Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 37 (2015) 199 – 204

www.elsevier.com/locate/procedia

CIRPe 2015 - Understanding the life cycle implications of manufacturing

Electromagnetic Levitation Guide for Use in Ultra-Precision Milling Centres

B. Denkena, D. Dahlmann and R. Krueger*

Institute of Production Engineering and Machine Tools, Leibniz Universität Hannover, An der Universität 2, D-30823 Garbsen, Germany

* Corresponding author. Tel.: +49 511-762-4840; fax: +49-511-762-5115. *E-mail address:* krueger_r@ifw.uni-hannover.de

Abstract

Today´s machine tools for ultra-precision machining are generally characterised by low productivity. Above all, practical cutting parameters are limited due to uncontrollable disturbance forces. Therefore, it is necessary to pursue the qualification of new technologies to overcome current limitations in productivity. In this paper, an approach for the design of a novel electromagnetic levitation guide for use in ultra-precision milling centres is presented. Design and arrangement of the magnetic guide's components are considered with regard to requirements and design principles of precision machines. Deterministic methods are utilised throughout the engineering process to ensure high stiffness and high dynamics. As a result, a concept for the electromagnetic ultra-precision linear guide is derived.

Peer-review under responsibility of the organizing committee of CIRPe 2015 - Understanding the life cycle implications of manufacturing

Keywords: Magnetic guide; Machine tool; Ultra-precision machining

1. Introduction

1.1. Ultra-precision machining

Ultra-precision machining provides production techniques for generating complex micro-structured surfaces and high precision freeform surfaces with optical properties [1]. It is considered as a key technology for the processing of optical components. The area of application covers astronomy, automotive and medical devices as well as metrology and optical industries.

Over the last decades research and development predominantly focused on measures for a further increase in accuracy [2]. However, the overall performance of ultra-precision machine tools is still limited by low feed rates along with time-consuming manual workpiece and tool alignment. Restrictions of cutting parameters in particular result from rigorous workpiece tolerances of optical elements. An increase in cutting performance inevitably leads to increased dynamic disturbances caused by process forces, drive torques and unbalances of rotating components. Consequently, a growing influence of these disturbance forces may compromise surface quality and process stability.

In order to overcome current limitations it is necessary to pursue the qualification of new machine concepts and technologies [3]. In this context, active magnetic bearings and guides offer considerable potential to improve the productivity of ultra-precision machining processes.

1.2. Potential of active magnetic guides in machine tools

The guide system in a machine tool has a significant impact on its overall performance. Active magnetic guides offer considerable advantages in comparison to conventional systems such as friction guides, roller guides, hydrostatic or aerostatic guides. Providing friction free operation, electromagnetic levitation technology enables fast and precise motion. The absence of fluid media and wear makes the system basically maintenance-free.

In contrast to established concepts, which utilise repelling forces, the working principle of magnetic guides is based on inherently unstable pulling forces of electromagnets. Thus, an

Peer-review under responsibility of the organizing committee of CIRPe 2015 - Understanding the life cycle implications of manufacturing
doi:10.1016/j.procir.2015.08.008

active control system is required to ensure dependable operation at all times. Accordingly, an active control of the electromagnetic actuators allows for an adaptive adjustment of the guide's properties, resulting in high damping and an infinite static stiffness. Furthermore, the guide functions as sensor and actuator, allowing identification of process forces and precision positioning operations.

Contemporary machine tool prototypes with magnetic guides demonstrate the potential of this technology [4, 5] (Figure 1). Experimental evaluation of electromagnetically guided spindle slides confirms improved chatter stability compared to operation with conventional ball guides [5]. In addition, an in-process force estimation and fine-positioning in 5 degrees of freedom can be accomplished [6].

