Square Foot Manufacturing – Advanced Design and Implementation of Mechanical Interfaces

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Abstract

Square Foot Manufacturing as a new modular machine tool system requires for the ability of reconfiguration mechanical interfaces which can easily and precisely couple and uncouple its machine tool modules. Based on studies presented at last year's euspen conference, this paper describes a new design principle of a mechanical interface, two new prototypes of different sizes and experimental findings.

1 Introduction

In the area of micro technology, Square Foot Manufacturing (SFM) is a new modular concept, developed at the Institute of Production Engineering at the Helmut-Schmidt-University in Hamburg [1], where small Micro Machining Units (MMU) are attached to a mounting plate of the size of one square foot. These reduced dimensions, if compared to the volume of ordinary ultra precision machine tools, facilitate the implementation of modularity in a simple and user-friendly way. The lightweight modules can be connected via mechanical interfaces which reconfigure a machine tool system fast and preferably without tools. Also, a minor machine size leads to forces and momentums which are smaller than in common systems. These characteristics enable the realisation of mechanical interfaces that couple repeatedly with high precision, while maintaining a sufficient stiffness. Additionally, the interfaces allow for the integration of multiple functions, for example, power supply or data interfaces.

2 Mechanical Interface Design

The mechanical interface which is based on [2] consists of two platforms, shown in Figure 1(a). The lower platform holds three hard metal balls positioned in an angle of 120° to one another. Those balls fit precisely into the upper platform containing six carbide rods arranged in parallel pairs. The geometric arrangement is also called kinematic coupling [3] and offers, due to its characteristics, a high repeat accuracy of position. Although the stiffness is low compared to other mechanical coupling principles, it can be used without reservation because the weight of the modules as well as the forces and moments during machining are low owing to the small size of the modules and cutting volumes.

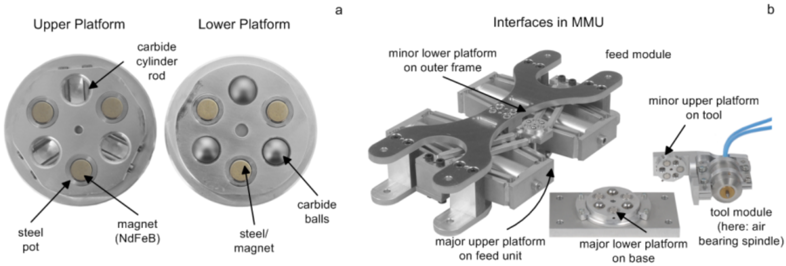

Figure 1: Design principle (a) and uncoupled MMU assembly (b)

The adhesion force is provided by six magnets, three in each platform. They are buried in steel pots to interrupt the radiation of the magnetic fields. These steel pots can be fixed in and easily removed from cavities between the coupling areas to vary the magnetic adhesion, for example, by exchanging three magnets with solid steel cylinders. As shown in Figure 1(b), there are two interfaces, one between base plate and MMU [4] and another between MMU and tool module [5], which merely differ in size in the ratio 2:1. Experimental results show that the greater interface has a holding force of 40 N in vertical direction, sufficient to keep the MMU with a weight of approximately 4 kg in place. The smaller interface can hold 19 N in vertical direction but has its highest external load in lateral direction because of the tool module's weight force of 0.3 kg and the process forces which vary depending on the task. Here, the lateral holding force is measured at 7 N. However, both interfaces can be connected and disconnected manually without tools.

3 Repeatable Position Accuracy

One of the most important features of a mechanical interface in a modular machine tool system is the repeatable position accuracy which can be initially observed. The position of both interfaces was measured between 60 and 80 times by a coordinate measuring system. This system itself has a repeat accuracy of less than 0.3 µm in all three axes for this certain task which is sufficiently accurate for a first examination that concerns only the repeatable position accuracy of the interface. Figure 2 shows exemplarily as one result the relative deviation of the smaller interface in x-direction of 0.3 µm as maximum with a standard deviation of 0.1 µm. All findings are presented with adjusted background, which is due, among other factors, to thermal drift of the axes of the measuring device. Here, only functions have been used that have no local maxima and minima or points of inflection so that they do not influence the inaccuracies to be measured resulting from the interface.

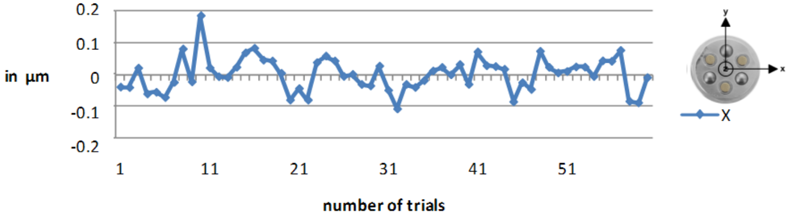

Figure 2: Relative deviation of the minor interface in x direction

Summarizing it can be said that mean values of the repeat accuracies in three directions, x, y and z, were less than 1 µm for the smaller interface and the greater interface. These are initially sufficient for the machining task to be dealt with and show that the design principle is suitable for connecting the modules of SFM repeatedly precise. Further examinations will quantify the results.

4 Milling Geometry Accuracy

To verify the functionality of the mechanical interface between a MMU and the base plate, several milling operations with an air bearing spindle and a milling tool (diameter 120 µm), both developed by the University of Kaiserslautern [5], were conducted. Figure 3 compares one result of using the interface versus bolts to connect the MMU to the base plate. The tool module was screwed on in both cases to ensure that deviations occurred from the greater interface only.

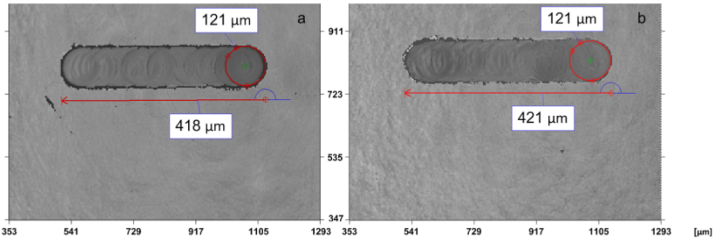

Figure 3: Milling geometry in TiAl6V4 without (a) and with (b) mechanical interface

All produced and measured two-dimensional geometries with and without the mechanical interface showed no significant differences in width and length. The relatively small deviations between all samplers, as well as within samplers manufactured with one setting, can be attributed to the milling process.

5 Conclusion

This paper presented a design of a mechanical interface which enables the reconfigurability of the Square Foot Manufacturing concept. The described experimental results have proved that this design can meet the requirements regarding the provision of a sufficient stiffness and high repeatable position accuracy. Further research will focus on verifying the design and integrating additional functions.

References:

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