To link to this article: DOI:10.1007/s00170-010-2884-z
http://dx.doi.org/10.1007/s00170-010-2884-z

MODELING AND SIMULATION OF HIGH SPEED MILLING CENTERS DYNAMICS

El Bechir Msaddek[a] and Zoubeir Bouaziz[b]
[a, b] *Unit of Research of Mechanics of the Solids, Structures and Technological Development, ESSTT. Tunisia.*
elbechir.msaddek@gmail.com, zoubeir.bouaziz@enis.rnu.tn

Maher Baili[c] and Gilles Dessein[d]
[c,d] *University of Toulouse ; INP / ENIT ; LGP, 47 Avenue of Azereix, BP 1629, F-65013 Tarbes Cedex, France*
Maher.Baili@enit.fr, gilles.dessein@enit.fr

Abstract

High speed machining is a milling operation in industrial production of aeronautic parts, molds and dies. The parts production is being reduced because of the slowing down of the machining resulting from the tool path discontinuity machining strategy. In this article, we propose a simulation tool of the machine dynamic behavior, in complex parts machining. For doing this, analytic models have been developed expressing the cutting tool feed rate. Afterwards, a simulation method, based on numerical calculation tools, has been structured. In order to validate our approach, we have compared the simulation results with the experimental ones, for the same examples.

1. Introduction

High speed milling has very interesting characteristics in the scope of the realization of high quality mechanical parts in automobile industry and aeronautics (TOURNIER *et al*., 2005). The complex parts machining in high speed milling (HSM) allows to take off the maximum material in the minimum time (BLANCHARD *et al*., 2005). The geometrical shape influences the trajectories. The latter, characterized by speeds and accelerations, will be treated by the Numerical Controlled Unit (NCU) and will engage a certain imprecision (machine behavior) (MONREAL *et al*., 2001). Thus, the dynamic modeling becomes a necessity for the machining optimization (TAPIE *et al*., 2006).

Recent studies have been interested in the HSM machines behavior modeling for pockets and complex shapes machining. (MONREAL *et al*., 2001) and (TAPIE *et al*., 2006) have treated the influence of the tool trajectory upon the machining time in HSM. Moreover, Dugas (2002) and (Pateloup *et al*., 2004) have integrated the dynamic modeling of HSM machines by justifying the variation applied to the feed rate. In most studies, the feed rate variation is not justified; this is one of the aims of this paper. Besides, there are no other studies which numerically examine and analyze the tool trajectory influence in CAM upon the HSM machine feed rate for the pockets hollowing out.

In this article, we present a feed rate calculation dynamic model according to the tool trajectory. This modeling includes the jerk, the acceleration and the interpolation cycle time. Then, we simulate the feed rate for a pocket hollowing out and for a complex part machining with the 840 D Siemens controller. In the first part, the dynamic models development, of both the axis and controller permits to better express the real behavior of the HSM tool machine. In the second part, the exploitation of the modeling for the real machining feed rate simulation is realized in the case of two parts of different shapes.

2. The Tool-Machine NC dynamic Modeling in HSM

2.1. NCU behavior modeling

2.1.1. Tool path modeling by arc of circle

In CAM, the tool path C^0 (figure 1a) presents sharp angles, while changing direction. The NCU integrates connecting arcs (of R_j radius (1) in figure 1c) in order to avoid a violent deceleration. We obtain, then, the modified trajectory C^1 with continuity in tangency (figure 1b).

