Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 46 (2016) 311 – 314

www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Investigating actuation strategies in active fixtures for chatter suppression

Lorenzo Sallese[a]*, Antonio Scippa[a], Niccolò Grossi[a], Gianni Campatelli[a]

[a]*Department of Industrial Engineering, University of Florence, Via di Santa Marta 3, 50139, Firenze, Italy*

* Corresponding author. Tel.: +39-055-4796291; fax: +39-055-4796400. *E-mail address:* lorenzo.sallese@unifi.it

Abstract

Active fixtures represent one of the most industrially relevant alternatives among active chatter control techniques in milling, even though control logics and actuation strategies could directly reflect on their effectiveness. Closed-loop controls targeted in the chatter frequency range are commonly adopted for this purpose, but this approach lacks of applicability when chatter frequency exceeds the achievable actuation bandwidth. The purpose of this work is to investigate the effectiveness of potential low-frequency actuation strategies in suppressing chatter vibrations. A dedicated time-domain simulation model, developed and validated by authors, is used to test different actuation strategies in order to highlight the most relevant factors in assessing actuation effectiveness. The simulation results demonstrated that employing actuation frequencies close to the first half-harmonic of the tooth-pass frequency could disrupt the regenerative effect. This allows the mitigation and suppression of chatter phenomenon, increasing the critical axial depth of cut, as discussed in the paper.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz

Keywords: Active fixtures; milling; chatter; model; control;

1. Introduction

Chatter vibrations have been a major concern during the last decades, due to their limiting effect on productivity and additional related effects, such as worse surface finishing [1], increased tool wear and potential damages to the machine tool itself [2]. Different strategies have been presented in literature with the purpose of preventing such unstable vibrations during milling operations by means of dedicated experimental tests [3] and analytical models [4-6], but the industrial application seems limited by the required expertise in modal analysis and the time consuming experimental tests. Alternative active techniques have been presented in order to overcome these limitations, as discussed by Quintana et al. [2], and intervene on the process itself to mitigate or suppress chatter vibrations by means of dedicated control logics. Among these, active fixtures [7,8] appear the most attractive for an industrial exploitation, being easily and directly retrofittable on different machine-tools unlike other techniques, such as spindle speed variation, that require dedicated hardware and control solutions for different machine tools. Nevertheless, as highlighted in [9, 10], developing effective control strategies to mitigate chatter with such active approaches directly relies on the modeling and simulation of cutting processes. For this purpose, a dedicated time-domain simulation model has been developed and validated by the authors and the main features are briefly described in this paper. Literature reports the implementation of alternative closed-loop control strategies aimed at suppressing unstable vibrations by mitigating the amplitude of the chatter frequency [7,8], but the tested applications are always limited to frequencies below 400Hz. General applications of such approaches would require wider bandwidth, but inertial forces and operability of the actuators could drastically limit it.

This paper discusses the effect of open-loop actuation strategies in mitigating the chatter instability in simulated cutting tests, highlighting the most influencing factors in defining the feasibility and effectiveness of low-frequency actuation strategies.

2212-8271 © 2016 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
doi:10.1016/j.procir.2016.04.073

2. Main features of the dedicated time-domain model

The simplest fixture architecture of an active fixture is represented by a two degrees of freedom (DOFs) compliant mechanism based on serial kinematics, as exemplified in [8]. This system can be schematized as in Fig. 1, where F_{px} and F_{py} represent the forces along the two DOFs by the actuators, generally piezoelectric ones [11].

There are different ways of modelling piezo actuators, possibly including different non-linearities like creep and hysteresis, but according to literature [12] a linear model that simply relates actuation force to input voltage could be consistent with this application, given that the purpose is not controlling workpiece position with the highest resolution.

