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Modelling of pocket milling operation considering cutting forces and CNC control inputs

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Abstract

Machining of large pocket is a key issue for the production of aerospace parts. The optimization of this phase may lead to interesting cost reduction.
This paper will study the prediction of the cutting forces acting on a milling tool while machining the corner of a pocket and the impact of the general behavior of the machine tool on the process time.
These aspects are combined in a simulation framework at a macroscopic level. Some simulation results are presented and commented. This work can be used to optimize the cutting condition and tested on various toolpath strategies.

Keywords: CNC, machine-tool, force

1. Introduction

In part manufacturing, reducing the production costs and optimizing the manufacturing time is an important issue. However, the produced part quality should not be neglected. Thus, the cost quality ratio should always be as low as possible [1].

In order to achieve that, simulation of manufacturing techniques has an increasing role for industrial applications. These techniques allow realization of virtual prototyping stage which gives access to a large flexibility in optimization of manufacturing parameters. Thus, the manufacturing process can be freed, partially or completely, from an expensive physical prototyping stage.

There are many works which focus on the simulation of the machining process. These works can be classified as follows:

- Toolpath generation by taking into account kinematic constraints [2, 3, 4];
- Modelling of different entities of a CNC (motor, amplifiers, guideways, …) [5, 6];
- Controller stage [7, 8];
- Machining process (prediction of cutting forces) [5, 9].

The simulation of the actual behavior of the machine tool plays a key role in order to predict an optimal toolpath for a given operation. Indeed, the shortest toolpath is not necessarily the fastest one. The physical limits of the machine in terms of maximum acceleration or jerk for example reduce the feedrate that can be reached along the toolpath [10, 11, 12].

In this context, this work presents a simulation framework developed for the simulation of CNC machining at a macroscopic level. The developed framework combines [13]:

- A multibody simulation library which takes into account the behavior of the machine tool and its control [14, 15], presented in section 2;
- A mechanistic model used to predict the cutting forces, detailed in section 3.

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In section 4, the results of 90° corner milling simulation, with cutting forces considered, are presented and commented.

2. CNC axes dynamic model

2.1. Multibody simulation library

The multibody simulation library (EasyDyn) is a C++ library, available freely and developed by the Theoretical Mechanics, Dynamics and Vibrations lab at the University of Mons [15]. The kinematic and the dynamic behavior of a mechanical system can be simulated based on configuration parameters and the expression of all forces applied on all bodies.

The library includes the following components:

- Vector algebra;
- Routines constructing the 3D models;
- Routines which solve second order differential equations;
- Numerical routines building the equations of motion.

Some detailed examples can be found in dedicated articles [14, 15].

2.2. CNC Feed Drive Model

The CNC model used in this work is based on the one proposed by Erkorkmaz (see Fig. 1) [8]. The current amplifier K_a transforms the control signal u to current i. The current is sent to the motor and is converted to motor torque T_m through the torque constant K_t. The motor torque T_m, from which the disturbance torque T_d is subtracted, gives the available torque on the motor shaft. The total inertia J reflected to the motor

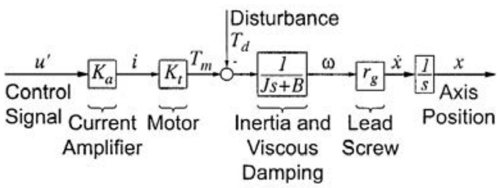

Fig. 1. Feed Drive Model [8]

shaft and the viscous damping B characterize the axis dynamic. The transmission ratio r_g multiplied by the rotation speed ω gives the linear speed of the table. The position x is then obtained by integrating the linear speed.

The Table 1 & 2 present, respectively, the constant parameters and the variable parameters of the model.

Table 1. Constant parameters of the feed drive model [6].

Parameter		Unit	X-axis	Y-axis
K_a	Current amplifier gain	[A/V]	6.4898	7.5768
K_t	Motor gain	[Nm/A]	0.4769	0.4769
J	Total reflected inertia	[kg.m²]	0.0077736	0.0098109
B	Viscous damping	[kg.m²/s]	0.019811	0.28438
r_g	Transmission gain	[mm/rad]	1.5915	1.5915

Table 2. Variable parameters of the feed drive model.

Parameter		Unit
u	Axis command	[V]
i	Motor current	[A]
T_m	Motor torque	[Nm]
T_d	Disturbance torque	[Nm]
ω	Motor shaft's rotation speed	[rad/s]
$\dot{x}$	Axis velocity	[mm/s]
x	Axis position	[mm]
s	Laplace multiplier	[1/s]

The constant parameter values in Table 1 come from the work of Yeung [6]. They correspond to a 3-axis milling machine (FADAL 2216). The axes are driven by DC motors. The cutting feed rate ranges from 0.25 mm/s to 10160 mm/s. The workspace dimensions are 559x406x508 mm (x-y-z).

2.3. Controller

The control structure used on the feed drive model is a PID controller which closes the position loop. Thus, the command of the system is no longer the parameter u, but the position x_r. A feedforward compensation is also applied to widen the servo tracking bandwidth (Fig. 2).

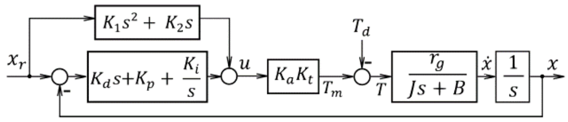

Fig. 2. Feed Drive with controller and feedforward compensation [16]

Parameters included in controller loops are presented in Table 3. They issue from an article which describes an identification technique for virtual CNC [16] and concern also the 3-axis milling machine (FADAL 2216).

The disturbance torque noted T_d combines the friction forces and cutting forces. A simple friction model, proposed by Erkorkmaz [16] is implemented in this framework. This model can easily be replaced by a more sophisticated one [17]. In such a case, the principal issue is to determine all parameters which constitute the model.

Table 3. Constant parameters of feed drive model [16].

Parameter		Unit	X-axis	Y-axis
K_d	Derivative gain	[V.s/mm]	0.3	0.278
K_p	Proportional gain	[V/mm]	500	462.539
K_i	Integral gain	[V/s.mm]	70	64.75
K_1	Feedforward on acceleration	[V.s²/mm]	0	0
K_2	Feedforward on speed	[V.s/mm]	-2.37E-6	5.55E-4

Concerning the cutting forces, they are estimated using a mechanistic model presented in section 3. Cutting forces are then included into the model as a disturbance torque acting on the motor axis.