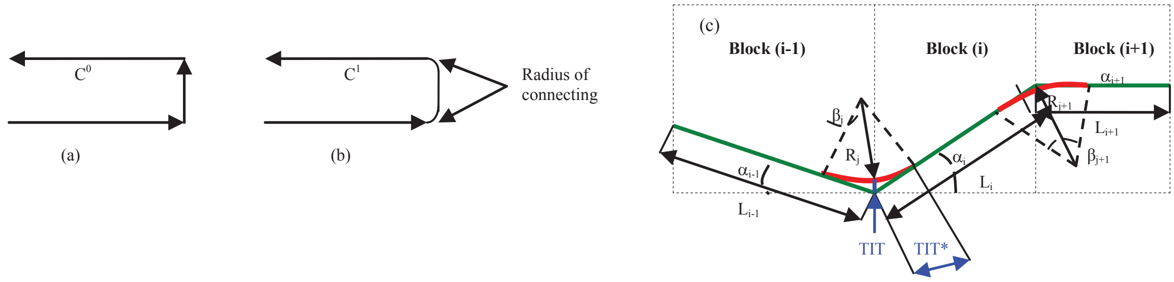

Figure 1. a) Tangential discontinuity. b) Connecting with arcs of circle. c) Trajectory modeling by arc of circle (Dugas, 2002).

$$R_j = MIN\left(\frac{TIT^*}{\tan(\frac{\beta_j}{2})} ; \frac{L}{2\tan(\frac{\beta_j}{2})} - TIT^*\right) \quad \text{With} \quad L=MIN\,(L_i\,;\,L_{i-1}) \tag{1}$$

2.1.2. Static Look Ahead

The HSM machines have at its disposal the interpolation axis X, Y and Z, and the NCU which are different at the level of their dynamic capacities. This is the origin of the static look ahead calculation (figure 2).

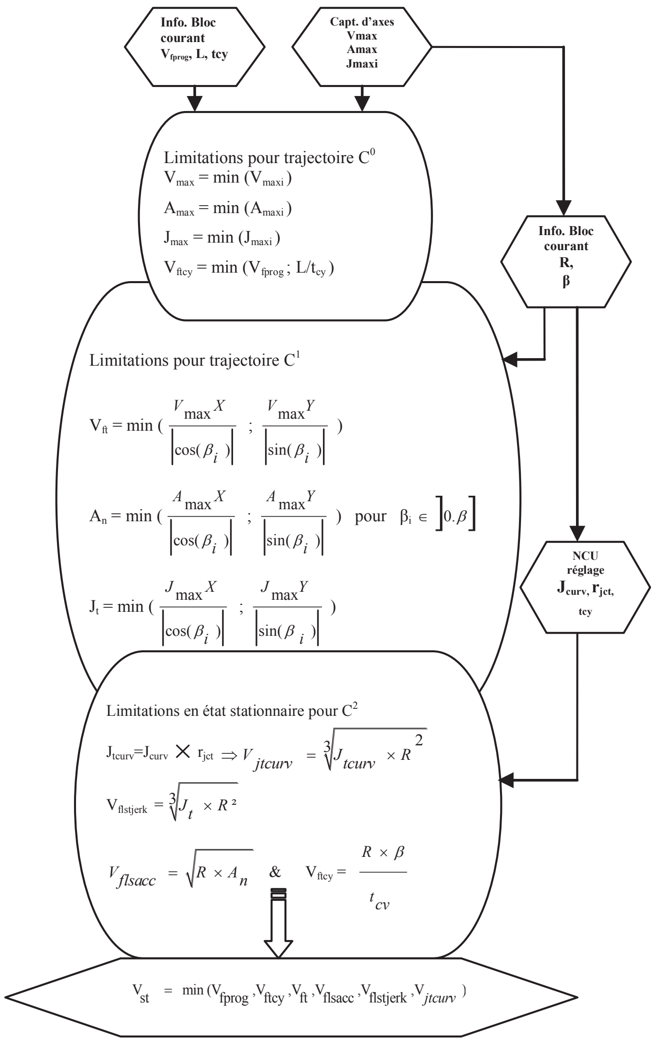

Figure 2. Static look ahead calculation (Tapis *et al.*, 2006)

The static look ahead, well describes the machine dynamic behavior, but this feed rate calculation is done in costume time for the running block unaware of the following block (violent deceleration in old machines). These problems are resolved by the integration of the dynamic look ahead (modern machines).

2.1.3. Dynamic look ahead

Thanks to the knowledge of the next blocks, the dynamic look ahead permits to anticipate in speed and in acceleration. Then, we must integrate the calculation model of the acceleration and deceleration distance.

