Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 55 (2016) 176 – 181

www.elsevier.com/locate/procedia

5th CIRP Global Web Conference Research and Innovation for Future Production

Intelligent fixtures for active chatter control in milling

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

[a]Department of Industrial Engineering, University of Firenze, Via di Santa Marta 3, 50139, Firenze, Italy
[b]Paragon S.A., Karaoli & Dimitriou 13, Athens, Galatsi GR-11146, Greece

* Corresponding author. Tel.: +39-055-2758726; fax: +39-055-2758755. E-mail address: lorenzo.sallese@unifi.it

Abstract

The mitigation of chatter vibrations in milling has collected the interest of several researches in the last decades. One of the most industrially oriented alternatives is represented by active fixtures, complex mechatronic devices capable of actuating the workpiece during machining operations, with the purpose of stabilizing the process by generating counteracting vibrations. Most of the previous works show different fixture architecture and model based control techniques. This paper deals with the development and testing of such an active fixture, presenting the main design aspects and the features of the black-box control-logic used. Experimental tests are presented to show the achievable chatter mitigation.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production

Keywords: Milling; Chatter; Control; Active Workpiece Holder (AWH)

1. Introduction

Chatter vibration represents one of the most limiting factors in assessing the achievable performance, in terms of productivity, of modern machining operations. Indeed, these detrimental vibrations could drastically decrease the achievable material removal rate and sensibly increase tool wear [1]. Literature reports several different approaches aimed at predicting or preventing such unstable vibrations by selecting optimal machining parameters, through numerical models [2] or dedicated experimental procedures [3]. These approaches are limited by the required expertise and by the fact that the predicted optimal condition is representative only of a specific tool-material combination. On the contrary, active approaches capable of monitoring the process and exerting adequate counteracting actions, are more easily adaptable to general applications. Spindle-speed-variation technique is a clear exemplification of these approaches [1]. Recently, the use of active materials has strongly contributed to the development of alternative active approaches based on the integration of mechatronic systems in the machine-tool structure. Among these, active fixtures, often referred to as Active Workpiece Holders (AWHs), seem to be more industrially appealing solutions. Their direct retrofittability and adaptive control logics would indeed demand for lower expertise and reduced set-up time [4].

This paper deals with the development of such a mechatronic device aimed at mitigating chatter vibrations by monitoring the milling process in real-time, through integrated sensors (i.e., accelerometers), and by generating adequate counteracting vibrations, by means of integrated piezo-actuators. The black-box control logic used in the present work allow avoiding preliminary system identification and modeling as generally required for the control development and implementation in this kind of devices [4,5].

The paper covers the main features of the mechanical design of the two degrees of freedom active fixture, along with the crucial aspects of the sensors/actuators selection and integration. Subsequently, the main aspects of the development and implementation of the novel control algorithm are presented to show its peculiar features. Finally, the developed active fixture prototype is experimentally tested in 2.5 axis milling operations in order to show the achievable improvements in terms of chatter mitigation.

Peer-review under responsibility of the scientific committee of the 5th CIRP Global Web Conference Research and Innovation for Future Production
doi:10.1016/j.procir.2016.08.019

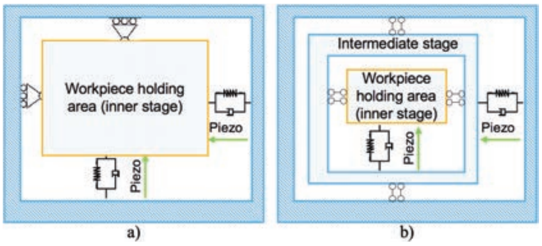

Fig. 1 Schematization of a) parallel-kinematics architecture, b) serial-kinematics architecture.

2. Active Fixture development

The development of an active fixture goes through the integration of different subsystems with peculiar issues to be tackled, as for most mechatronic devices. The next sections cover the most relevant aspects of the prototype development, discussing the main issues that needed to be addressed in order to achieve the desired global behavior.

