Improving Productivity in Machining Processes Through Modeling

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Abstract

Selection of appropriate cutting conditions is of great importance in order to achieve high productivity in metal cutting industry. Virtual machining, which make use of physical models considering both mechanics and dynamics of metal cutting, is a useful tool in achieving this objective. In this paper, use of science integrated machining approaches is demonstrated for selection of high performance cutting conditions. The results obtained from simulations of several industrial applications are utilized in selection of cutting parameters and the results are discussed through applications and experiments.

Keywords:

Machining, modeling

1. Introduction

Increasing demand for production of high quality parts at low cost and short lead time requires deep insight into the process at the manufacturing development phase. It has been shown that process simulation is very useful in order to decrease number of trials and to improve the machining operations. For instance, cutting forces may cause tool deflections and even tool breakage at extreme cases. Chatter vibrations, on the other hand, deteriorate the surface quality and in the long term they may even damage the machine tool. High cutting forces and chatter vibrations can be eliminated by using conservative cutting parameter at the cost of decreased productivity. On the contrary, using process models help selection of cutting parameters in such a way that high cutting forces and chatter vibrations are eliminated keeping the productivity at the highest possible level.

An overview of virtual machining is given in [1] which shows that geometric calculations are also necessary in modeling of a machining cycle in addition to the process mechanics [2]. One of the most challenging parts in modeling of complex machining operations is to predict the cutter engagement boundaries [3]. There are several software developed for physical simulation of the machining processes. In this paper, after a brief overview of the models, their use in real industrial applications is shown and discussed.

2. Modeling of Machining Process

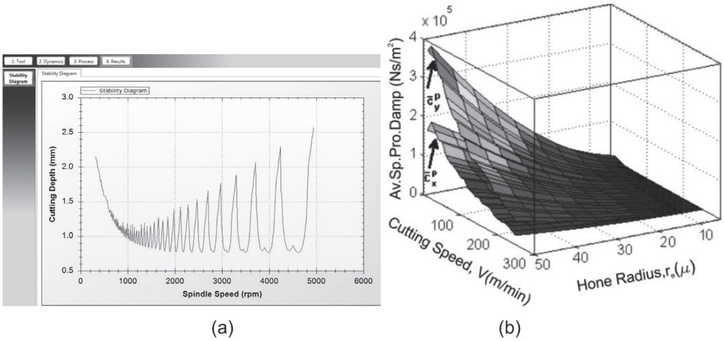
Process modeling is one of the most important steps in order to conduct physical simulation of the cutting operation in computer environment. Modeling of cutting mechanics for calculating cutting forces, power and torque is the first usual step. The second step is to model dynamics of cutting, i.e. chatter vibrations, and process stability. Several transformations are usually needed in order to model real-life industrial applications.

2.1 Cutting Mechanics

The approach used to model the cutting mechanics is developed for orthogonal cutting and then extended to oblique cutting and industrial machining operations. The thermo-mechanical model includes mechanical behavior of the work material in the primary, secondary and the third deformation zones [4, 5]. The analytical nature of this approach makes the computation very fast as compared to the numerical methods such as the Finite Element Method which is also used in modeling of cutting operations. In addition, the thermo-mechanical model needs very limited number of calibration tests compared to mechanistic models. In this method, the primary shear zone is modeled using the thermo-mechanical model and material constitutive relationship where both sticking and sliding contacts are considered in the second and third deformation zones. The model needs Johnson-Cook material constants and sliding friction coefficient which are identified through orthogonal cutting tests. The shear angle is computed by using the minimum energy principle.

2.2 Cutting Dynamics and Stability

Chatter is one of the most important problems in machining causing high cutting forces, poor surface finish and shortened tool life. Stability models for machining operations provide stability diagrams which can be used for selection of chatter-free conditions. A generalized model of chatter stability for complex milling operations is given in [6]. Although stability diagrams are useful for high speed machining, some difficult-to-machine materials such as aerospace alloys can only be machined at slow cutting speeds where process damping is an important source for increased stability limits (Figure 1) [7]. The process damping mainly depends on the indentation volume between the flank face of cutting edge and the work material, which is a function of the cutting parameters and tool geometry as illustrated in Figure 1.

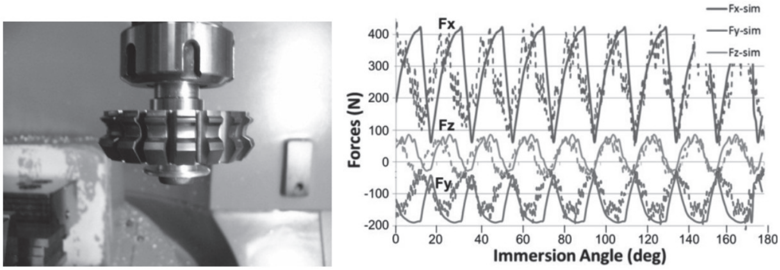


(a) (b)

Figure 1: Process damping (a) effect on low speed stability limits
(b) cutting speed and cuttimng edge hone radius effects on process damping.

2.3. Unified Cutting Model

In industrial applications there are several obstacles that prevent the direct application of these models. One of them is the cutting tools with complex geometries. Therefore, there is a need for a unified cutting model for different processes and cutting tools.In order to apply the aforementioned models to the industriral processes a generalized elemental division model is used [2, 3, 6]. The division should be selected carefullyconsidering the cutting geometry and computation time. The last step of the approach is to calculate the local cutting angles for each element in-cut which can be determined according to the element position. Once all these parameters are calculated the local forces and vibrations can found and transformed into cutting tool or machine tool. The unified model is applied on a multi segmented cutting tool with 18 cutting edges (Figure 2) where a good agreement is seen between simulations and experiments.