➢ ***Calculation model of the acceleration and deceleration distance***

For a block i, the model of the distances d_{acc} and d_{dec} is the following:

$$d_{acc}(i) = \left(Vf\ (i) - Vf\ (i-1)\right) \times t_{cy} \tag{2}$$

$$d_{dec}(i) = \left(Vf\ (i) - Vf\ (i+1)\right) \times t_{cy} \tag{3}$$

3. HSM machining simulation

3.1. Machining simulation of a complex shape test pocket

3.1.1. Pocket definition and tool path simulation

A trajectory proposed by Cherif (figure 3a) (MEHDI, 2000) has been tested on a HSM machining center (IUT of Nantes / HERMLE C800U 5 axis - HENDENHAIN TNC430 - Acceleration 5 m/s²), for two programmed feed rates from 15m/min to 35 m/min. The tests have permitted to record the real feed rate during the time. A confrontation between the simulation results and the experimental ones will be realized in order to validate the developed simulation model.

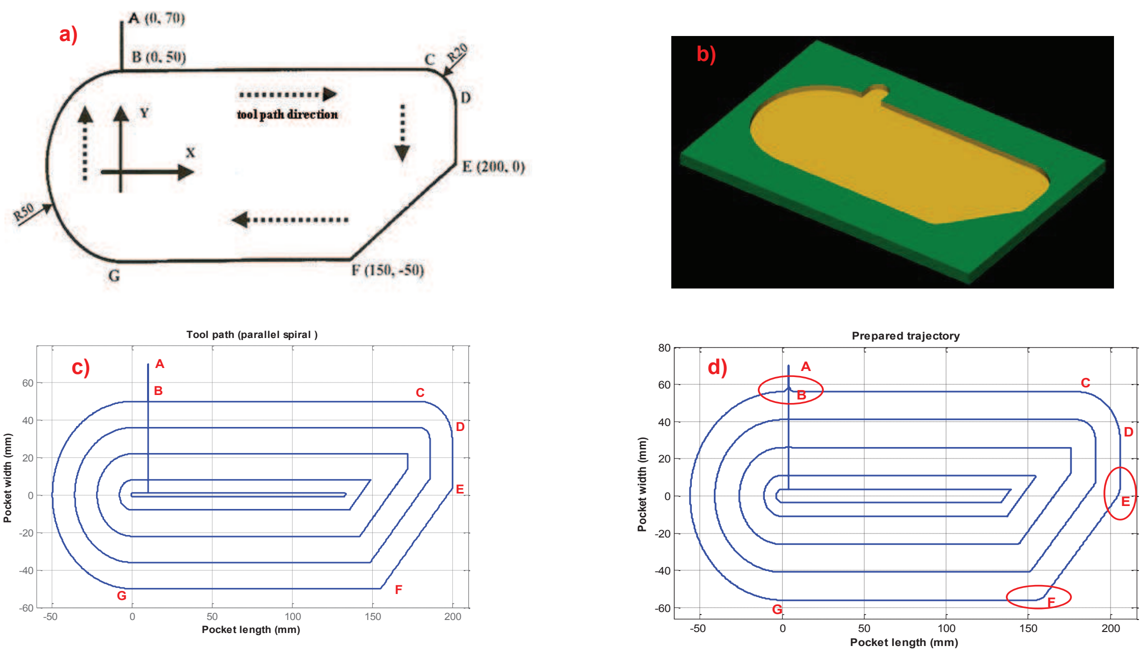

Figure 3 a) Tested trajectory (MEHDI, 2000). b) Pocket obtained by Mastercam©. c) Tool path simulated with Matlab©. d) Modified tool trajectory.

3.1.2. Real feed rate simulation

➢ ***Calculation of the Static Look Ahead type on the trajectory***

The integration of the dynamic behavior in the simulation is carried out by the calculation of the type static Look Ahead. The tool feed rate profile influenced by the HSM Hermle machining center (capacity of axis, discontinuities...) is simulated under Matlab©. This simulation corresponds to the CAM pocket machining for the programmed speed 15 m/min (figure 4).

