Repeatable Positioning Accuracy of Mechanical Interfaces for Micro Manufacturing

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Abstract

For a modular micro machine tool system the highly repeatable positioning accuracy of mechanical interfaces used is indispensable. At last year's euspen conference the design of a mechanical interface was described whose positioning accuracy had to be quantified with a feasible measuring method. This paper presents the developed measuring setup as well as the measuring procedure, findings and evaluation of the repeatable positioning accuracy in x- and y-directions and all rotational axes of the mechanical interface prototypes.

1 Introduction

The new machine tool approach "Square Foot Manufacturing" (SFM) is an enhancement of common desktop manufacturing systems. The machine tool is not only miniaturized and can produce parts on a base of one square foot in size, but it also uses its reduced dimensions to achieve advantages in production [1]. Firstly, new technologies as well as new production methods can be included, which allows for smaller and more precise geometries to be manufactured – as, for example, the feed unit based on flexure hinges already presented at euspen [2]. Secondly, the reduced size simplifies the implementation of a modular concept. Based on the manufacturing task, the small machine tool is divided into lightweight modules that can easily and quickly be configured to Micro Machining Units (MMU). Besides small modules, standardized interfaces are essential for receiving an appropriate modular machine tool system. This standardization refers not only to power supply and data transmission, but also to the transmission of processing forces and moments. Therefore, a prototype of a mechanical interface (Figure 1) capable of including other interfaces was developed and presented at last years' euspen conference [3]. It is based on the kinematic coupling principle [4], whereby three hard metal spheres are brought into point contact with six corresponding hard metal rods. The preload is provided by six magnets. Initial studies have validated the feasibility of the design concept [3].

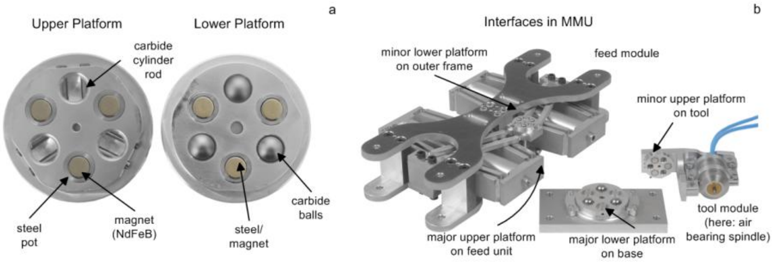

Figure 1: Design of the mechanical interface (a), uncoupled MMU assembly [3] with air bearing spindle [5] (b)

2 Measuring Setup

The key task of the mechanical interface is the ability to precisely couple and uncouple machine tool modules. Due to the required tolerances in micro manufacturing, the repeatable positioning accuracy should be less than 1 µm. Concerning this requirement, the described prototype was examined for last year's contribution in x-, y- and z-directions using a coordinate measuring system. It was observed that accuracies of the interfaces were within the accuracy range of the measuring systems. Furthermore, the influence of thermal drift increased as one set of measurements lasted relatively long. Rotational deviations were initially not considered. Although the results showed sufficient position accuracy below 1 µm, they have to be verified and quantified with a more precise measuring system. With its resolution of 0.025 nm, a laser interferometer by attocube systems[1] appears to be suitable. It is rather uncommon for this type of measuring task, because both platforms have to be separated during measurement, thus possibly leading to signal loss. For this reason, two measuring devices which integrate the laser interferometer have been developed. They ensure the separation of the interfaces without a tilt of more than one degree, whereas the coupling process is not constrained. Method and device contribute to a quick measurement procedure, leading to less thermal drift and other error sources due to surrounding conditions.

[1] with a 1 ppm position error (equals a position variation of 100 nm at 100 mm length) per 1K change in air temperature, 3.5 mbar change in air pressure or 80 % change in relative humidity

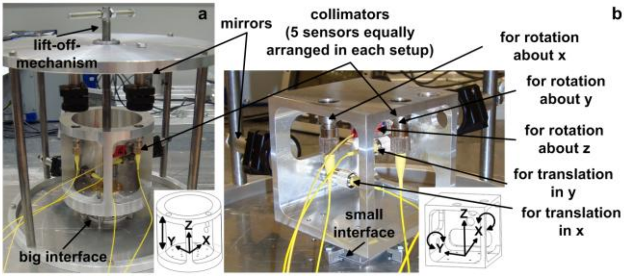

Figure 2: Measuring setup for lift-off (a) and tilt (b)

There are two measurement setups, as shown in Figure 2, one for the bigger interface only whereby the interface is separated orthogonally and one for both interface sizes whereby the interfaces are separated in an angle.

3 Measuring Procedure

The two measuring setups, as mentioned above, require a different procedure. The cylindrical measuring device (Figure 2a) is bolted to the upper platform of the bigger interface. Using a threaded rod, the bolted parts can be lifted off to a specific height. Here, measurements with a lift-off of 2 and 8 mm are conducted to ensure the magnetic field, whose strength declines over distance, does not influence the measured results. The rectangular measuring device (Figure 2b) is bolted to the upper platform of the bigger or the smaller interface. This device and the platform is then tilted manually into the x- or y-directions. Firstly, this setup is used for the repeatable positioning accuracy of the small interfaces because the cylindrical device is too heavy for the small magnetic preload. Secondly, it is used to investigate if the tilting motion has any influence on the repeatable positioning accuracy in comparison to the orthogonal lift-off. At least 25 of these measurements are conducted in each configuration. Two versions of the big and of the small interface are examined concerning the translatory errors in x- and y-directions and the rotatory errors about the x-, y- and z-axes (see Figure 2).

4 Results

With a sampling rate of 10 MHz, 30 values before and 30 after the lifting/tilting are recorded for all five sensors. Through linear regression the absolute term of start and end values are calculated. The difference between these two absolute terms is then the result of one measurement. All results out of one configuration, for example, the bigger interface I with the cylindrical setup, have a mean value and a standard deviation. The standard deviation is equivalent to the repeatable positioning accuracy, also called repeatability. The following table displays the maximum standard deviation for both interfaces of all configurations.

Table1: Maximum standard deviation, both sizes of interface

	translatory errors in µm		rotatory errors in 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

The rotatory errors as well as the translatory errors are independent of the measurement setup, regardless of whether the interfaces are lifted or tilted. There is no influence detected due to the different lift-off height.

5 Conclusion

This paper describes the application of a laser interferometer for measuring the repeatable positioning accuracy or repeatability of a mechanical interface. The results show the feasibility of the method combined with an appropriate measuring device. According to [6] repeatability is 3σ, whereby σ is the standard deviation. Therefore it can be said that for both interfaces the translatory repeatability is under 0.16 µm and the rotatory repeatability is under 8.22 arc s.

Acknowledgment
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