model obtained could then be reduced and simplified in order to let the dynamic simulator be faster [9]. On the other hand the component to be machined must be represented using an adaptative mesh, at least along the tool path. The machined workpiece must be modeled with a coarse mesh, while for the machining allowance a refined mesh is to be used in order to consider also the effect of the material removal rate on its dynamic (vibrational) behavior: during the simulation the chip volume is removed, according to the kinematic of the cutting. The nodes of the stock allowance are tied to the finished surface thanks to a glued interface, which uses a constraint formulation in order to avoid small penetration, usually permitted with the penalty approaches used in other type of contact equations. The tool considered in this work is a flat end mill with two flutes, which has been modeled as a solid beam: two sets of diametral nodes identify the cutting edges of the tool with a helix angle of 30°. In Figure 2 is reported a picture of the