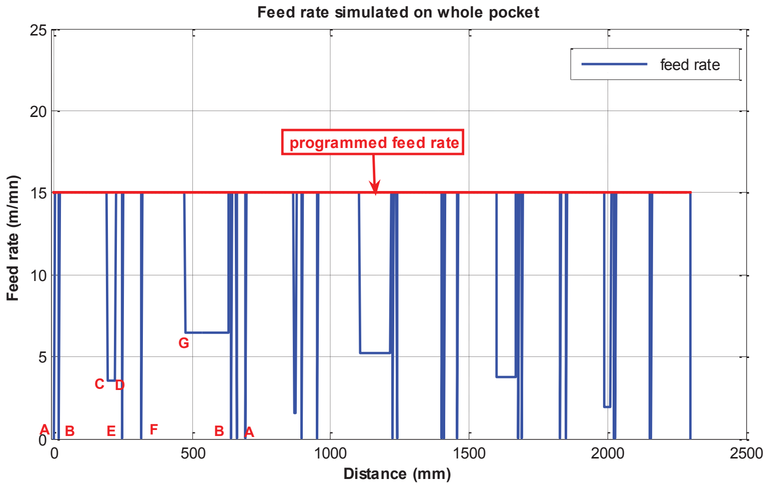

Figure 4. Simulated feed rate profile (Static Look Ahead) on the whole pocket.

The static look ahead describes the machine dynamic behavior. This is visible in the difference between the programmed and the real feed rate. This difference will be more obvious and will be examined in the feed rate profile generated with the dynamic look ahead.

➢ ***Calculation of the Dynamic Look Ahead type on the trajectory***

With the anticipation, we can avoid the overtaking caused by the violent decelerations. The feed rate profile, simulated with the dynamic look ahead and the parameters of HSM machining center Hermle C800U 5 axis (jerk 0.5 m/s^3), on the trajectory ABCDEFG (figure 3c), is shown in figure 5a. Then a comparison with the experimental statement (figure 5b) for the same trajectory tested on the HSM MC Hermle, is realized with the same programmed feed rate 15 m/min.

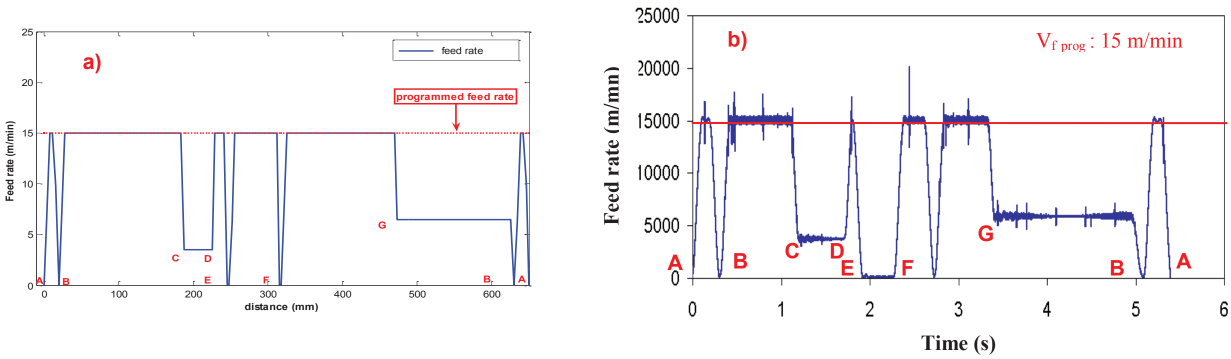

Figure 5. a) Real feed rate profile simulated with the dynamic look ahead on the trajectory ABCDEFG. b) Feed rate profile recorded experimentally (MEHDI, 2000).

The speed profile simulated (figure 5a) on the test trajectory (figure 3c) is very near (2% of error) to the profile of the experimental statement (figure 5b). We notice the influence of the anticipation on the speed profile in comparison to that of the static look ahead. The decelerations are known in advance and are carried out on the current blocks. That really describes the recent HSM dynamic machines behavior. The controller imposes these limitations according to the HSM machine axis characteristics and mainly the maximal jerk.