(a) Profiling tool used in the test. (b) Simulated (-) and measured (---) cutting forces

Figure 2: A complex milling tool geometry with force measurement and simulation results.

The proposed chatter stability solution for generalized tool geometry can be seen in Figure 3. The limiting axial depth of cut is calculated for each disc and compared with the total disc height. The iteration continues until convergence is satisfied. The predictied and experimentally determined stability limits for a bull-nose end mill as can be seen in Figure 3.

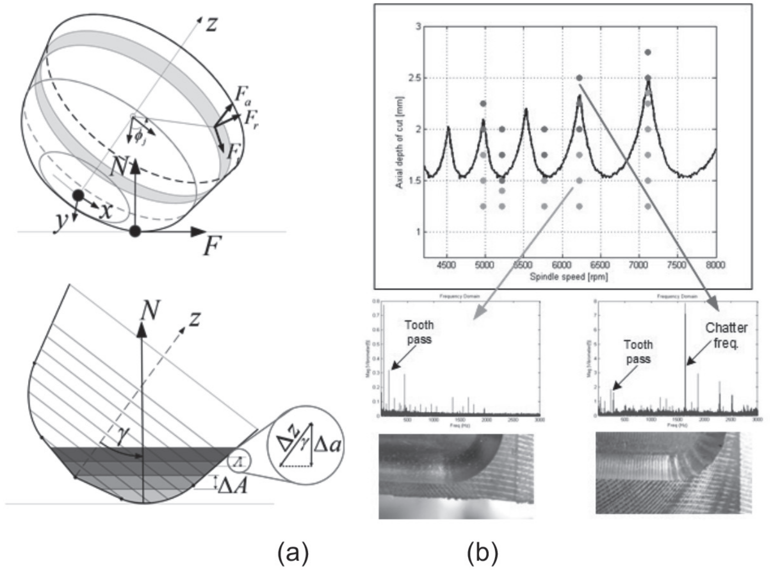


Figure 3: (a) Axial division of cutter (b) Simulation and experimental results for a bull-nose milling tool.

3. Machining Cycle Simulation

In this study, dexel based Z-mapping method is used to determine the engagement boundaries along a milling cycle and to update the in-process workpiece where the details are summarized in Figure 4. The rough workpiece information is obtained in STL format, whereas the cutting tool information is obtained using the standard tool definition. Then, the workpiece geometry is converted into vectors on an equally spaced grid, storing the Z values of the workpiece geometry. The engagement boundary is determined using the intersection use of the workpiece grid by each tool patch is determined.

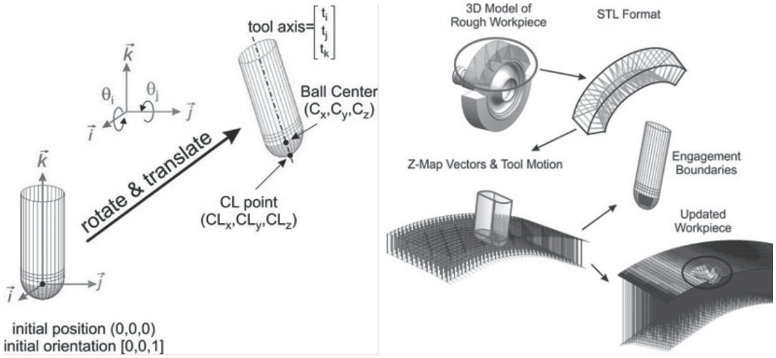
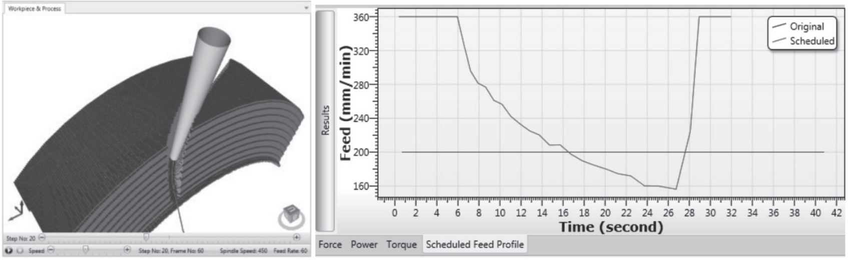


Figure 4: Application of Z-mapping method and modeling of tool motion for cycle simulations.

4. Example Application

5-axis flank mill roughing of a thin-walled part made of Ti6Al4V alloy is considered (see Figure 5). In the simulated process the total depth varies along the tool path and reaches up to 70 mm. There are approximately 150 CL points along the cutting pass and the forces are simulated per 4 CL points. According to the simulation results, feed rate scheduling is applied to keep the maximum bending force acting on the tool at predefined level. The scheduled and original feed profiles are plotted in Figure 5b. It is clearly seen that almost 20% of time saving is obtained through feed scheduling.



Step No: 20

Step No: 20, Frame No: 60

Spindle Speed: 450

Feed Rate: 60

(a) The simulated cycle (b) Original and scheduled feed rates

Figure 5: The simulated flank milling process results.

4. References

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