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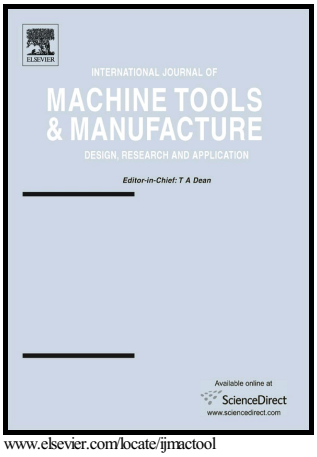

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PII: S0890-6955(16)30391-1
DOI: http://dx.doi.org/10.1016/j.ijmachtools.2016.10.005
Reference: MTM3203

To appear in: *International Journal of Machine Tools and Manufacture*

Received date: 30 March 2016
Revised date: 9 October 2016
Accepted date: 12 October 2016

Cite this article as: Hongrui Cao, Xingwu Zhang and Xuefeng Chen, The concep and progress of intelligent spindles: A review, *International Journal of Machin Tools and Manufacture,* http://dx.doi.org/10.1016/j.ijmachtools.2016.10.005

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The concept and progress of intelligent spindles: A review

Hongrui Cao[a*], Xingwu Zhang[a], Xuefeng Chen[b]

[a]Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, Xi'an Jiaotong University, Xi'an 710049, China

[b]State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Xi'an 710049, China

[*]Corresponding author. Tel.: +86 29 82663689; fax: +86 29 82663689. chr@mail.xjtu.edu.cn

Abstract

Intelligent spindles are core components of the next-generation of intelligent/smart machine tools in the Industry 4.0 Era. The purpose of this paper is to clarify the concept of intelligent spindles and provide an in-depth review of the state-of-the-art of related technologies. A new integrated concept for intelligent spindles is proposed, followed by descriptions of required characteristics, key enabling technologies and expected intelligent functions. Relevant research that may be beneficial to the development of intelligent spindles is reviewed from six thrust areas, which include monitoring and control of tool condition, chatter, spindle collision, temperature/thermal error, spindle balance, and spindle health. Finally, current limitations and challenges are discussed, and future trends of intelligent spindles are prospected from various perspectives.

Keywords: intelligent spindles; machining process; condition monitoring; control; machine tools

1. Introduction

As the Industry 4.0 Era (i.e., the Fourth Generation Industrial Revolution) builds, machines are becoming interconnected, forming a collaborative community in smart factories [1]. "Smart production" is becoming the norm, in a world where intelligent machines, systems and networks are capable of independently exchanging and responding to information, to manage industrial production processes. A key to building smart factories is to turn traditional machines into more intelligent machines.

The concept of "smart machine tools" or "intelligent machine tools" was first introduced about ten years ago. The basis of this next-generation machine tool is the ability to monitor and control multiple process modules [2, 3]. As core components of machine tools, spindles have direct effects

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