3.2. Machining Simulation and experimental validation of a complex part with connections

3.2.1. Part definition and tool path simulation

We have developed the simulation of the tool trajectory and of the machining feed rate (in linear interpolation G1) of a piece having two curvatures: one convex and one concave. Thus, we have succeeded in confronting the experimental results recorded by the CMAO team (ENIT France) in terms of speed profiles, following X and Z, to validate our simulation model. The machining is carried out on the 3 axis HSM Huron KX10 machine with NCU siemens 840D. The tool path (first pass of go and back trajectory) is simulated in the figure 6.

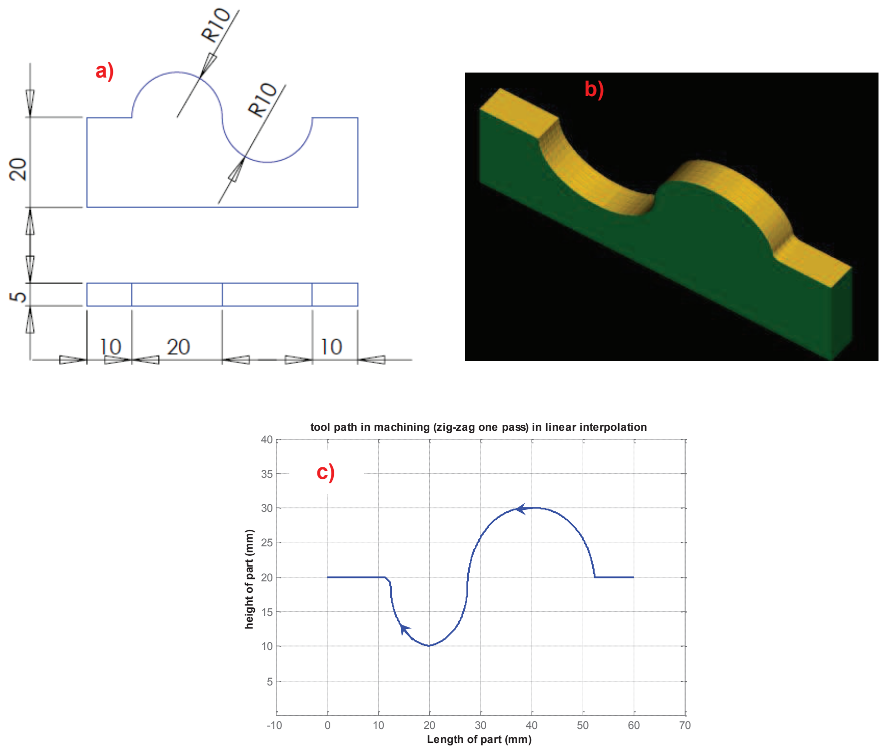

Figure 6. a) The drawing of a part definition. b) Virtual piece obtained by Mastercam©. c) A go and back simulated trajectory.

3.2.2. Feed rate profile simulation and validation with the experimental result

➢ ***Integrated arcs of circle model with compaction (C^1 trajectory)***

The feed rate profile generation in linear interpolation on Matlab© passes then by the dynamic modeling of the NCU of the HSM machine. One of the crossing models of tangential discontinuities is the integration of arcs between two linear blocks. Since the whole part machining trajectory is in linear interpolation, we adopt this model to estimate the NCU behavior, badly mastered during the passage of the tangential discontinuities. Besides, the NCU achieves the blocks compaction of small blocks into 5 mm segments. Afterwards, we are going to simulate the feed rate profile and compare it with that of the experimental statement.

➢ ***Feed rate profile***

Figure 7 presents the simulated and the measured feed rate profiles .The experimental statement speed profile for the Huron KX10 is measured for a set speed of 9.6 m/min.

