Precision Engineering 38 (2014) 109–115

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

A function integrated and intelligent mechanical interface for small modular machine tools

Jens Peter Wulfsberg[a], Silka Grimske[a,*], Nanxi Kong[a], Benny Röhlig[a], Jens Storjohann[b], Jens Müller[c]

[a] Institute of Production Engineering, Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg, Holstenhofweg 85, 22043 Hamburg, Germany
[b] Electrical Power Systems, Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg, Holstenhofweg 85, 22043 Hamburg, Germany
[c] Institute of Control Engineering, Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg, Holstenhofweg 85, 22043 Hamburg, Germany

ARTICLE INFO

Article history:
Received 19 March 2013
Received in revised form 30 July 2013
Accepted 6 August 2013
Available online 20 August 2013

Keywords:
Machine tool
Reconfiguration
Multifunctional interfaces
Micro manufacturing

ABSTRACT

A modular structure is essential for versatile, reconfigurable micro machine tools to meet future requirements and to achieve flexibility. Therefore, to exploit modularity, the design of a function integrated, intelligent mechanical interface is presented in this paper. The interface is based on a six-point mounting and a switchable permanent magnet system guaranteeing high precision. Thus, various machine tool modules can quickly be coupled to functioning units without tools and further adjustments. Energy supply, information transfer and data processing are also incorporated, without diminishing precision. The interface characteristics are analytically described. Simulation and experiments show performance and feasibility for micro manufacturing.

1. Introduction

In today's micro production adapting the size of machine tools to micro parts is an obvious trend [1]. By reducing the size, the segmentation of the machine tool into small modules is possible [2]. The idea of modularity can be extended to the requirement for changeability of the complete machine system [3]. Appropriate, consistent interfaces are needed for a flexible configuration of machine tools [4]. In conventional machine tools, interfaces which allow for a quick reconfiguration are merely located between tool and drive or workpiece and machine bed. These interfaces are based on mechanical principles, such as steep taper and zero point systems. Recent research is concerned, for example, with the development of a mechanical interface to change various processing modules in a machine tool [5] or to open the machine frame for reconfiguration without weakening the tight structural loop of the machine tool [6]. However, the designs of interfaces for modular micro machines shall not only be limited to its mechanical properties, but also include the necessary parts to transmit information and power.

2. Interface functions and requirements

Interfaces are defined as locations where adjacent system units are linked or a single system is connected to its environment [7]. A visual definition is shown in Fig. 1a.

Technical interfaces in production systems have allocated functions. [8] classifies interfaces into supply, physical, information, adjusting and production process interfaces. Another approach by [9] categorizes interface functions into transmission of energy, material, signal and information. At the same time, the relation between these types of transmission is emphasized. For example, the transmission of information is only achievable through the transmission of a signal which in turn relies on the transmission of electrical and mechanical energy. Fig. 1b displays the specific functions that were identified in this project to ensure the coupling of machine tool modules as described e.g. in Refs. [10, 11 or 12]. Additionally, for micro manufacturing high precision of the interface is postulated and as the newly developed modules are small and lightweight, the coupling process via interfaces should be effortless. Feed, tool and clamping modules should be supplied in by one interface design with their specific energy and information and without long configuration times.

* Corresponding author. Tel.: +49 40 6541 3037; fax: +49 40 6541 2839.
E-mail addresses: jens.wulfsberg@hsu-hh.de (J.P. Wulfsberg), silka.grimske@hsu-hh.de (S. Grimske), nanxi.kong@hsu-hh.de (N. Kong), benny.roehlig@hsu-hh.de (B. Röhlig), jens.storjohann@hsu-hh.de (J. Storjohann), jmueller@hsu-hh.de (J. Müller).

0141-6359/$ – see front matter
http://dx.doi.org/10.1016/j.precisioneng.2013.08.001

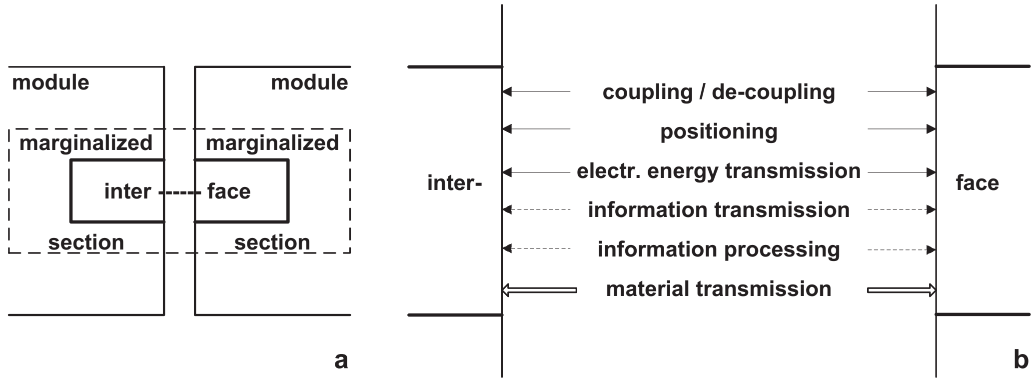

Fig. 1. Definition of an interface based on [7] (a) and purposes of the function integrated and intelligent interface (b).