2.1. Fixture architecture and mechanical design

Referring to literature, two main fixture architecture can be chosen to develop a two degrees of freedom (DOFs) device capable of counteracting tool vibrations in the plane normal to tool axis. The simplest solution could be represented by a compliant mechanism with parallel kinematics, schematized in Fig. 1a, which would allow for symmetric fixture response and to reduce the overall masses and dimensions [4].

The main drawback of this kind of architecture is represented by the relevant cross-talk effect that could arise between the actuated axes and that could be overcome only by employing additional sensors and control strategies. For this reason, a different architecture was selected for the active fixture prototype, opting for a structure based on serial kinematics, schematized in Fig. 1b, that would allow for theoretically decoupled motion of the stages [5]. Nevertheless, the nested structure would imply different geometries and masses for the inner and outer stages, that would hence show different dynamics and should be carefully regarded during the fixture design.

Regardless the fixture architecture selected, the design of the fixture frame plays a crucial role in assessing the achievable active fixture performance. It should be capable of simultaneously ensuring the needed stiffness, imposed by precision requirements, while allowing enough flexibility for the actuators to produce adequate workpiece displacements [6]. These conflicting requirements are usually met by integrating monolithic flexure hinges in the frame in order to adequately decouple axes motion and achieve the desired compliance level. A first dimensioning of these mechanical components can be carried out according to some of the empirical equations presented in literature [7]. Numerical models could then be useful to optimize the positioning of the flexure hinges within the fixture frame, with the purpose of achieving the desired dynamic response that would contribute to the maximization of the device bandwidth, as exemplified in Fig. 2.

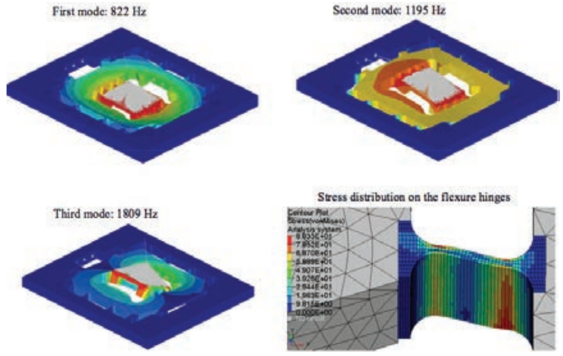

Fig. 2 FEM analysis of the developed prototype fixture (workpiece mass not included) and stress distribution on the flexure hinges.

Moreover, detailed numerical model would allow estimating the stress distributions within the fixture, needed to investigate the fatigue limits in highly dynamic application, such as the proposed one.

The development of the AWH was carried out according to these considerations and following the general guidelines provided by the work of Haase [8]. The developed prototype is shown in Fig. 3.

2.2. Actuators selection and implementation

As shown in Fig. 3, the developed prototype integrates four piezoelectric stacks actuator for each dynamic axis. The selection of suitable actuation devices represented the main issue to be tackled for the development of a device with adequate bandwidth and reliability.

In recent years, several alternative actuation techniques became available and their level of performance is continuously growing. Nevertheless, piezoelectric technology still represents the most appealing alternative, mainly due to the achievable power density and bandwidth. The integration of this kind of actuation devices in the machine tool components with the purpose of interacting with the machining process, is a renowned topic, but the features of the piezo-ceramic used could drastically reflect on the achievable bandwidth and performance.

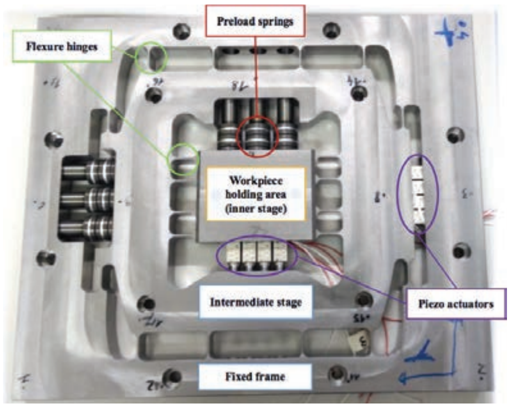

Fig. 3 Active fixture prototype (external dimensions 343x289x20mm).