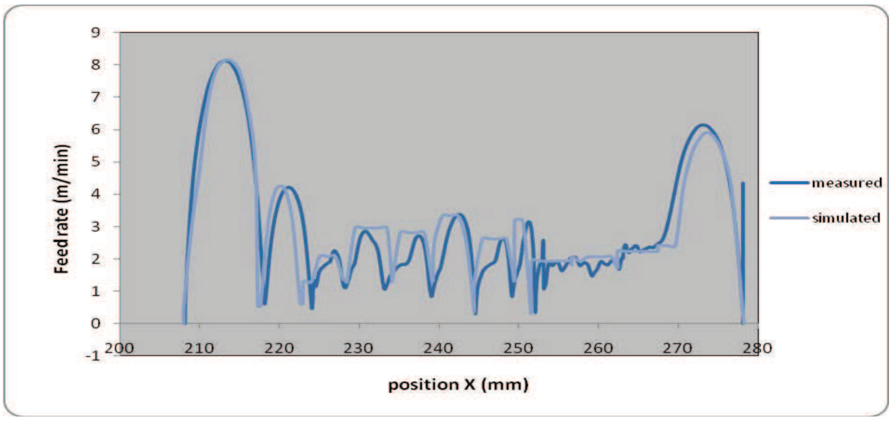

Figure 7. Feed rate profile simulated and measured on Machine.

- ***Comparison of the simulation result and the experimental statement***

We have simulated a speed profile by the arcs of circle integration model, with compaction. This profile is very near (5% of error) the experimental statement profile. But, there are some differences caused by a slight trajectory discretization. Hence, we notice that the compaction has conserved a more important value of the feed rate. For, it consists in compacting the blocks of small segments which provoke the slowing down of the machine, imposed by the interpolation cycle time t_{cy}. If we have less compaction, we will get more slowing down and consequently a greater machining time.

4. Conclusion

In this article, we have been interested in machining simulation of a pocket and of a complex profile. The objective is to introduce the dynamic modeling of the HSM machine in the simulation of a given trajectory. In a first step, we have detailed the HSM machining center dynamic modeling. Then, we have explained the passage of the CAM model towards numerical simulation software, passing through the modeling. In a second step, we have simulated the real feed rate of a pocket hollowing out. In the second part, we have been interested in the feed rate simulation of a complex part machining, in order to show the anticipation influence with compaction. We have discovered that the speed is variable according to the shape to be machined and the anticipation keeps a more important speed evolution. Afterwards, we come to the conclusion that the simulation tool which permits to give values very near the reality ($\leq 5\%$ of errors) for the pocket hollowing out and for the complex part machining. The real feed rate profile indicates that several parameters must be put into evidence to optimize the complex shapes machining. Hence, in order to make an optimal choice of a machining strategy, all we have to do is to analyze the different critical criteria.

References

TOURNIER Christophe, LAVERNHE Sylvain, LARTIGUE Claire, « Optimisation en fraisage 5 axes grande vitesse », *CPI'2005,* CDRom paper, pp. 1-11, Casablanca, Morocco, 2005

BLANCHARD Nicolas, RABANY Thierry et DUC Emmanuel, « Lobes de stabilité en UGV approche expérimentale en usinage de poches », *Journal of mécanique & industries,* vol. 6, pp. 411–415 France, 2005.

MONREAL Manuel, RODRIGUEZ Ciro A., « Influence of tool path strategy on the cycle time of high speed milling », *Journal of Computer-Aided Design*, vol. 35, pp. 395-401, November 2001.

TAPIE Laurent, MAWUSSI Kwamivi Bernardin, ANSELMETTI Bernard, « Machining strategy choice: performance viewer», *IDMME 2006*, CDROM paper, Grenoble France, May 17-19, 2006.

DUGAS Arnaud, « CFAO et UGV, Simulation d'usinage de formes complexes », Thesis of doctorate of central school of Nantes (France), 13 December 2002.

PATELOUP Vincent, DUC Emmanuel et RAY Pascal, « Corner optimization for pocket machining », *International Journal of Machine Tools & Manufacture,* vol.44, pp. 1343–1353, le 26 Avril 2004.

L. Tapie, K.B. Mawussi, B. Anselmetti « Circular tests for HSM machine tools: Bore machining application», *International Journal of Machine Tools & Manufacture,* vol.47, pp. 805–819, le 01 September 2006.

MEHDI chérif ''Reconstruction d'un modèle CAO à partir des mouvements réels d'une machine MOCN'' master Memory, IRCCyN, central school of Nantes (France), 29 september 2000.