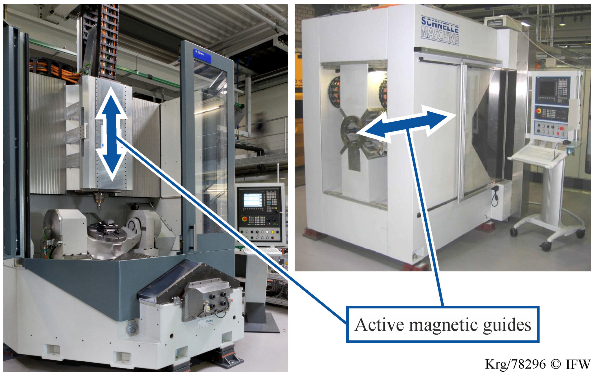

Fig. 1. Machine tool prototypes with active magnetic guides

Ultra-precision machine tools are sure to benefit from the before mentioned features of active magnetic guides. A process-oriented adaption of the guide's stiffness and damping creates ideal conditions for improved cutting performance without compromising quality or stability. Implemented within a workpiece-sided biaxial positioning system, fine-positioning operations allow for compensation of static and dynamic deviations, e.g. manufacturing and assembly errors, mechanically and thermally induced deformations of the machine frame or position errors of subordinated axes. Moreover, the mechanism can be used for accurate alignment of workpiece and tool.

1.3. Objective

Despite the general benefits of electromagnetic levitation technology, existing magnetic guides for use in machining centres do not achieve the accuracy needed for ultra-precision machining. Known precision applications are limited to transport and positioning [7], e.g. in lithographical processing. An active magnetic guide for actual use in ultra-precision machining has not yet been published.

This paper presents a design approach for an electromagnetic levitation guide for use in ultra-precision milling centres. First, a methodology for the design of electromagnetic ultra-precision linear guides is proposed. It is then exemplarily applied to derive a suitable magnet arrangement. Also, choice of construction materials and integration of functionally relevant components are considered. Finally, a concept for the novel electromagnetic guide is presented.

2. Design approach for electromagnetic levitation guides

To begin with, design of precision machinery is guided by specific concepts and principles (Figure 2). Methods, techniques and tools are provided to ensure a high working precision of the constructed machine [8, 9]. For the application of magnetic bearings and guides in machine tools, basic functional requirements of electromagnetic levitation technology have to be considered. Distinctive feature of active magnetic guides is a reversed direction of bearing forces. Thus, simple substitution of existing guide elements is not possible. Implementation of this technology requires a redesign of the guide's components and surrounding modules in consideration of the designated application.

Hence, a holistic design approach for the novel magnetic guide is required. In order to structure the development process, it can be divided into several work steps. Throughout the distinct work steps special attention is paid to fundamental principles of precision machine design. Deterministic methods and tools are applied throughout the engineering process.

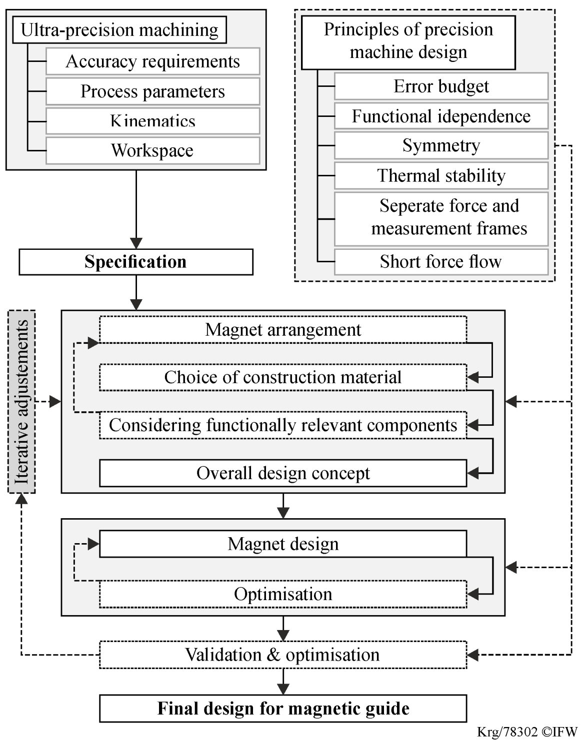

Fig. 2. Design approach for an electromagnetic ultra-precision linear guide

Initially, the area of application and its specific requirements are defined. On this basis, the arrangement of the electromagnets is derived, followed by selection of construction materials and essential components. Then, integration of relevant components is considered. The prior work steps determine the overall appearance of the magnetic