3. Mechanical characteristics

3.1. Principle selection

As mentioned above, mechanical energy transmission is of great significance in fulfilling the interface's purpose. This transmission of mechanical energy is divided herein into two functions, "coupling/de-coupling" and "positioning" (see Fig. 1b). Principle analysis and evaluation of mechanical linkages and connections are described in e.g. [13] or [5]. Here, a six-point mounting, as previously stated in [14], is selected as the positioning principle due to its high precision. Although being uncommon in macro machine tools, stiffness of a six-point mounting is sufficient as forces and momentums are relatively low for these novel, miniaturized machine modules [2]. Other error sources such as thermal influences are reduced because of size effects [15]. Again, based on the small size, magnetic force provides an adequate holding force within the limited space to constrain the movement between both interface halves. This way overdeterminacy is prevented.

3.2. Mechanical prototype

A first design of a mechanical prototype was presented in [16]. The six-point contact is realized by using three carbide balls and six carbide cylinder rods (see Fig. 2a). To achieve a uniform load on all contact points, the balls are arranged in an angle of 120° to one another (see Fig. 2b). The magnets, which are shielded by steel pots to prevent harming any surrounding electronics, generate vertical holding forces. The practical application of this prototype is shown in Fig. 3. The interface is used in two sizes (with 44 N and 76 N magnetic preload) for the coupling of various modules to a complete micro machine tool. Here, the configuration consists of a flexure-based feed unit [17], an elastic deformation clamping device [11] and a high speed spindle [12]. The measurement data for precision and accuracy of the mechanical prototype underlines the prior machining results. The position of the upper platform was measured after each coupling process by a fiber laser interferometer with a specific experimental setup which allows for coupling and de-coupling without signal loss. This procedure was repeated N = 30 times. The maximum translatory error has a mean value of $\phi = 0.044\,\mu m$ with a standard deviation of $\sigma = 0.040\,\mu m$. The maximum rotatory error is $\phi = 61.92$ arc s with a standard deviation of $\sigma = 0.60$ arc s ([11,18]). The detailed standard deviations are described in Table 1. To validate the interfaces during machining processes, milling operations with the high speed spindle (see Fig. 3a) are conducted and show no significant differences in the machining quality with or without the interfaces [16]. It also shows the feasibility of the interface design. The error budget of the configuration with both interfaces, shown in Fig. 3, is described in [11].

Table 1
Standard deviation of the interface [18].

	Translatory errors (μm)		Rotatory errors [arc s]		
	x	y	x	y	z
Big interface	0.036	0.054	2.743	1.642	0.042
Small interface	0.021	0.047	1.058	1.375	0.011

$N = 30$

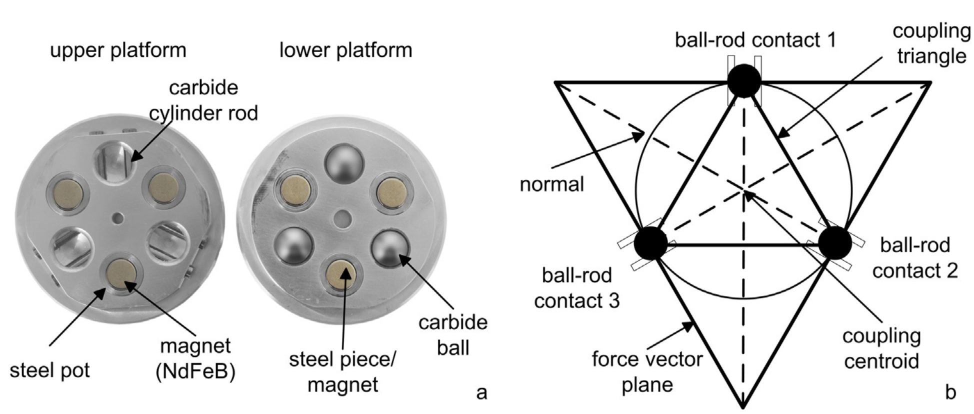

Fig. 2. Design [16] (a) and principle (according to [19]) (b) of the mechanical prototype.