The following relations can thus define the characteristics of the piezoelectric actuators:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K_{uu}]\{u\} + [K_{u\psi}]\{\psi\} = \{f\} \tag{1}$$

$$[K_{u\psi}]^T\{u\} + [K_{\psi\psi}]\{\psi\} = \{q\} \tag{2}$$

where: $[K_{uu}]$, $[C]$ and $[M]$ are respectively the mechanical stiffness, damping and mass matrices, $[K_{\psi\psi}]$ is the dielectric stiffness matrix, $[K_{u\psi}]$ is the piezoelectric coupling matrix, $\{u\}$ is the nodal vector displacement, $\{f\}$ is the vector of the external mechanical forces, $\{q\}$ and $\{\psi\}$ are the nodal vectors of the electric charge and scalar electric potential, respectively.

By modeling the tooling system (i.e., spindle, tool-holder and tool assembly) and the fixture with a two degrees of freedom (DOFs) lumped model respectively, as discussed by Altintas and Weck [5], and including the additional force generated by piezo actuator, it is hence possible to model the cutting process with over imposed fixture actuation.

Time-domain model detailed description can be found in [13], along with the supportive results of the experimental validation, conducted comparing simulated and measured forces compensated with adequate procedures [14].

3. Simulation set-up

In order to realistically investigate the effectiveness of different actuation strategies on active fixtures, the features of a real prototype have been implemented in the time-domain model and realistic cutting conditions have been recreated.

3.1. Active fixture design

The prototype fixture, which features have been implemented in the simulations, is shown in Fig. 2. The fixture integrates flexure hinges to decouple actuation directions and ensure the required stiffness. Each axis is driven by four piezoelectric actuators, whose specifications are reported in Table 1, and adequate preload is applied by disc springs in order to prevent tensile stress on the actuators.

Table 1. Main specifications of the selected piezo actuators.

Blocking force	Max. displacement	Max. voltage	Stiffness
3200 N	32 μm	200 V	100 N/μm

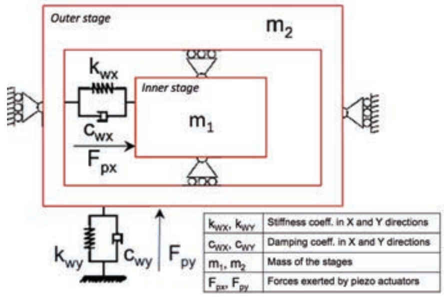

Fig. 1. Basic architecture of an active fixture with two DOFs.

The modal parameters required for the time-domain model have been extracted by curve fitting in the actuation direction of the frequency response function of the fixture, obtained by finite element analysis, with a single DOF. The identified parameters are reported in Table 2, along with the tooling parameters, discussed in the following section.

Table 2. Fixture and tooling identified modal parameters.

	Inner stage	Outer stage	Tooling
Stiffness, k	$4.28e^8$ N/m	$4.39e^8$ N/m	$1.15e^7$ N/m
Damping coeff., ζ	0.0432	0.0432	0.0231
Natural freq., f_n	2689.8 Hz	1782.8 Hz	1836.6 Hz

3.2. Cutting conditions

Cutting conditions have been recreated starting from data identified in the experimental validation tests of the time-domain model, discussed in [13]. Tool-tip dynamics, reported in Table 2, have been extracted by experimental tests, while cutting force coefficients of Aluminum 6082-T4 have been experimentally identified with the procedure reported in [15]. Main simulated cutting tests parameters are summarized in Table 3. The dominant frequency of the tooling, responsible for chatter instability, is sensibly higher than the ones reported in previous work on active fixtures [7], as common in many practical applications.

Table 3. Cutting tests parameters and identified cutting coefficients.

Number of flutes, z	2	Radial depth of cut	Slotting
Feed per tooth, f_z (mm)	0.05	Tool diameter, D (mm)	10
K_{tc} (N/mm^2)	K_{te} (N/mm)	K_{rc} (N/mm^2)	K_{re} (N/mm)
1086.66	764.29	139.03	33.32

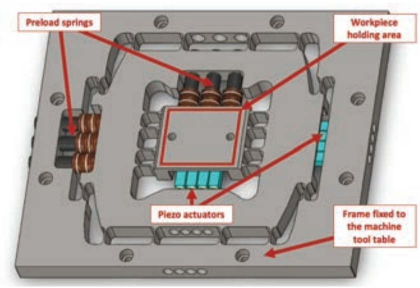

Fig. 2. Active fixture prototype design.